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Polymer Modification Of Paving Asphalt Binders.

L. H. LEWANDOWSKI

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POLYMER MODIFICATION OF PAVING ASPHALT BINDERS

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I. INTRODUCTION

Polymers have played an important role in the asphalt paving industry for a long time. In 1873, Samuel Whiting was granted a patent for an asphalt paving mixture containing a % by weight quantity of latex from the *balata* plant. Although no roads were documented using this material, a French rubberized asphalt paving company laid rubberized asphalt roads as earlier as 1902.[1] In the 1930's numerous test roads were installed by the British

and French.[2] From 1945 to present the use of polymers in asphalt has been looked upon as a method to improve the performance of the pavement.

The interaction of the polymer with the asphalt has the potential of addressing many of the problems that exist in today's highway, county and city roads. The main reasons that asphalt modification has become more accepted are listed below[3]:

- The perception that asphalt cement has changed since the 1970's.
- Traffic factors have increased; *e.g.* heavier loads, higher traffic volumes and higher tire pressures. (Twofold increase in truck traffic from 1974–1989[4].)
- Deferred maintenance because of funding shortages.
- Higher costs have created a tendency to construct thinner pavements, thus reducing the service life of the pavement.
- Environmental and economic pressures to dispose of industrial waste materials (tipper landfills).

The implementation of the Strategic Highway Research Program (SHRP) binder specifications provides a way to measure the viscoelastic contribution of the polymer to the asphalt binders properties. SHRP was a five year, $150 million dollar research effort established and funded under the 1987 Surface Transportation and Uniform Relocation Assistance Act. A total of $50 million dollars was directly allotted to study asphalt binders and asphalt-aggregate mixtures. One of the primary products of this work was the development of a performance-based specification for asphalt binders. The specification was developed to address the major distresses observed in asphalt pavements: high-temperature permanent deformation, load-associated fatigue cracking and low-temperature thermal cracking. The viscoelastic behavior of the binder becomes critical as the temperature and rate of loading are varied. Since different parts of the country display different temperature ranges, these specifications were directed toward that concern. With new emphasis on the rheology of the binder, asphalt paving technologists are gaining a better understanding of the viscoelastic nature of asphalt and polymer-modified asphalt binders.

The primary reason for using polymer modification is the improved properties it provides the asphalt with respect to distresses observed in pavements. The most common types of distresses are rutting, thermal cracking and load-associated fatigue cracking. Rutting is the permanent deformation of the asphalt concrete pavement caused by the accumulated plastic deformation with repeated application of loads at upper service temperatures (40–65°C). This deformation produces channels parallel to the direction of travel and becomes a hazard during and after rain showers. Thermal cracking is caused when the asphalt is exposed to a single thermal cycle where the temperature reaches a critical low temperature or from thermal cycling above the critical low temperature. Cracks usually appear perpendicular to the direction of traffic. Load-associated fatigue cracking occurs over the lifetime of the pavement and usually results in severe structural damage of the asphalt concrete pavement. There are other problems which also should be addressed to include stripping and aging. Stripping is caused by the water's greater affinity for the aggregate than the asphalt. Aging is the hardening of the asphalt over time and temperature. Polymers have been found to lower the apparent age hardening, reduce the moisture susceptibility and improve adhesion of the binder to the aggregate. Table I gives a more in-depth list of reasons for using modified binders and mixtures.[3] There are polymer modifiers on the market which address these different problem areas.

It is difficult to determine the actual amount of asphalt pavements which have polymer modification because polymers are used in a variety of pavements. Polymer-modified asphalt are used for dense-graded hot-mix asphalt concrete (Figure 1), open graded friction course (Figure 2), stone mastics (Figure 3), seal coats and chip seals.[5] During the course of this review the term *binder* is used to describe either the asphalt binder modified or unmodified. The term *mixture* is used when discussing the product of mixing and compacting of aggregates, fines and the asphalt binder together, and *asphalt concrete pavement* defines the in-place pavement structure (road).

TABLE I

REASONS FOR MODIFYING ASPHALT BINDERS AND MIXTURES WITH POLYMERS[3]

1.	Obtain softer mixtures at low service temperatures and reduce cracking
2.	Obtain stiffer mixtures at high temperatures and reduce rutting
3.	Reduce viscosity at construction temperatures
4.	Increase strength and stability of mixtures
5.	Improve abrasion resistance of mixtures
6.	Reduce raveling
7.	Reduce low temperature cracking of pavements
8.	Improve workability and compaction
9.	Accelerate early stiffening of tender mixtures
10.	Improve fatigue resistance of mixtures
11.	Upgrade marginal asphalt binders
12.	Rejuvenate aged asphalt binders
13.	Reinforce asphalt binders and mixtures
14.	Permit use of marginal aggregates
15.	Replace asphalt as an extender
16.	Permit thicker asphalt films on aggregate
17.	Improve bonding and reduce stripping of asphalt and aggregate
18.	Reduce flushing or bleeding
19.	Improve resistance to aging or oxidation
20.	Reduce structural thickness of pavement layers
21.	Reduce life cycle costs of pavement
22.	Improve overall performance of pavements

This review mainly addresses the use of polymer modifiers in dense-graded hot-mix asphalt concrete pavement applications. An introductory background to asphalt chemistry and tests used to grade asphalt binders will be presented. Emphasis will be placed on methods used to characterize the compatibility, rheology and mechanical properties of polymer-modified asphalt binders. The tests discussed in the first chapters will be related to the mixture properties in the later chapters. A brief chapter is also dedicated to asphalt-rubber.

II. CHEMISTRY OF ASPHALTS

A. STRUCTURE AND CHEMISTRY OF ASPHALT BINDERS

Unlike the chemical structure of polymers, asphalt binders contain an infinite variety of chemical compounds. These variations are caused primarily by the type of crude source and

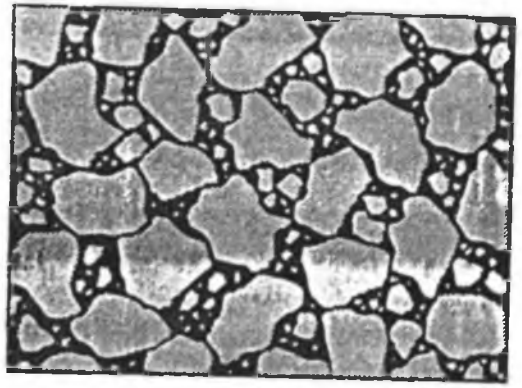


FIG. 1.— Cross-sectional view of dense-graded hot mix asphalt concrete; volume percentages: ~91% aggregate, 5% asphalt binder, and 4% air voids.[5]

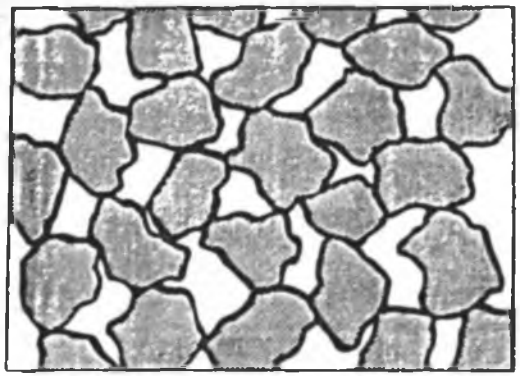


FIG. 2. — Cross-sectional view of open-graded friction course; volume percentages: ~72–85% aggregate, 5–8% asphalt binder, 10–20% air voids.[6]

refining process involved in obtaining the final paving asphalts. According to a recent survey,[6] there are over 120 different crude sources used in the United States and these are processed by four major refining techniques: fractional crude oil distillation under atmospheric pressure with steam, topped crude distillation under vacuum with or without steam, solvent refining (propane deasphalting, residual oil supercritical extraction), and air blowing. These processes can be divided into two groups. The first group contains the distillation and refining processes and involves the recovery of the asphalt as they exist in the unprocessed crude oil. The last method, air-blowing, results in chemical and physical changes in the material. In many cases several different crude sources are mixed to together to produce asphalt binders which meet the required specifications.[7]

Table II displays the elemental analysis of four asphalts from different crude sources.[8] The carbon/hydrogen ratios in the asphalts are similar in most cases. The concentration of the heteroatoms (oxygen, nitrogen, sulfur, etc.) and heavy metals tend to vary. These elements combine to form an infinite variety of compounds in the asphalt binder. The heteroatoms play a major part in the resulting properties of the asphalt as will be discussed in the upcoming paragraph.

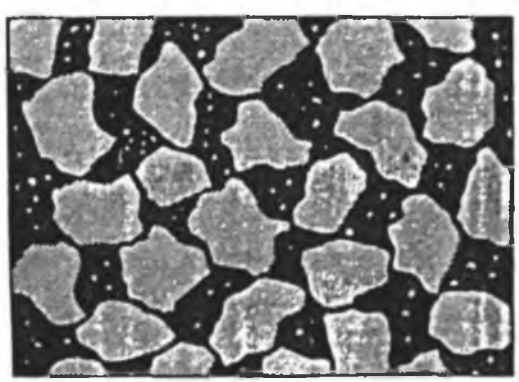


FIG. 3. — Cross-sectional view of stone mastics; volume percentages: ~85–80% aggregate, 7–10% asphalt binder, 4–6% air voids.

TABLE II

ELEMENTAL ANALYSIS OF ASPHALT BINDERS[8]

Element	Composition (%)			
	Mexican blend	Arkansas-Louisiana	Boscan	California
Carbon	83.77	85.78	82.90	86.77
Hydrogen	9.91	10.19	10.45	10.03
Nitrogen	0.28	0.26	0.78	1.10
Sulfur	5.25	3.41	5.43	0.90
Oxygen	0.77	0.36	0.29	0.20
Vanadium (ppm)	180	7	1380	4
Nickel (ppm)	22	0.4	109	6

A schematic of the typical asphalt molecule is shown in Figure 4.[9] This is one of the models used to describe the asphalt binder structure (micellular model). The primary component of the asphalt is the asphaltene, which is a multi-ring, polar, aromatic compound which gives the asphalt its structure. This has been confirmed by x-ray diffraction measurements where the structure consisted of up to five condensed aromatic rings surrounded by cyclic and paraffinic substituents.[10] Also when the asphalt is separated by molecular weight, electron microscopy has shown that the asphaltenes are predominant in the high molecular weight fractions.[11] Surrounding the asphaltene are several different chemical structures with varying functionalities from polar, aromatic to nonpolar, aliphatic in nature. This phase gives the asphalt its Newtonian type behavior and maintains the asphaltenes in a colloidal solution. A second model which has recently been suggested is the polar-dispersed solid model (PDF Model), which states that the amphoteric chemical species, *i.e.* those containing strong acid and strong base components on the same compound, give the asphalt its viscous behavior. Both models require that a dispersed phase forms some network in a nonpolar matrix. This becomes a very important issue when polymers are added to the

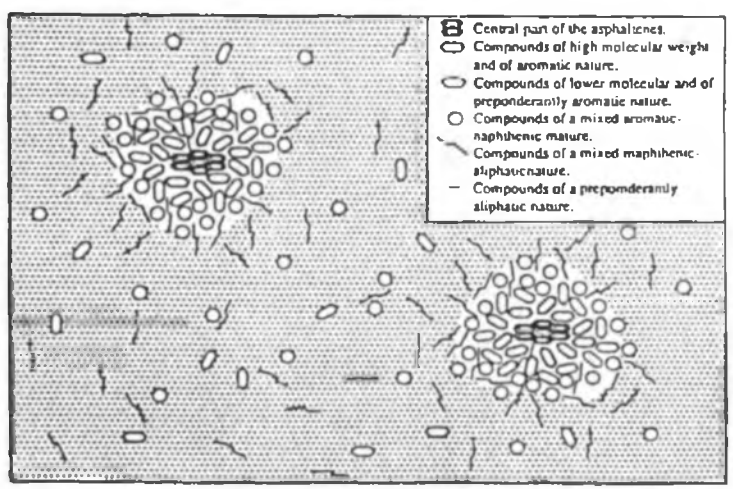


FIG. 4. — Schematic of micellular model for asphalt binders.[9]

TABLE III

BLOCK COPOLYMERS AND OTHER THERMOPLASTIC POLYMERS USED IN ASPHALT MODIFICATION[12]

Modifier type	Producer	Trade name
SBS and proprietary additive	Ergon	Seala-Flex
Ethylene/vinyl acetate	DuPont	ELVAX
Ethylene copolymer	DuPont	ELVALOY AM
Ethylene/propylene/butylene terpolymer	Huls	Vestoplast 5
Ethylene based copolymer	ARE, Inc.	STARFLEX
Ethylene based copolymer	ARE, Inc.	MODIFLEX
Styrene/butadiene/styrene	EniChem	Europrene Sol
Ethylene copolymers	Exxon Chemical	POLYBILT
Styrenic block copolymer	Dexco Polymers	Vector
LDPE	Advanced Asphalt Technologies	NOVOPHALT
Styrene/butadiene/styrene	FINA	Finaprene
Styrene block copolymers	Shell	Kraton D&G

asphalt, because the nonpolar matrix swells the polymer chains and changes the colloidal stability of the system.

B. POLYMERS USED FOR ASPHALT MODIFICATION

There are a large variety of polymers currently being used in the asphalt paving industry. The purpose of modification depends on the problems it addresses or the type of asphalt mixture it will be used to modify. Most polymer-modifier manufacturers for paving asphalt suggest the modifier improves the asphalt concrete pavement by: (a) improved resistance to high temperature permanent deformation; (b) increased low temperature flexibility; (c) improved fatigue resistance; (d) increased tensile strength; and (e) reduced temperature susceptibility. The types of polymer-modifiers used in the asphalt paving industry can be loosely categorized into three groups: block copolymers and other thermoplastics, synthetic and natural rubbers, and others.[12,13]

1. *Block copolymers and other thermoplastics.* — This group of modifiers consists mainly of block copolymers containing styrene as the end block and butadiene as the rubbery mid block. This group consists of styrene–butadiene (SB), styrene–butadiene–styrene (SBS), styrene–isoprene–styrene (SIS), styrene–ethylene–butylene–styrene (SEBS) and acrylonitrile-butadiene–styrene (ABS). To behave like an elastomer some block copolymers (*i.e.* SB) require the addition of sulfur. Also included in this group are thermoplastics such as low-density polyethylene (LDPE), ethyl vinyl acetate (EVA) and ethylene propylene diene monomers (EPDM). Table III shows the block copolymers and thermoplastic modifiers available with the manufacturer's generic description, producer and trade name.

2. *Synthetic and natural rubbers.* — The second group consists of synthetic and natural rubbers, and usually require a crosslinking agent to form a continuous network which will

TABLE IV

SYNTHETIC AND NATURAL RUBBERS USED IN ASPHALT MODIFICATION[12]

Modifier type	Producer	Trade name
Styrene/butadiene latex	Ultrapave/Goodyear	UP-70, UP-7289, UP-2897, UP-65K
Styrene/butadiene latex	Rub-R-Road	R-504, R-550
Styrene/butadiene latex	BASF Corp.	Butonal NS
Polychloroprene latex	DuPont	Neoprene

not flow at high temperatures. This group consists of homopolymers like natural rubber (NR), polybutadiene (PBD), polyisoprene (PI) and poly(2-chloro-1,3-butadiene). Also random copolymers like styrene butadiene rubber (SBR) are included in this group. Table IV shows several of the commonly used synthetic rubber modifiers.

3. *Others (ground tire, fibers, etc.).* — The remaining types of modifier are grouped loosely into an 'others' category which contains modifiers such as ground tire, fibers and antistripping agents (Table V). Ground tire in asphalt binders (asphalt-rubber) has become a topic of much discussion over the last several years. A chapter is devoted to asphalt-rubber and its effects on the mixture's performance. Fibers and antistripping agents will be addressed briefly here and further discussion is beyond scope of this review.

Unlike the other polymer modifier groups previously mentioned, fibers do not normally interact chemically with the asphalt binder. Their primary purpose is to increase the toughness of the asphalt mixture by increasing the amount of energy absorbed during fatigue and fracture processes. Fibers also allow higher binder contents to be used such as in stone mastics and open-graded mixtures. Generally, fibers range in size from 0.0002–0.012 in and can be made up of cellulose, polyester, polypropylene, poly(vinyl chloride) or polyamides.[3]

Antistripping agents are another type of polymer modifier. Although most antistripping agents are not polymeric in nature, they are common additives to dense-graded and open-graded asphalt mixtures. Polyamines and polybutadiene are two types currently on the market. Polyamines are not high molecular weight polymers and volatility is a problem. Polybutadiene is applied to the aggregate surface to form a uniform layer. Antistripping agents are used to prevent moisture damage in the asphalt concrete pavement. The primary cause of stripping is the loss of adhesion between the asphalt binder and aggregate due to water displacing the asphalt binder at the aggregate surface. The reader is directed to several references for further information.[14–19]

III. TEST METHODS FOR CHARACTERIZING ASPHALT BINDERS

A. CLASSICAL TEST METHODS

Most asphalt binders are currently classified by a viscosity-graded system. The viscosities at 60°C and 135°C are important to the application and use of the asphalt binders. The apparent or absolute viscosity in poise is listed under ASTM 2171 "Viscosity of Asphalt by Vacuum Capillary Viscometer" and is performed at 60°C under vacuum.[20] While at 135°C, the asphalt binder displays Newtonian behavior and ASTM 2170 "Kinematic Viscosity of Asphalts" is performed where the asphalt binder flows under gravity.[20] The viscosity at

TABLE V

OTHER TYPES OF POLYMER USED IN ASPHALT MODIFICATION[12,13]

Modifier type	Producer	Trade name
Polyamine (antistripping)	Morton Int.	Pave Bond
Crumb rubber	GRF-80	Rouse Rubber
Crumb rubber	IGR	Baker
Crumb rubber	EnviroTire, Inc.	Plusride II
Styrene based copolymer	Lubrizol	Ductilad
Polybutadiene (polymeric antistrip system)	Goodyear/Ultrapave	UP-5000
Polypropylene fibers	Petro Fibers	PetroFiber
Polypropylene fibers	FiberPave	Hercules, Inc.
Styrene based copolymer	Ductilad D1002	Lubrizol
Polyester	Bonifibers	Kapejo
Cellulose-based	American Fillers and Abrasives	Knyolee
Polyamine/Polyamide	Carstab Products	PaveBond

60°C defines the asphalt cement (AC) grade as AC-5 (500 poise), AC-10 (1000 poise), AC-20 (2000 poise) and AC-40 (4000 poise). On the west coast, the viscosity after aging, based on the Rolling Thin Film Oven Test(RTFOT) (ASTM D2872-80), is sometimes used and referred to as an AR grade. Another classical technique for describing asphalt binders is the penetration test (ASTM D5). The viscosity-graded system replaced the penetration system in the sixties.[21] A needle is loaded with either a 100 g (25°C) or 200 g (4°C) load and allowed to penetrate into an asphalt sample for 5 s (25°C) or 60 s (4°C). The depth of penetration is measured in dmm. The penetration at 4°C is used to describe the low temperature properties of asphalt binders. Other test used to characterize the asphalt binder are the Ring and Ball Softening Point (ASTM D36) and Ductility (ASTM D113).[20]

B. METHODS FOR DETERMINING POLYMER MODIFICATION

A limited amount of work has been performed on characterizing polymer-modified asphalt binders with classical test methods a limited amount of work has been performed. Rostler noted in an annotated bibliography that between 1020 and 1037, rubber additives were found to increase the ductility and reduce the temperature susceptibility.[22] This was also observed by Endres *et al.* in 1951.[23] The first extensive work in studying polymer-modifier's effect on the properties of the binder was performed by Lewis and Welborn.[24] They studied fourteen different types of rubber in three different 85/100 penetration graded asphalt binders. They found that rubber increased the softening point and flow behavior, but decreased the temperature susceptibility. It was observed that the changes in asphalt from the addition of rubber were directly related to the degree of dispersion. While many subjective test methods exist to identify the presence of modifier in the asphalt binder, no quantitative methods have been accepted industry wide.

Once a polymer is added to the asphalt binder there is a dramatic increase in the viscosity. The viscosity can increase by a factor of two with just a 3 wt. % addition of polymer. The polymer-modified asphalt binder also displays a decrease in viscosity as the rate of shear increases. The thixotropic behavior of these materials led to the development of several techniques for measuring their properties. Some of the commonly used tests include force ductility, infrared spectroscopy, toughness and tenacity, elastic recovery and torsional recovery.

Several variations on the standard ductility test have been employed to measure the properties of polymer modified asphalt binders. Force ductility uses a modified version of the standard ductility test where the specimen has a longer region with uniform cross-sectional area. Force ductility measures the load-deflection curve for an asphalt binder at a deformation rate of 5 cm/min. A typical force ductility curve is shown in Figure 5. Shuler divided the curve into several regions.[25] The maximum stress is represented by the area under the curve. The second slope is said to relate directly to the polymer modification, while the first slope is only related to the asphalt. This measurement technique does have some serious deficiencies. First, the rate of deformation produces nonlinear type behavior which may not be found in asphalt concrete pavements. Second, the geometry is poorly

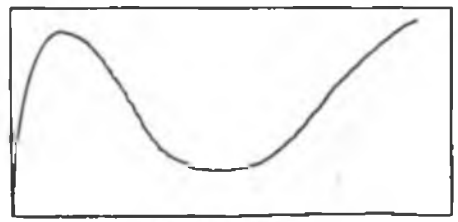


FIG. 5.—Typical force ductility curve for polymer-modified asphalt binder.

defined and the test results are material specific. SBS modified asphalt binders tend to perform differently than EVA, LDPE and SBR modified asphalts. A simple procedure was developed by ELF Mineraloel Laboratories to measure the elastic recovery of ductility samples.[26] The sample is elongated to 20 cm at 10°C and held for 5 minutes. The elongated specimen is then cut in half and the two ends are measured after the sample relaxes for one hour. This test is simple and employs equipment already in the laboratory.

Infrared spectroscopy has been used by numerous researchers to quantitatively determine the presence of polymer in polymer-modifed asphalt binders. Button used specular reflectance fourier-transform infrared spectroscopy to determine the amount of LDPE in an AC-10 binder extracted with xylene at 140°C from a mixture sample.[27] The band at 1601 cm^{-1} was used for the asphalt reference representing the double bond in the benzene, while the polymer was identified by a carbonyl peak at 1738 cm^{-1} associated with a small amount of acetate in the polymer (Figure 6). A calibration curve was produced using the peaks associated with the asphalt and the polymer. The Texas State Highway Department of Transportation routinely uses transmission infrared spectroscopy for determining the SBR-Latex and EVA content in asphalt binders.[28] The Shell Development Company also has developed procedures for determining the level of SBS block copolymers in asphalt using infrared spectroscopy.[29] A wide range of modifiers were fingerprinted using attenuated total internal reflectance fourier transform infrared spectroscopy (FTIR-ATR).[30] This technique can also be used for quantitative determination reducing the preparation time and the use of solvents. Although infrared spectroscopy is an excellent quantitative method, it does not give the user the effect of modification on the resulting mechanical properties.

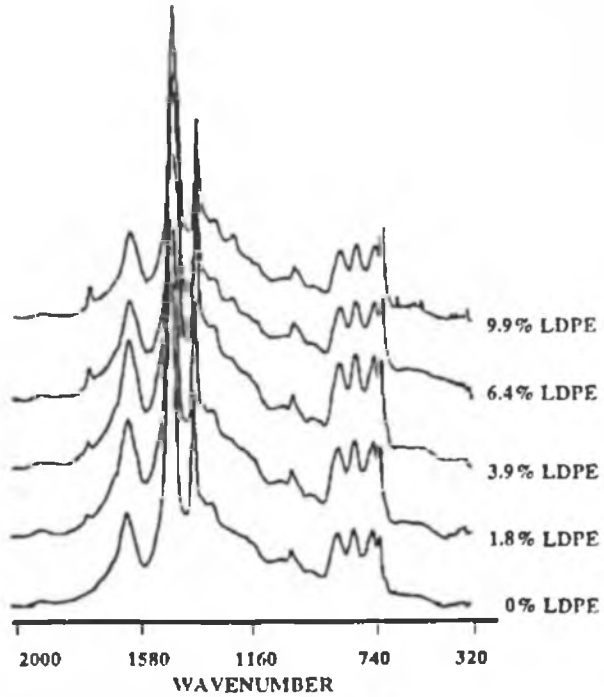


FIG. 6.—Specular reflectance infrared spectra of LDPE modified AC-10 asphalt binders at various wt.% LDPE.[27]

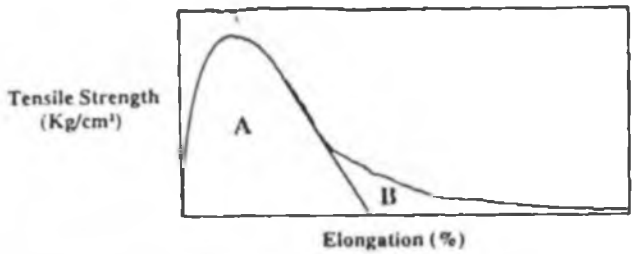


Fig. 7. — Tensile strength vs. load deflection; toughness calculated from area (A+B) and tenacity from area (A)[32]

Another method used to monitor the tensile strength properties of polymer-modified asphalt binders is the Toughness and Tenacity Test. Benson developed this test by imbedding a hemispherical head in molten asphalt and allowing the sample to cool.[31] The head is then pulled at a rate of 20 cm/min to produce a load-deformation curve. A typical tensile strength load deflection curve is shown in Figure 7, where tenacity is defined as the area B (kg/cm²) and toughness is the total area under the curve (A+B).[32] Figure 8 shows the toughness and tenacity curves for several different polymer-modified asphalt binders.[33] Several problems also arise with this test. First, the tangent to the negative slope for determining area A is hard to define. Second, a stress-strain curve cannot be reproduced due to the lack of a well-defined cross-sectional area. Finally, the test gives different results for different polymers with the same level of loading.

The torsional recovery test is used in California to test for the recovery of latex modified asphalt emulsion residue.[34] A disk is submerged in a tin containing hot asphalt and allowed to cool to room temperature. The disk is then rotated 180 degrees and released. The recovery between 30 seconds and thirty minutes is used to define percent recovery. Shuler performed statistical analysis on the results obtained with this method and found that the identification of different polymers was possible based on their % recovery.[35] By applying a 10 minute relaxation period, the modified asphalt could be grouped into three categories based on elastic recovery (Table VI). Unfortunately, the deformation is applied manually resulting in poor control.

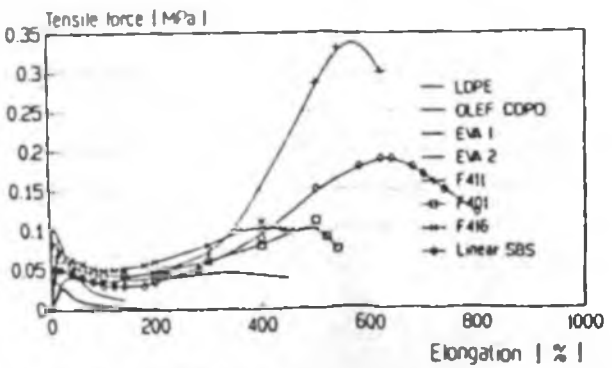


Fig. 8. — Tensile force vs. elongation for various polymer-modified asphalt binders for determination of toughness and tenacity.[33]

Table VI

Elastic Recovery of Different Polymer Modifiers in Asphalt Binders[35]

	Group A	Group B	Group C
Elastic recovery (%)	60–100 ~6 wt. % SBS	20–60 ~3 wt. % SBR, EVA, SB, SBS	0–25 EVA

IV. MORPHOLOGY OF POLYMER-MODIFIED ASPHALT BINDERS

A. POLYMER/ASPHALT COMPATIBILITIES

A critical part of any polymer-modified asphalt blend is the compatibility of the system. The formation of a homogeneous, and at high polymer loading, a polymeric network is a function of many variables including: polymer concentration, polymer chemical structure, polymer molecular weight, degree of branching, types of interactions between the polymer and asphalt, asphaltene content, and the thermal/mechanical history of the blend. For SBS type polymers, Kraus stated that for optimum effectiveness of the polymer for asphalt modification several important structural criteria must be met.[36] First, the block polymer must be rich in butadiene, and contain 30–40% styrene. The polymer must have two polystyrene blocks or a suitable branch point giving either a linear (SBS) or radial (SBx) configuration. Finally, the molecular weights of the polystyrene must exceed 10,000 to obtain polystyrene rich domains.

B. TYPES OF POLYMER-MODIFIED ASPHALT BINDERS

The morphology of polymer-modified asphalt binders can be described by four basic groups depending on the concentration, presence of a crosslinking agent and the chemical structure of the polymer. The most commonly used system consists of up to six weight percent polymer (wt. %) added with respect to the asphalt binder. In this case the polymer is a separate and dispersed phase in the asphalt. The polymer domains represent polymer swollen with the solvating phase of the asphalt (Figure 9). A significant amount of work has been performed on studying the morphology of SBS block copolymers in asphalt.[36–38] In the polymer-rich phase, the polybutadiene is swollen by the nonasphaltene fraction, while the polystyrene stays in pure domains. If the polymer loading is increased, the polymer becomes the dominant phase, and the transition is followed by a change to polymeric type properties.[40] There are two other types of structures formed because of chemical and physical constraints of the polymer and/or asphalt in the asphalt binder. Block copolymers with polystyrene endblocks can form a network in the asphalt through the polystyrene domains providing physical crosslinks. An example of this is roofing asphalts which routinely have 15 wt. % block copolymer and display elastic behavior.[41] Also, the polymer can be chemically bonded to the asphalt or to the asphalt molecules. An example of this chemical bonding is the presence of asphalt involves the addition of a small percentage of sulfur to crosslink

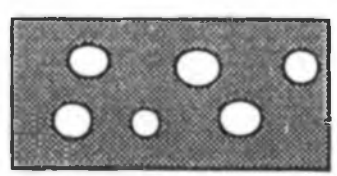


Fig. 9. — Schematic of polymer-modified asphalt binder morphology with up to 6 wt.% polymer.

the polymer. Another type of structure is formed with the *in-situ* reaction of acrylic acids and maleic anhydride via a Diels-Alder reaction in the asphalt.[42,43]

C. METHODS OF DETERMINING COMPATIBILITY WITH MICROSCOPY

Since conventional techniques for determining the compatibility of polymer/asphalt blends and polymer blends (T_g, solubility diagrams, etc.) are not applicable to polymer-modified asphalt binders, several analytical techniques have been employed. Scanning Electron Microscopy (SEM), Scanning Transmission Electron Microscopy (STEM) and Fluorescence Optical Microscopy (FOM)[11] have all been employed to study the phase behavior of polymer-modified asphalt binders.

SEM has been used to study the formation of the polymer domains in the asphalt binder. This method requires the polymer-modified asphalt binder to react with a solution containing Osmium Tetroxide (OsO_4). The OsO_4 reacts with the double bonds on the polymer backbone to a form a continuous structure in which the asphalt binder can subsequently be extracted. The samples are then microtomed or cryofractured to create a cross-sectional area for SEM analysis. Work performed by Petersen and associates showed that depending on the asphalt source and grade, a variety of morphologies can be found.[44] They found that for different AC-10 and AC-20 samples with 6 wt. % SBR latex, five characteristic polymer asphalt morphologies were formed: fine and coarse continuous strings, open cells, closed cells, sheetlike thin films and thick discontinuous fibrils. The honeycomb structure shown in Figure 10 was found to be more favorable to the resulting physical properties than the other morphologies. They concluded that crude source has a definite effect on latex phase morphology and that the mode of mixing may also play a role. Similar work was done studying the morphology of SBS block copolymers.[45] It was observed that as the concentration of polymer increased the microstructure became more coarse. At low concentrations the polymer modified binder displayed good stability. They also found that *in-situ* chemical reactions can reduce this coarseness and enhance solubility of the polymer in the asphalt.

Another method employed by asphalt researchers is STEM.[39] This method requires the sample to be freeze fractured and then treated with a solution containing OsO_4. The OsO_4 was used to stain the unsaturated component on the polymer backbone and fix the internal structure of the polymer. Various asphalt binders were modified with SBS and the effect of morphology on the rheological properties was studied. An excellent example of the selective compatibility of different asphalt binders is displayed in Figure 11. The dark phase in these

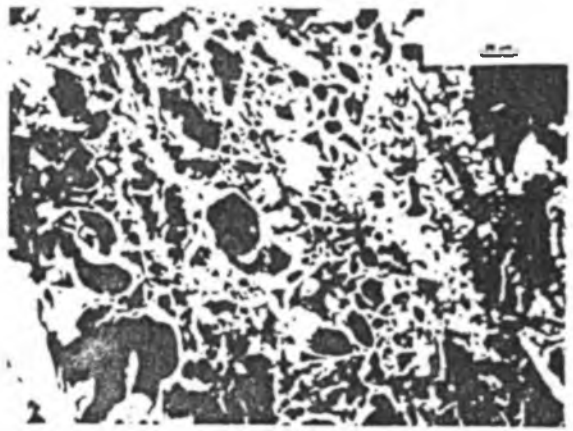


FIG. 10. — SEM of honeycomb structure of a SBR modified asphalt binder.[44]



FIG. 11. — STEM of asphalt binders modified with 4 wt.% SBS, showing effect of asphalt source; (A) Martinez AR-1000, (B) Boscan AC-6, and (C) Deer Park AC-5.[39]

pictures represents the swollen polymer and distinctively different morphologies are observed with different asphalts. For each micrograph, 4 wt. % SBS was added. The SBS modified Boscan showed the largest polymer domains in the morphology, suggesting a large degree of incompatibility. Both the SBS modified Martinez and the Deer Park showed smaller polymer domains and a fairly homogeneous dispersion of the polymer in the asphalt matrix.

Fluorescence microscopy is another valuable tool in studying the morphology of polymer-modified asphalt binders. This method is suited for studying microstructure because most the structure is in the range of 10–100 μm in size. Although reflective microscopy allows the material to be observed in the neat state, fluorescence microscopy allows for the observation of structure and homogeneity.[40] In this method, the sample surface is bombarded with blue light and fluorescent re-emitted yellow light is observed with an optical microscope. The oils swelling the polymer phase fluoresces yellow light (appear white), and the asphalt binder remains dark. Work performed by Brule, Brion and Tanguy demonstrated the effect of mixing time and temperature on the resulting compatibility.[40] An asphalt binder with 10 wt.% SBS and 10 wt.% aromatic oil was mixed for different times and temperatures (Figure 12). At 200°C, the asphalt domains ranged from 6–40 microns in size, while after seven hours the domains were reduced to 1–5 microns in diameter. At 220°C, after seven hours almost complete dilution of the asphalt in the oil-extended polymer was observed. It was also noted that the size of the globules of asphalt decreased dramatically with mixing time. DeFoor studied the morphology of several different polymers in both compatible and incompatible asphalt binders.[11] They developed a rating system for their fluorescence micrographs according to the aspect and fineness of the granular structure:

microhomogeneous — (quasi) compatible;
vermicular — acceptable compatibility, particle size <2 μm;
globular — slightly compatible, <10–20 μm;
strands — incompatible, >50 μm.

It was observed that when a linear SBS is added to asphalts with differing amounts of asphaltene, the morphology and viscoelastic properties change. A low percent asphaltene (< 6 wt.%) binder gives a quasi-homogeneous morphology and good viscoelastic properties, while higher concentrations of asphaltenes increase the coarseness of the morphology.

The various microscopy techniques have shown that a variety of morphologies can be found in polymer-modified asphalt binders. More work is required in understanding the phase behavior and its effect on the properties.

V. DEFORMATIONS AND DISTRESSES OBSERVED IN ASPHALT PAVEMENTS

A. DISTRESSES IN ASPHALT PAVEMENTS

The primary pavement distresses in asphalt concrete pavements are high temperature permanent deformation, low-temperature thermal cracking and load-associated fatigue cracking. Aging and moisture susceptibility compound these deficiencies.

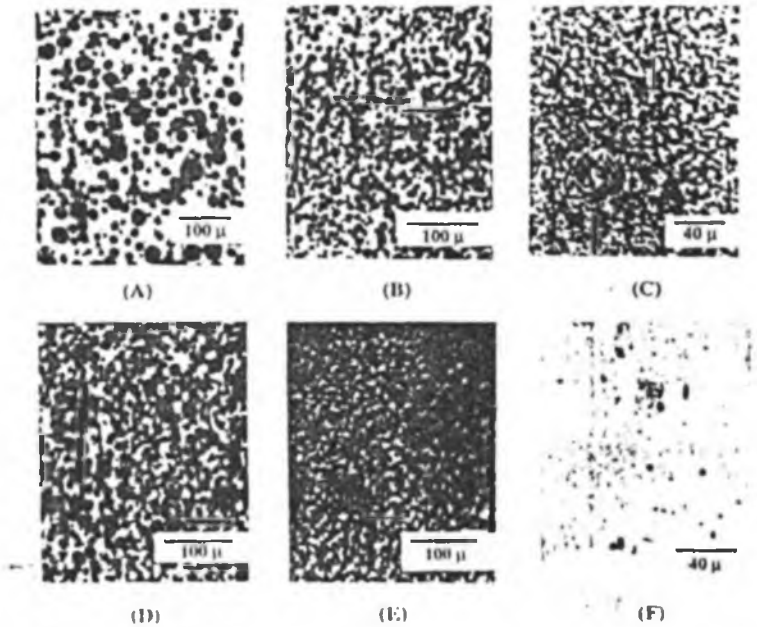


FIG. 12. — Fluorescence micrographs showing the effect of time and temperature on the compatibility of a 10% SBS / 10% aromatic oil / 80% asphalt binder; (A) 200°C, 1 hour; (B) 200°C, 4 hours; (C) 200°C, 7 hours; (D) 220°C, 1 hour; (E) 220°C, 5 hours, and (F) 220°C, 7 hours.[46]

1. *High temperature permanent deformation.* — Permanent deformation consists of rutting, shoving and distortion. Rutting is usually caused by the accumulated plastic deformation in the asphalt pavement with repeated applications of loads at upper service temperatures. Some of the causes of rutting are high truck tire pressures, high asphalt binder content, poor quality of asphalt binder, use of large amounts of rounded aggregate and water sensitivity. The rutting is usually visible with depressions forming in the wheel tracks parallel to the direction of traffic. These are formed from the consolidation of one or more layers as a result of repetitive shear stresses.[46] An asphalt binder that contains more of the associating phase and cannot respond elastically to the applied stresses will be more likely to rut. Two indicators of rutting potential are binders with high temperature susceptibility and those that do not harden upon oxidation. Polymer modification generally stiffens the binder and reduces its temperature susceptibility.

2. *Load-associated fatigue cracking.* — Load-associated fatigue cracking is caused by the continuous application of loads over a long period of time. This permanent distress occurs from the result of low binder content, too stiff a binder, water sensitivity and poor bearing capacity of the support layers. Fatigue cracking is caused by loads being applied and traffic volumes exceeding the design criteria for the asphalt concrete pavement.

3. *Low-temperature thermal cracking.* — The final distress is low-temperature thermal cracking. Thermal shrinkage cracking results from either a single thermal cycle where the temperature reaches a critical low temperature or from thermal cycling (thermal fatigue) above the critical low temperature. Some of the likely causes of low-temperature thermal cracking are stiff binders, low binder content and high dust to asphalt ratio. When the tensile stress in the asphalt pavement exceeds the tensile strength, brittle fracture occurs. Low-[illegible] usually causes cracks transverse to the pavement direction.

At low temperatures, the binder becomes rigid and its ability to deform elastically is lost. The neutral materials (nonpolar) in the asphalt binder become more ordered or structured making the asphalt binder more brittle.[47] The asphalt binder's stiffness at low temperatures is dependent on many variables (viscosity-grade, crude source, pavement age, etc.). This is the area where polymer modification can contribute significantly. First, by using polymer modifiers a lower viscosity asphalt can be employed, resulting in a lower stiffness temperature. Second, the glass transition of the polymer is considerably lower than the asphalt in the case of PBD or NR, allowing for low temperature flexibility.

B. ASPHALT AND POLYMER-MODIFIED ASPHALT BINDER DEFICIENCIES

1. *Asphalt aging.* — The asphalt binder displays several characteristic physical and chemical changes when subjected to thermo-oxidative processes. These processes cause the asphalt binder to harden during the mixing, laydown and life of the asphalt pavement. This is caused by a loss of volatiles or low molecular weight species in the asphalt and the formation of hydrogen bonds. Figure 13 shows the groups usually formed in the asphalt binder upon aging.[8] These oxidation products form polar, strongly interacting groups which increase the viscosity and alter flow properties. In the case of polymer-modified asphalts, changes are also observed during the storage at the hot-mix plant or at the asphalt terminal.

The RTFOT (ASTM D2872-80) and Thin Film Oven Test (TFOT ASTM D1754-83) represent aging as it would occur in the hot-mix plant.[70] Some western states also use the viscosity after RTFOT to grade their asphalts, these usually have an AR designation.[48] Other aging tests such as the Thin Film Accelerated Aging Test (TFAAT),[49] California Tilt Oven Durability Test (CATOD)[50] and the Pressure Aging Vessel (PAV)[51] are used to simulate the aging of the asphalt over the life of the pavement.

2. *Storage stability of polymer-modified asphalts.* — When a polymer-modified asphalt binder is blended with an asphalt and stored at temperatures exceeding 150°C, thermo-oxidative degradation of the polymer can occur. During the mixing of the modifier with the asphalt there is some polymer breakdown due to the thermal and mechanical action of the mixing process, but this is minimal (4–5%).[48] Short-term aging as a result of storage of the asphalt and polymer-modified asphalts can affect the performance dramatically.

For both unmodified and polymer-modified binders the long and short-term stability are affected by asphalt aging, polymer microstructure and compatibility of the polymer/asphalt blend. In previous sections there was discussion on the asphalt aging and polymer-modified asphalt binder compatibility. An important aspect which has not been addressed is the polymer's stability. It is very common in the asphalt industry for the polymer to be blended with the asphalt and stored for weeks at a time. When the polymer contains unsaturation as in the case of SBS, SBR and SB, polymer degradation will occur. Collins and Bouldin

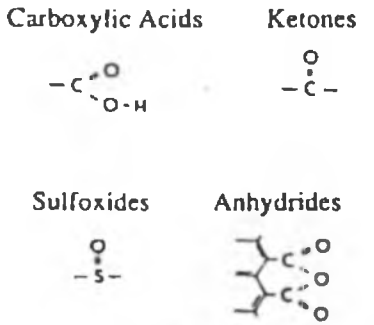


FIG. 13. — Types of oxidation products formed in asphalt binders during aging.[8]

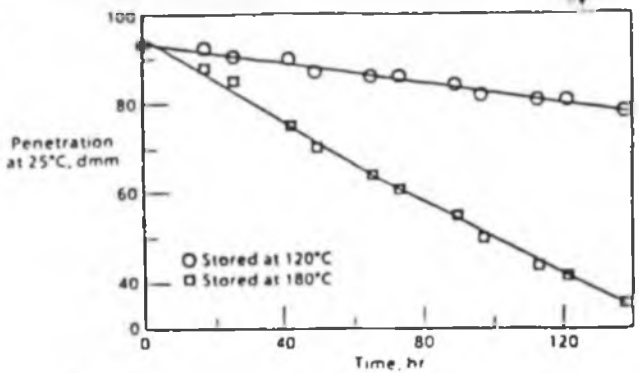


Fig. 14 — Effect of storage time and temperature on the penetration of SBS modified asphalt binders; 120°C (circles) 180°C (squares).[60]

measured the effect of storage time and temperature on a 4 wt.% SBS in a California Valley AR-1000.[48,52] Figure 14 shows that penetration decreased at a much greater rate at the higher temperature. This behavior has also been observed in SBR modified asphalt binders.[60] The oxidation of the asphalt binder and chain scission of the polymers have caused the asphalt's properties to change. Measurements of the storage modulus (G') and complex modulus (G^*) were made on the same binder. Figure 15 shows that the storage modulus of 4 wt.% SBS polymer-modified asphalt — measured at 1 rad/s and 60°C — decreased with storage time at 180°C. This is important because (G') plays a role in the resistance to permanent deformation. Polymer fragmentation from chain scission has caused the elastic nature of the blend to change. Collins and Bouldin concluded that polymer stability in the asphalt can be maintained if the storage of the binder is at 120°C or less and the mix temperature does not exceed 160°C for extended periods.

VI. RHEOLOGICAL BEHAVIOR OF POLYMER-MODIFIED ASPHALT BINDERS

A. HISTORICAL REVIEW OF THE RHEOLOGY OF ASPHALT BINDERS

The rheological properties of asphalt binders have been an area of interest to asphalt paving technologists for the past 40 years. Numerous studies have been performed on the

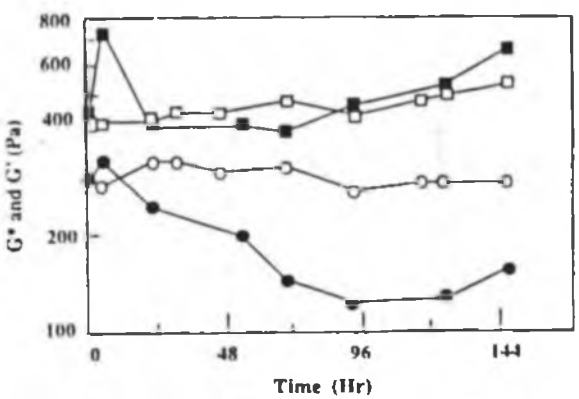


Fig. 15 — Effect of storage time and storage temperature on the G'(circles) and G^* (squares) measured at 1 rad/s, 60°C; storage temperatures, 180°C (filled) and 120°C (open).[60]

rheology of asphalt binders.[39,44,46] The earliest and most famous attempt at relating classical measurements to fundamental rheological properties (stiffness modulus) as a function of time and temperature is the van der Poel Nomograph.[50] He developed the nomograph to describe the viscoelastic properties of an asphalt binder and its relation to routine test data (penetration and ring and ball softening point). The term stiffness was used to describe the stress and deformation under conditions where a linear relationship exists between the two. The stiffness depends on the loading procedure, time of loading or frequency and temperature. This has been demonstrated in several papers.[53-55]

B. TIME TEMPERATURE SUPERPOSITION

Time-temperature superposition first developed by Williams, Landel, and Ferry,[61] has been applied to describe the effect of time and temperature on the viscoelastic processes of asphalt binders and polymer-modified asphalt binders. Using the equation:

$$\log a_T = -C_1(T - T_0)/(C_2 + T - T_0), \quad (1)$$

where a_T is the horizontal shift factor, C_1 and C_2 are constants. Several researchers have used this technique to develop mastercurves for asphalt binders[62,63] and polymer-modified asphalt binders,[39,58,64] assuming that binder's response is in the linear viscoelastic region. Unlike the mastercurve generated for an amorphous, uncrosslinked polymer which displays four distinct regions in the mastercurve,[65] asphalt has rather simple thermorheological properties. The mastercurve of a typical graded asphalt binder has two distinct regions: a glassy plateau and viscous asymptote.[63] When polymer is added to the asphalt binder, substantial changes occur in the shape of the mastercurve. Figure 16 shows the effect of increasing wt.% of EVA in the asphalt binder on the reduced storage shear modulus versus reduced frequency.[64] The addition of the polymer increases the complex shear modulus response at low frequencies. Collins and Bouldin also created stress relaxation mastercurves for 8 and 16 wt.% SBS modified asphalt binders (Figure 17). They found the mastercurve started to develop a rubbery plateau region at high SBS loadings, which suggested the formation of a polymer network in binder.[39]

Schmidt and Santucci studied 52 asphalt binders and used time-temperature superposition to relate the viscosities at two different temperatures.[58] They found C_1 to vary from 24.8 to 51 and C_2 to vary between 92.88 and 555.7 depending on the shear rate. The higher number may be due to nonlinear viscoelastic responses. T_g varied from −15°C to −37°C for the asphalt binders tested and they found satisfactory agreement between values measured at 39°C and those calculated using the WLF equation. Anderson found C_1 and C_2 equal to 51 and 92, respectively, when a defining temperature for the asphalt binders was used.[63] Heukelom found a correlation between the ring and ball softening point and T_g.[62] The shift factor (a_T) has also been related to the temperature susceptibility of the asphalt.[60,67-69]

At high temperatures and low rates of loading the binder approaches Newtonian type behavior.[61] Figure 18 shows the relationship between the transient viscosity test and dynamic measurements by employing Cox-Merz rule (when $\eta = \eta^*$ then $\dot{\gamma} = \omega$).[70,71] Others have related simple shear test to dynamic results.[71,72] Also the viscosity as a function of shear rate at 60°C was compared between an unmodified, SBS modified, Maleic Anhydride (MAH) and MAH/SBS.[44] Only the control and SBS modified displayed Newtonian behavior. The MAH displayed shear-thinning behavior where n ranged from $0.65 < n < 0.68$ for the power law relation $\eta = k\dot{\gamma}_a^{n-1}$. They observed that the zero shear modulus or the plateau modulus was unaffected by SBS, while MAH increased G_n^0 by 75 percent.

Shuler, Collins and Kirkpatrick using a dynamic shear rheometer found tangent delta does not increase with temperature for polymer-modified asphalt binders, while conventional asphalt binders show large increases.[73] They concluded that the polymer-modified asphalt binders behaved as an elastic network. This has also been observed with SBR modified asphalt binders at low frequencies.[44]

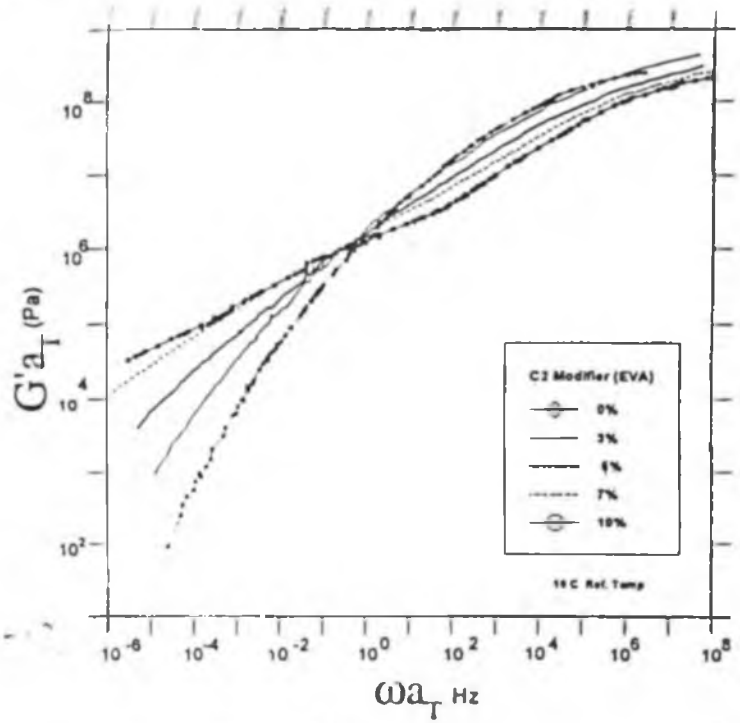


FIG. 16. — The reduced storage shear modulus (G') versus reduced frequency for various wt.% EVA modified asphalt binders.[64]

C. MEASUREMENT OF LOW TEMPERATURE PROPERTIES OF ASPHALT AND POLYMER-MODIFIED ASPHALT BINDERS

Low-temperature thermal cracking occurs when the asphalt binder becomes too stiff to withstand thermal and load-associated stresses. This problem is usually magnified by both oxidative and physical hardening which occur in the asphalt pavement. The fundamental question is whether thermal cracking occurs from the binder exceeding a critical limiting stiffness at a limiting stiffness temperature (TLST) or from pavement shrinkage applying tensile strains exceeding the binders tolerance to respond without fracture.[74] The definition for limiting stiffness temperature or fracture temperature is when the cryogenic stress becomes equal to the tensile strength of the asphalt and the specimen spontaneously cracks.

Traditional tests which are used to evaluate a binder's resistance to low-temperature thermal cracking consist of penetration at 4°C, ductility at 4°C, Frass brittle point[75] and the Shell critical cracking temperature method.[76] Low temperature penetration is used in the Task Group 3H and performance based specifications for estimating low temperature properties.[77] The problem is that this test is not run at sufficiently low enough temperatures. Low temperature ductility is another test which shows the enhanced properties of polymer-modified asphalt binders. SBR modified asphalt binders exhibit remarkable ductile properties. The Frass brittle point[75] test places a film of asphalt on a thin metal plate. The plate is flexed

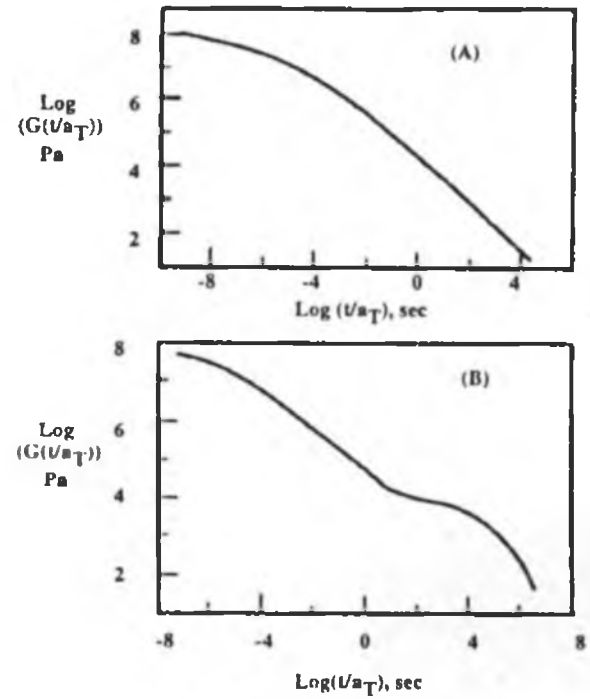


FIG. 17. — Stress relaxation mastercurve for 8 wt.% SBS modified (A) and 10 wt.% SBS modified (B) asphalt binders.[39]

at decreasing temperatures until cracks are observed in the asphalt film. This method usually predicts cracking temperatures up to 20°C higher than the mixture test. This can be attributed to the much higher strain rates applied in this test. Shell developed a method to observe

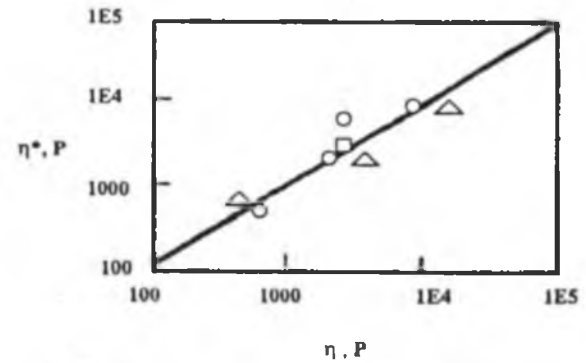


FIG. 18. — Comparison of η^* and η for various SBS modified asphalt binders based on transient and dynamic measurements. Brookfield (circles), capillary (triangles), and RMS 800 (squares).[39]

when microcracks form on a surface of an asphalt or polymer-modified asphalt while the temperature is lowered at a constant rate.[78] The Strategic Highway Research Program has proposed two tests to study the low-temperature properties of asphalt binders: bending beam rheometer and the direct tension test.

As mentioned earlier the traffic conditions correlate with short loading times on the order of a second or less, whereas low-temperature thermal cracking results from tensile stresses built up over longer periods of loading. While the higher temperature measurements can be made with dynamic techniques, low temperature measurements are generally made with transient techniques.[78-79] Four different polymer-modified asphalt systems were studied using dynamic mechanical analysis: carboxy-terminated butadiene-co-acrylonitrile, polybutadiene terminated with allylic bromine substituents, SBR latex from Polysar effluent recovery system, and vulcanized reclaim tire from Goodyear.[79] The measurements were done in shear using a Rheovibron operating at a frequency of 35 Hz from −35°C to 15°C. Plots of tangent delta versus temperature showed the location of the glass transition point for the different polymers in an 85/100 penetration Venezuelan asphalt. Figure 19 shows that the addition of polybutadiene produced the lowest glass transition temperature of the binders tested. Others have used the dynamic shear rheometer to measure low temperature properties.[79-80] Several problems have been noted, specifically the compliance of the instrument is critical and slippage occurs.

Two transient techniques used to measure the low temperature properties of asphalt and polymer-modified asphalt binders are the bending beam rheometer (three point bending) and the direct tension test. The bending beam rheometer was developed to measure the creep behavior of the binder at low temperatures.[80] Unlike the classical test methods, the three point bending geometry is well-defined by elastic beam theory. Using the equation

$$S(t) = PL^3/4bh^3\delta(t), \tag{2}$$

where $S(t)$ is the time-dependent flexural creep stiffness (in Pa) measured after a constant load (P) is applied and the deflection $\delta(t)$ is measured over a period of 240 seconds for a

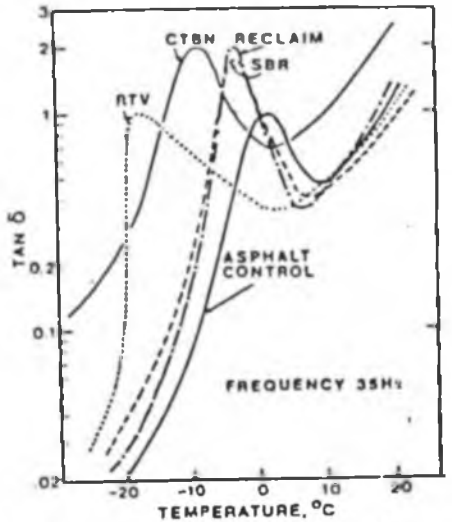


FIG. 19 — Tan δ vs. temperature for asphalt binders modified with 20 wt.% of the following polymers: carboxy-terminated butadiene-co-acrylonitrile (CTBN); polybutadiene terminated with allylic bromine (RTV); SBR from effluent recovery system (SBR); reclaim tire (RECLAIM); and the asphalt control.[79]

rectangular beam having a span length (L), width (b) and depth (h). Also the slope $d(\log(S(t))/d(\log(t))$ is used to describe the creep behavior. Performing the test up to strains of 1% maintains the response in the linear-viscoelastic region.[81]

The direct tension test is used to evaluate asphalt and polymer-modified asphalt binders which are very stiff at low temperatures.[82] Polymer-modifiers have been observed to have a significant effect on the low temperature strain and energy to failure of asphalt binders.[83] This strain tolerance gives the polymer modified asphalt binder the ability to withstand greater strain to fracture. Table VII shows how the addition of SB chemically reacted *in-situ* affects the failure strain at −15°C for various penetration graded asphalt binders. Generally, the addition of polymer increases the failure strain of the binder by as much as 100%.[74]

D. PERFORMANCE-BASED SPECIFICATIONS FOR ASPHALT AND POLYMER-MODIFIED ASPHALT BINDERS

In order to implement the use of polymers in asphalt concrete pavements, specifications or guidelines dictating their use must be established. Several specifications are currently in use or are being proposed for polymer-modified asphalt binders. These include: AC-20R (rubberized), Performance Based Asphalt (PBA), and Task Group 31, which specifically address polymer modification. The Strategic Highway Research Program (SHRP) performance based asphalt binder specifications (AASHTO MP-1 designation) have been developed to evaluate the binder regardless of modification.[83]

The specifications written specifically for polymer-modified asphalt binders use the classical test methods (penetration, viscosity, ring and ball softening point, etc.) and those established to detect the presence of polymer use (force-ductility, torsional recovery, toughness and tenacity, etc.). One problem with these techniques is their material specificity; *i.e.* they favor one type of polymer-modifier over another because of the way the test is performed.[26] Also, it is important to understand that these methods have only empirical relationships to resulting mixture performance. The SHRP specifications allow for a fundamental rheological measurement of the binder's properties under controlled conditions loosely duplicating those observed in the field. The SHRP specifications are the same for both unmodified and modified asphalt binders.

The SHRP binder specifications address the measurement of rheological properties (G^*,complex shear modulus; δ, phase angle, and S, flexural creep stiffness) at different temperatures to evaluate different asphalt binder properties.[51] A dynamic shear rheometer using a parallel plate geometry is used for higher temperature measurements and the bending beam rheometer is used for low temperature measurements. Table VIII displays the SHRP specifications which are divided into three testing protocols.

TABLE VII

FAILURE STRAIN OF POLYMER MODIFIED ASPHALT BINDERS UNDER DIRECT TENSION[74]

Asphalt grade (penetration grading)	wt. % polymer	Failure strain[a] (%)
40/50	0.0	0.23
40/50	1.0	0.78
40/50	1.5	1.46
40/50	2.0	1.42
80/100	0.0	0.73
80/100	1.0	4.20
80/100	1.5	6.90
80/100	2.0	8.43

[a] Test conditions: −15°C, 0.13 cm/min.

TABLE VIII

SHRP BINDER SPECIFICATIONS[81]

Performance Graded Asphalt Binder (AASHTO MP1)

Performance Grade	PG-82							PG-76							PG-70						
	10	16	22	28	34	40	46	16	22	28	34	40	16	22	28	34	40	10	16	22	28
Average 7 day Maximum Pavement Design Temperature, °C	<52							<58					<64					<70			
Minimum Pavement Design Temperature, °C	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	>-22	>-28	>-34	>-40	>-16	>-22	>-28	>-34	>-40	>-10	>-16	>-22	>-28
Original Binder																					
Flash Point Temp, AASHTO T48, Min, °C	230																				
Viscosity, ASTM D 4402, Max 3 Pa·s (3000 cP), Test Temp, °C	135																				
Dynamic Shear, AASHTO TP5, G*/sin δ, Min, 1.0 kPa, Test Temperature @ 10 rad/s, °C	52							58					64					70			
Physical Hardening, Info	Report																				
Rolling Thin Film Oven Test Residue (AASHTO T 240)																					
Mass Loss, Max, percent	1.0																				
Dynamic Shear, AASHTO TP5, G*/sin δ, Min, 2.2 kPa, Test Temp @ 10 rad/sec, °C	52							58					64					70			
Pressure Aging Vessel Residue (AASHTO PP1)																					
PAV Aging Temp, °C	90							100					100					100/110			
Dynamic Shear, AASHTO TP5, G*sin δ, Max, 5000 kPa, Test Temp @ 10 rad/sec, °C	25	22	19	16	13	10	7	25	22	19	16	13	28	25	22	19	16	34	31	28	25
Creep Stiffness, AASHTO TP1, S, Max, 300 000 kPa, m-value, Min, 0.30, Test Temp, @ 60 sec, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18
Direct Tension, AASHTO TP1, Failure Strain, Min, 1.0 %, Test Temp @ 1.0 mm/min, °C	0	-6	-12	-18	-24	-30	-36	-6	-12	-18	-24	-30	-6	-12	-18	-24	-30	0	-6	-12	-18

The first two parts of the specification require the asphalt binder to be measured at the highest weekly pavement temperature for the asphalt concrete pavement's location. First, the binder is tested in its original state to determine if the binder has sufficient viscosity to coat the aggregate and prevent tenderness of the mixture. $G^*/\sin\delta$ is the measured parameter at the highest weekly pavement temperature observed (40°C–82°C) at a frequency of 10 rad/s. The binder must exceed a value of 1.0 kPa. The binder is then aged with the RTFOT or TFOT and tested again under the same conditions. This test measures the amount of nonrecoverable permanent deformation of the asphalt binder at the upper service temperatures of the pavement. The ideal measure to use is the inverse shear loss compliance J' which, under the test conditions prescribed, is numerically equal to $G^*/\sin\delta$.[81] In this case the value must exceed 2.2 kPa. Since $G^*/\sin\delta \sim G^*$, this can be related to the dynamic stiffness of the pavement when the loading frequency is in the range of vehicle traffic, i.e. 1–16Hz.[81]

Finally the RTFOT or TFOT residue is PAV aged and $G^*\sin\delta$ ($\sim G''$) measured. In this case an average between the highest and lowest temperature is used to represent average pavement temperature. The value G'' is used to determine how much of the viscous component will be available to dissipate energy which would normally go towards crack propagation. This gives an indication of the resistance to load-associated fatigue crack propagation. Low temperature measurements are also performed on the PAV aged binder using the bending beam rheometer and direct tension test. Creep measurements are made at 10°C higher than the lowest observed air temperature and the flexural creep stiffness ($S(t)$) and m-value, $d\log J(t)/d\log(t)$, at 60 seconds are used to characterize the asphalt binders properties. These measurements are related to the binder's resistance to low-temperature thermal cracking. With polymer modification, sometimes the stiffness is too high and fails the stiffness requirement of 300 MPa. Recent test results would suggest that the m-value is the limiting requirement at low temperature. In this case the direct tension test is employed to measure the strain at failure.[81] The validity of both the SHRP and classical methods will be examined further when they are compared to the performance of the mixture.

VII. RELATIONSHIP BETWEEN BINDER PROPERTIES AND MIXTURE PERFORMANCE

A. FIELD SURVEYS

Numerous surveys have been performed on the use and field results of polymer-modified asphalt binders.[6,30,85–87] By 1989, over 39 states were experimenting with polymers.[88] Anderton surveyed over one hundred airport agencies in the United States about the use and performance of modifiers in their asphalt concrete pavements.[30] Pavement cracking (including fatigue and thermal) was the most significant failure mode prompting the use of asphalt modifiers. Of the different types of cracking, thermal cracking was of primary concern. The other distress areas mentioned were ravelling, stripping and permanent deformation by shoving. Those airport agencies that used modifiers, used them predominantly on runway pavements. Also, 76% of those responding rated the modifiers as good or excellent.

As part of SHRP, a survey was conducted of the state highway authorities and asphalt modifier manufacturers on the performance of asphalt modifiers.[85] The performance rankings were determined for a variety of modifier types with respect to permanent deformation, fatigue cracking, thermal cracking, aging and moisture susceptibility. An elaborate weight evaluation was performed combining the binder and mixture test data with the test asphalt concrete pavement data from both the state highway officials and modifier manufacturers into one performance ranking number. The results from thirty-eight different modifiers were analyzed via this questionnaire. The modifiers included polymers, reclaimed rubber products, fillers, fibers, extenders and anti-stripping agents. It was observed that modifiers from the same classification displayed variations in their effect on pavement performance with respect to a particular distress category. Figure 20 shows the resulting performance rankings for the different modifiers for permanent deformation, load-associated fatigue cracking and low-temperature thermal cracking. In these bar graphs, the numbers on the abscissa are identifiers for a particular modifier in that category, while the number at the top of each bar represents the number of responders and non-responses (with X). The polymer and reclaimed rubber type modifiers had high rankings in each category.

Another survey, performed by Button, involved questioning department of transportation officials about the use of polymer modifiers on asphalt paving projects in their respective states.[87] Of the fourteen states involved in the survey, most are using or plan to use modifiers in future projects. Most of the agencies are concerned with addressing the cost effectiveness of polymer modification and feel that only additional historical data will answer that question. The conclusion concluded that the increasing demands on pavement structures from vehicle weights, traffic volumes and tire pressures require the use of asphalt binder modifiers. Although the survey results are incomplete, the asphalt modifier industry is advancing rapidly and the outlook is excellent.

B. LABORATORY STUDIES

Although the rheological properties of asphalt and polymer-modified asphalt binders has been extensively studied, correlation with mixture properties and field test is less understood.

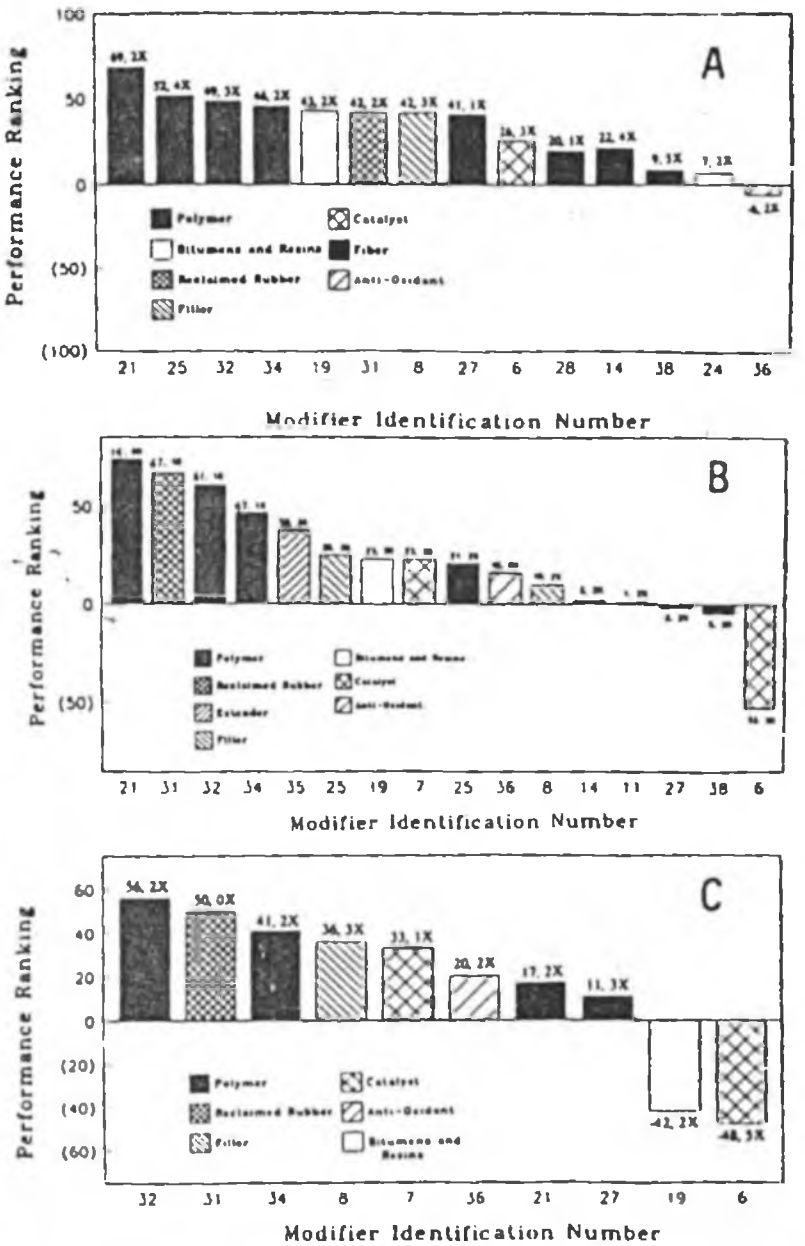


FIG. 20. — Survey results for the performance rating of modifiers with respect to the following characteristics (A) permanent deformation; (B) load associated fatigue; and (C) low-temperature thermal cracking.[89] The numbers on the abscissa are identifiers for a particular modifier in that category, while the number at the top of each bar represents the number of responders and non-responses (with X).

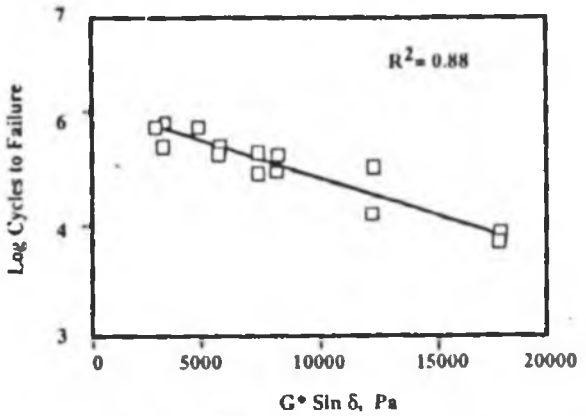


FIG. 21. — Relationship between $G^*\sin\delta$ and log cycles-to-failure for asphalt mixture.[91]

The SHRP specifications have outlined criteria for evaluating the performance based properties of asphalt binders. Presented in this section is some of the research which has correlated the classical and rheological properties of asphalt and polymer-modified asphalt binders to performance properties of the mixture.

Several studies on mixtures have been performed to evaluate the effect of polymer modification on laboratory properties. Methods used include indirect tension (ASTM D 4123), resilient modulus (ASTM D 4123) and creep rebound.[89] Anderton reported the mixture properties of SBS, LDPE, EVA and AC-40 asphalt mixtures.[90] He found good agreement with previous results of Button and Little that the SBS, LDPE, and EVA are recommended to substantially reduce rutting and other deformation distresses.[90] For the SBS modified asphalt mixtures, a substantial decrease in temperature susceptibility was observed. Also, Khosla and Zahran found SB modified asphalt mixtures provided higher resilient modulus values at higher temperatures.[91]

This comprehensive study was performed by Hicks, *et al.* to validate the proposed SHRP binder specifications on the testing of mixtures.[92] It was shown that good correlation was observed between fatigue life (log cycles to failure) of the mixture and the recommended binder measurement, $G^*\sin\delta$ (Figure 21).

For permanent deformation, the correlation between wheel tracking and shear testing of the asphalt binder via $G^*/\sin\delta$ was very poor. This poor correlation suggest that the rutting is more dependent on densification and shear deformation of the asphalt concrete pavement than on the asphalt binder specifically. Monismith *et al.* found that for both unmodified and polymer-modified asphalt mixtures, the aggregate exerted a significant influence on the mixture performance at high temperatures.[92] In the case of low-temperature cracking, good correlation was found between the *m*-value and the fracture temperature for different aggregate mixtures as determined by mixture measurements (Figure 22). From these results, polymer modification helps in the resistance to thermal cracking and load-associated fatigue, but has less effect on the resistance to permanent deformation. Other workers have found good correlation between $G^*/\sin\delta$ and the rutting resistance for polymer-modified and unmodified asphalt mixtures as shown in Figure 23, a plot of $G^*/\sin\delta$ versus rut-depth at 20,000 cycles at 60°C.[91]

Goodrich has performed extensive work in trying to correlate the binder properties to the low temperature diametral creep, flexural fatigue and high temperature creep of asphalt mixtures containing unmodified and polymer-modified asphalt binders.[58] The temperature at which the mixture had a creep stiffness of 10.3 GPa was used to define the TLST. The

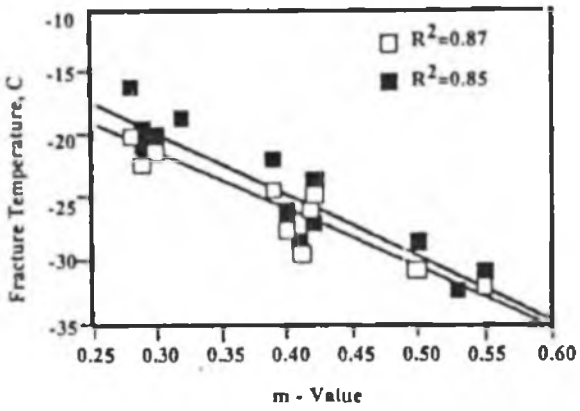


FIG. 22. — Relationship between the *m*-value of the asphalt binder and the fracture temperature of asphalt mixture with different aggregates.[91]

polymer-modified mixtures had lower TLSTs than the unmodified mixtures in most cases. When these results were correlated with traditional asphalt test only the penetration at 4°C, asphalt modulus at 4°C, and Frass brittle point showed correlations (R^2 above 0.80). Excellent agreement was found between the TLST and the loss tangent. It was noted that when the temperature, where tangent delta is maximum, is lowered, resistance to thermally induced cracking is improved. In flexural fatigue, the polymer-modified asphalt mixtures displayed an order of magnitude increase in fatigue life as compared to the unmodified asphalt mixture. Poor correlation was found between classical asphalt binder tests and the mixture's beam-fatigue results. The tanδ, at 0.1 rad/s and 25°C, showed excellent correlation with beam-fatigue results. Brodynyan also suggested that higher storage modulus and tan δ may improve fatigue life.[92] Creep experiments were performed on asphalt and polymer-modified mixture beams at 40°C to study permanent deformation. The creep deformation

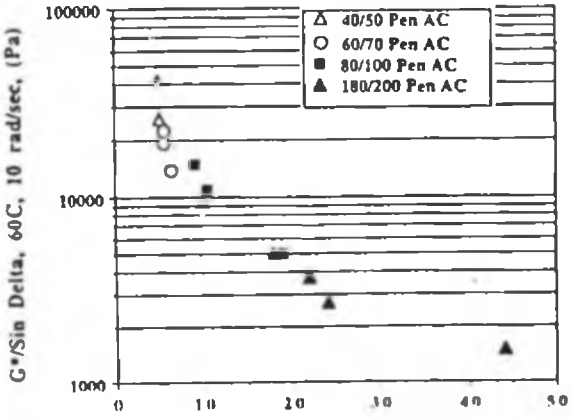


FIG. 23. — Relationship between rut-depth after 20,000 cycles at 60°C and and $G^*/\sin\delta$.[14]

was recorded during a 60 minute loading period and 30 minute recovery period. Again, $\sin\delta$ showed the best correlation with creep deformation behavior. The results of his work showed that classical tests for binders do not correlate with performance of the mix, while rheological tests showed good correlation and provide useful information about the viscoelastic behavior of the mixture. It was also mentioned that improved binders require a good mix design to fully optimize their contribution to the asphalt pavement.

A novel approach was used by Goodrich to study the dynamic mechanical properties of polymer modified asphalt mixtures.[93] A rectangular bar configuration was used to test the asphalt concrete samples dynamically in torsion. The limiting stiffness temperature of the mix was determined by finding the temperature at which the creep loading reaches a modulus of 10.3 GPa after 10,000 seconds. The polymer-modified mixtures showed much lower temperatures than the unmodified mixtures except in one case. Goodrich concluded from these studies that the mixture properties at low temperatures are dominated by the asphalt binder, from 10–50°C, the rheology is sensitive to the binder characteristics, while above 50°C the asphalt concrete rheology is dominated by the aggregate.

The effect of polymeric additive on the flexural fatigue life of asphalt mixtures was studied using the modified crack layer model.[94,95] Fatigue crack propagation studies were performed on rectangular beams under four point bending in a stress control mode at 21°C using an inverted haversine load. The effect of SBS, LDPE and EVA were compared to an unmodified AC-5 mixture. Figure 24 shows the crack length versus the number of cycles for the different polymer-modified asphalt mixtures. The SBS and EVA displayed superior fatigue crack propagation resistance. More work was expended on damage formation and dissipative processes around the crack tip for the SBS modified asphalt mixture than for the other modifiers. This is shown in Figure 25 where the change in work W_f versus crack length for the SBS is superior to the other polymer modified mixtures.

Wheel tracking experiments have been performed on polymer-modified asphalt mixtures using the Transport and Road Research Laboratory (TRRL) device and Wheel Tracking Device (WTD) developed by SWK Pavement Engineering, both from England.[96] The TRRL method is designed to measure the rutting of asphalt concrete slabs or cores under repeated loads of 535 kPa corresponding to typical truck tire pressures (~77.6 psi). Good agreement was found between the G^* measured at 60°C and the wheel tracking results. Figure 26 shows

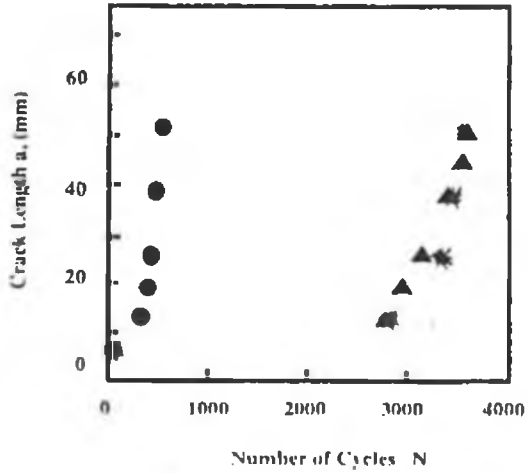


FIG. 24. — Crack length vs. number of cycles for SBS modified (triangles), EVA modified (asterisks), and LDPE modified (circles) asphalt mixtures.[95]

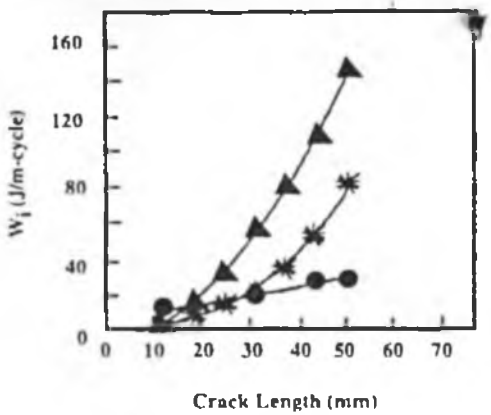


FIG. 25. — Change in work W_f vs. crack length for SBS modified (triangles), EVA modified (asterisk) and LDPE modified (circles) asphalt mixtures.[99]

the deformation, in mm, versus the number of load cycles and it is evident that the polymer modified mixtures are superior to the unmodified AR-1000 mixture. The AR-1000 with 3 wt.% SEBS showed the least permanent deformation as predicted from both G^* and G^*. The WTD was used to evaluate permanent deformation characteristics of four modified asphalt mixtures (SBS, fibers, organic fillers and soft asphalt binder) using a variety of asphalt binders and aggregates. The SBS type modifier showed improved resistance to rutting with all the asphalt concrete mixtures tested.[97]

Goodrich and Reese performed extensive rheological characterization on a number of polymer-modified asphalt binders removed from asphalt concrete pavements exposed to severe high temperature conditions.[100] They found that $G^*/\sin\delta$ does not correlate well with field results and recommended separating the phase angle into contributions from the asphalt ($\delta_{asphalt}$) and the polymer modifier ($\delta_{modifier}$). It was not clear how this would be accomplished. Also, they recommended that with respect to load-associated fatigue cracking, the dynamic viscosity (η^*) versus shear rate and phase angle (δ) versus shear rate be included in any performance-based specification for asphalt binders.

As defined earlier, the fracture temperature at which an asphalt mixture cracks is when the tensile stress equals the tensile strength. An ideal method for making these measurements is the Thermal Stress Restrained Specimen Test (TSRST) coupled with the direct tensile test.[26] TSRST measures the tensile stress as the mixture is cooled and tries to contract. Direct tension measurements are then run at constant strain rates at different temperatures on a similar specimen. In Figure 27 the fracture temperature is indicated as the intersection of the individual plots of tensile stress and tensile strength vs. temperature. Stock found that polymer modification lowers this observed fracture temperature.[70] King et al. found good correlation between the fracture temperature and the asphalt binder temperature that yields a bending beam stiffness of 200 MPa.[45] With the addition of 2 wt.% polymer, the fracture temperature of the mixture was lowered by 10°C.

VIII. ASPHALT-RUBBER

Asphalt-rubber is the term used to describe ground tire from passenger vehicles and trucks blended in asphalt binders. The material contains at least 15 wt.% of the ground tire, mixed with the asphalt at high temperatures so that swelling of the rubber particles occurs

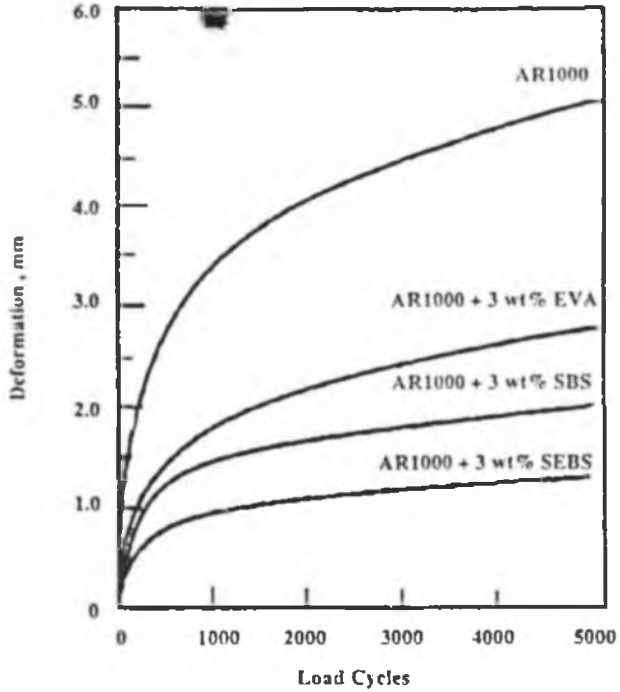


FIG. 26. — Wheel tracking results for SBS, SEBS, EVA and unmodified asphalt mixtures.[96]

t method).[100] The dry method involves adding the the ground tire as aggregate. In recent rs a growing debate has developed over the use of asphalt-rubber in asphalt pavements. 1986, the Federal Register describes a proposed rule by the Environmental Protection ncy for "Federal Procurement of Asphalt Materials Containing Ground Tire Rubber for nstruction and Rehabilitation of Paved Surfaces," which has not been implemented. More ntly the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) was passed. s law requires that 5% of the total tons of asphalt pavement financed in part or whole h federal funds, contain recycled rubber, beginning in 1994 (this has been delayed until 6). The minimum utilization increases 5% each year up to 20%.

Based on this level of interest in ground tire, a review of the literature on asphalt-rubber been performed. Emphasis again is placed on the asphalt-rubber binder properties with pect to both classical tests and the performance of asphalt-rubber mixtures with regard ugh temperature permanent deformation, load-associated fatigue cracking and low-temature thermal cracking.

A. LABORATORY TEST WITH ASPHALT-RUBBER BINDERS AND MIXTURES

Limited studies have been performed on the testing of asphalt-rubber binders and mixes. Anderton studied the effect of AC-5 with 16 wt.% Baker IGR Rubber and 5 wt.% nder oil (AC-5RE) and 17 wt.% Baker IGR Rubber (AC-5R) versus unmodified AC-5, AC- nd AC-40.[101] The incorporation of ground tire in the asphalt was found to increase the osity by 100–2000%. At 135°C, the Brookfield viscosity was similar for all the modified

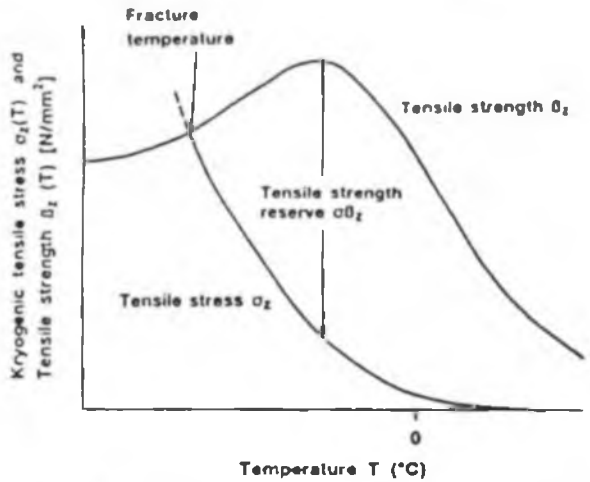


FIG. 27. — The tensile stress and tensile strength as a function of temperature for an asphalt mixture[99]

binders tested, suggesting that the high temperature viscosity — related to the processi of the asphalt and coating of the aggregate — was controlled by the rubber. This showed that asphalt-rubber binders are less temperature susceptible, have improved res tance to aging, and higher elastic recovery than unmodified asphalt binders. Pavlovich studi the effect of mixing time and temperature on different asphalt-rubber binders using classi tests including ring and ball softening point, absolute viscosity, ductility, force-ductil and elastic rebound, as well as several rheological properties.[104] Using 75% AC-5 with wt.% ground tire, a substantially higher softening point, and an absolute viscosity 100 tim greater than the unmodified asphalt was observed. Salter and Mat, using 3–7 wt.% rubbe found the rubber to decrease the temperature susceptibility and exhibit higher tensile lo during testing than the unmodified asphalt binder.[105]

Mixture testing was performed on the previously discussed asphalt rubber binders. Tens creep experiments were made on AC-5, AC-5RE, AC-5R, AC-20 and AC-20R mixtures applying a load for 1000 seconds and measuring the resulting deformation. The AC-5 a AC-20 mixtures showed much higher compressive strains then their counterparts. Permane deformation was measured using both static and dynamic (haversine) loading on unmodifi and modified asphalt mixtures. It was observed that for measurements at 40°C, the dynam loading better differentiated the creep behavior of asphalt-rubber mixtures. Low-temperatu tests were performed by measuring the stress required to maintain a constant length specim with a constant rate of cooling. Figure 28 shows the thermal stresses generated on cool constrained AC-5 and AC-5R mixture specimens. The addition of ground tire to the mixt was found to lower the fracture temperature approximately 10°C.

In many states trials are currently being conducted to answer questions of proper pr cessing methods, recyclability and cost effectiveness. Also, a limited amount of laborat and pavement test data has given differing results. Meanwhile, other methods of disp of scrap tire rubber continue to be studied.

IX. SUMMARY

Many different types of polymers are used as modifiers in asphalt binders. The th groups discussed were block copolymers and other thermoplastics, synthetic and natur

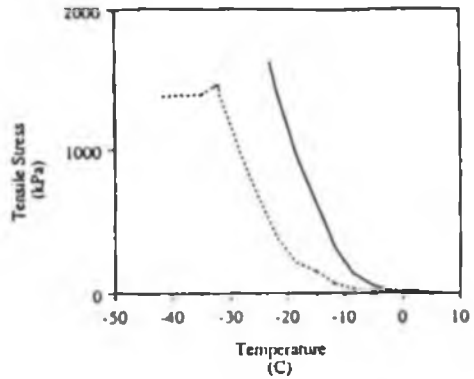


FIG. 28. — Thermal stresses generated when constrained unmodified (solid line) and asphalt-rubber modified (dashed line) asphalt mixtures are exposed to a constant rate of cooling.[101]

bers, and others. Styrene–butadiene (SB, SBS, SBR, etc.) type polymers are the most mmonly employed modifiers.

Many factors must be consider when using a polymer-modified asphalt binder. In this ew, the effect of crude asphalt source, polymer microstructure, mixing, and storing con- ons were examined with respect to compatibility between the polymer and the asphalt. roscopy provided information about the homogeneity of the systems and the morphology the polymer/asphalt blends.

Various test methods have been devised to measure the properties of polymer-modified halt binders. Classical methods are either empirical or are performed under conditions ere material properties are hard to extract. Rheological measurements of the asphalt der have been shown to correlate with mixture performance with respect to high tem- rature permanent deformation, load-associated fatigue and low-temperature cracking. ymer modified mixtures have been shown to have reduced temperature susceptibility viding better resistance to permanent deformation. Improved fatigue properties have been observed with polymer modified mixtures, where the fatigue life in some cases is ended by an order of magnitude or more. The fracture temperature of the mixture was found to decrease by 10°C when polymer modifiers were added to the mixture. In the se of asphalt-rubber mixtures, insufficient data is available to evaluate its performance.

X. CONCLUSIONS

- Polymer modification of asphalt binders has become a more accepted method for ad- ssing pavement distresses. The heavier vehicle loads, higher traffic volumes and increased pressures have forced user agencies to explore polymer modification for asphalt pavement plications.
- The compatibility between the asphalt and polymer depends on many factors. The most nificant of these, based on microscopy, are the asphalt crude source, polymer microstruc- e and the thermal/mechanical history of the polymer-modified asphalt binder.
- Classical methods and methods derived specifically for measuring the effect of polymers the asphalt have poor correlation to mixture performance. The tests also seem to be ecific to the different polymers tested. The test conditions make it difficult to extract basic ormation about the binder s mechanical properties.
- Considerable work has been done on the rheology of asphalt and polymer-modified phalt binders over a wide range of temperatures and rates of loading. Time-temperature perposition has been used to describe the effect of rate of loading on the complex shear

modulus (G^*) of both polymer modified and unmodified asphalt binders. The addition of polymers has been found to dramatically change the properties at high temperatures or low rates of loading. This has been correlated with varying degrees of success to permanent deformation in the asphalt mixture.

• The bending beam rheometer and the direct tension test are ideally suited for measuring the low temperature properties of polymer-modified asphalt binders. Good correlation was found with bending beam results and the fracture temperature of the mixture using the TSRST method. Failure strains, measured for polymer-modified asphalt binders with the direct tension test, were up to ten times greater than that observed for unmodified binders. Polymer-modifiers generally decreased the fracture temperature of the mixture by 6–10°C.

• Polymer modifiers for asphalt binders which contain a large percentage of butadiene (50% or greater), exhibit improved low temperature properties. This was observed as a decreased T_g for a polybutadiene modified asphalt measured using dynamic mechanical analysis. Also direct tension results for SB (50% butadiene)-modified asphalt binders showed a marked increase in low temperature failure strains.

• The performance-based specifications (SHRP) show good correlation with mixture performance. The best correlations were observed between the binder's rheological properties and the load-associated fatigue and low-temperature thermal cracking resistance. For permanent deformation, it was observed that the aggregate plays a significant role in the resulting rutting. Further testing and field studies are required to validate these laboratory measurements.

• Asphalt-rubber mixtures have been shown to have useful properties with respect to distresses observed in asphalt concrete pavements. Most notably a large increase in viscosity and improved low-temperature cracking resistance have been measured. Only a limited body of test results exists and further testing is required to fully understand the contribution of asphalt-rubber to the mixture's performance.

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A REVIEW OF METHODS TO CHARACTERIZE RUBBER ELASTIC BEHAVIOR FOR USE IN FINITE ELEMENT ANALYSIS

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I. ABSTRACT

The purpose of this paper is to provide a review of methods used to characterize the elastic behavior of rubber for use in Finite Element Analysis (FEA). A sample of elastic strain energy density functions used to characterize rubber is given, along with the tests required to characterize rubber according to these functions. The use of synthetic test data as an alternative to full physical testing is discussed, and highlighted by a case study. The paper closes with a discussion on potential errors associated with FEA of rubber components.

II. INTRODUCTION

Rubber has been recognized as an engineering material since the mid 1800s with vulcanization of rubber being pioneered by Charles Goodyear in 1839. Its properties of elasticity and resilience have resulted in applications in load carrying structural bearings, springs, seals, shock absorbing bushes, couplings and tires. However, unlike metals which require relatively few properties to characterize their behavior, the behavior of rubber is complex. It is nonlinear in terms of both material and geometric behavior. Its mechanical behavior is further complicated by much greater sensitivity to the effects of temperature, environment, strain history, loading rate and amount of strain. Method and ingredients (*e.g.* amount and type of carbon-black filler) of manufacture also have significant effect. This has meant that for much of the history of rubber as an engineering material, its applications have been developed largely by trial and error, rather than by a fundamental understanding.

Many theoretical models have been developed in attempts to characterize the mechanical behavior of rubber, a sample of which are reviewed in this paper. However, closed form solutions involving the developed models are usually quite complex for all but the simplest

POLYMER MODIFIED BITUMEN AND RELATED PROPERTIES

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ABSTRACT

From the view point of pavement design there is a need for materials which show the improved properties and the following characteristic features:
- low temperature susceptibility
- elastic, rubber elastic, improved visco elastic recovery or responses
- improved resistance to fatigue
- high flexibility and impact resistance
- higher stability and resistance to permanent deformation at high temperatures and lower loading frequencies.

These properties can be achieved by modifying the bitumen by using polymers. However, simply the addition of polymer into a compatible bitumen at high temperature will not produce the required properties. This has been experienced by various laboratories throughout the world. One have to cope with incompatibility of bitumen, incompatibility of bitumen and polymer, phase seperation in modified bitumen, storage stability problems, molecular weight distribution and thermal susceptibility problems, etc.

All these aspects have been studied by using various test methods along with the microscopic morphological analysis (quality analysis by microscopy, using fluorescence light). The paper deals with the methodology which helps coping with the problem areas associated with production, processing and designing of polymer modified binders to ensure better performance of these materials in their service life.

1.0 INTRODUCTION

Generally the overlay mixes are meant to strengthen the pavement and to prevent reflection of cracks through the overlay. Such mixes must be insensitive to rutting, corrugation and surface cracking. It should be mentioned here that during the last decade worldwide an increase in the rate of surface cracking has been observed to occur, probably due to a combination of thermal stresses and stresses due to interactions of tire and pavement (in- and outward shear, edge effects, etc.) due to enormous increase in traffic load (1, 2). In this respect it is important to note that the average axle- and

wheelloads and the average tire pressure increases year by year. This is more pronounced and almost phenomenal in and around the big cities and at major airports.
In such conditions where overlays are to be applied on pavements suffering from these kinds of distresses, the overlay mix must be able to withstand the stresses and strains involved. Of course like any other wearing course, overlay mixes must be resistant to aging and wateringress as well. The aging may be due to oxygen and ultraviolet radiation, whereas the resistance to water in practice means retainment of adhesion of the binder to the aggregate elastic response of the material in terms of material properties. These requirements may not be at the cost of workability.
It is a well known fact that the commonly used asphalt concrete mixes do not fulfil the sets of requirements put on the overlay-mixes; they have not been designed for this purpose. Sealoflex was developed by Ooms Avenhorn B.V., The Netherlands, with the aim to meet such requirements of overlays. However, its stringent properties make it possible to be used also as in sub-base and base course mixes. Sealoflex is an SBS modified binder which is treated chemically to revertibly improve workability as well as service performance based properties, using certain suitable additives to improve binder properties, such as resistance to ultraviolet radiation, adhesion, viscosity and insensitivity to thermal stresses.

Products like Sealoflex binders need carefully designed manufacturing and process technology. Optical fluorescence microscopy is a good laboratory tool to observe the morphological structure and dispersion of the modifier into the bitumen (3). It was indicated that the coarser the structure of the binder the brittler it is at lower temperatures. Therefore one has to try to get a homogeneous, finely distributed microstructure. One can characterise the binder also by measuring its ductility. It is shown that the ductility based property 'the elastic recovery' of the binder is increased by an order of a magnitude (many times higher than the standard bitumen) if Sealoflex modification method is used.
Regarding the aging it can be stated that the part of the aging which is due to oxydation, is less pronounced in chemically modified Sealoflex bitumen than in conventional polymer modified bitumen (4). This is caused by the fact that the molecules in the bitumen that are chemically active and thus are bound to oxidise will undergo micro-structural interactions with the modifier and so prevent the molecules from picking up an oxygen molecule. Of course other aging effects like evaporation of lighter components, chemical conversion of aromates into resins and of resins into asphaltenes and physical hardening (disorientation of molecules) are not affected here. From general experience it is evident that the aging of Sealoflex bitumen is significantly less than conventionally modified bitumen.
In the following pages the Sealoflex binder SFB-5 is broadly discussed. This binder is one of the main SBS products, generally used for manufacturing asphaltic mixes for road application.

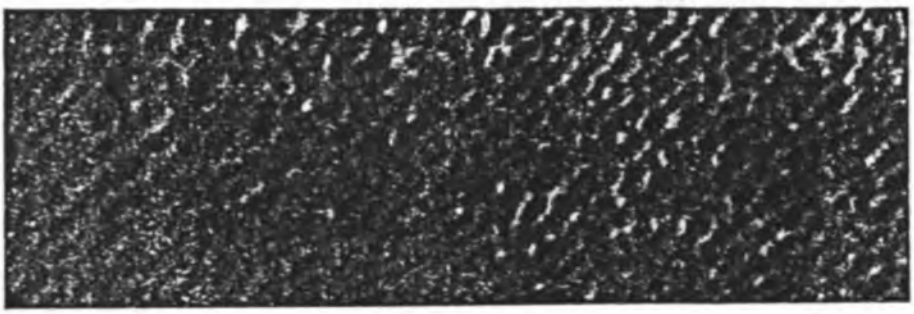
The mechanical properties of the desired quality product for overlay mixes can be characterized by indirect tensile tests, repeated loading tests and dynamic creap tests. These tests characterise the stiffness, the tensile strength, the stress intensity factor and the (permanent) deformation. Moreover, in principle, indications can be obtained by modeling the mix behaviour in terms of a Burgers' model.

3.0 BINDER MODIFICATION

3.1 Modified Bitumen

In general terms the modification of binders had been described elsewhere in extenso (3, 5, 6). So it suffices here to describe briefly the essentials of the Sealoflex modification. Polybutadiene blocks are connected chemically at several ends to polystyrene blocks. As the butadiene and stryrene are not compatible the blocks would try to separate from each other. As they are connected chemically, an overall phase separation cannot occur. Locally phase separation will take place which makes in fact the modification work: The coagulation of the styrene blocks causes a three dimensional network of the rubbery butadiene. Clearly this coagulation and the connected three dimensional network can be removed by augmenting the temperature. It can be achieved and chemically stabilised by adding an additive which diminishes the driving force for the coagulation, which is the incompatibility of stryrene and butadiene. The other way around one can reinforce the network by adding additives which strengthen the incompatibility. This dependence on additives is the physico-chemical basis of the modification, used in the Sealoflex bitumen described here.

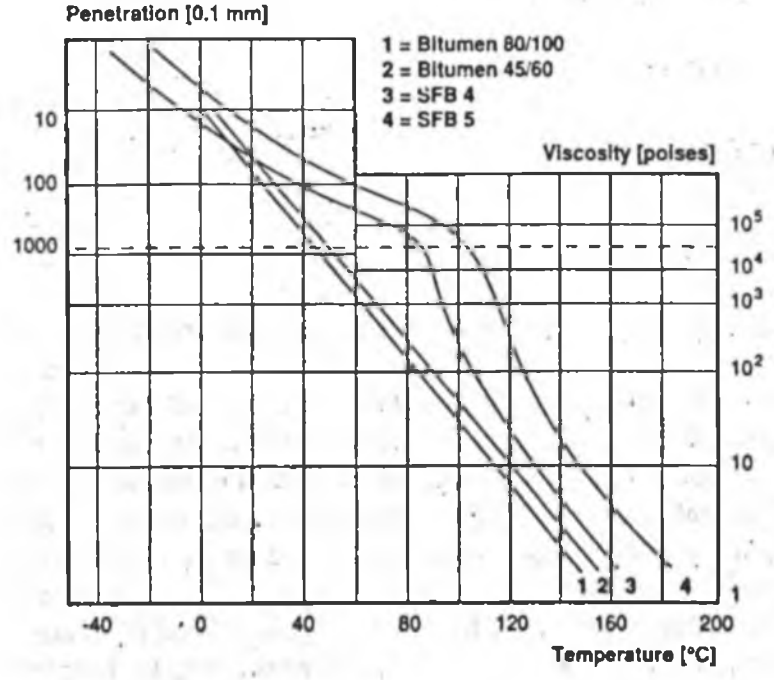
FIGURE 1: FLUORESCENCE MICROSCOPIC PICTURE OF SBS-MODIFIED BITUMEN.



Using fluorescence microscopy it is possible to obtain directly an image of the dispersion of the main modifier in the bitumen. In Figure 1 an example is given. It appears, as is also shown by others (7), that the modifier SBS is distributed throughout the bitumen in a certain defined pattern, which obviously is needed for a consistent overall performance.

The effect of the modification can be observed by making a viscosity temperature diagram (see Figure 2), although one must be very careful by interpreting these plots, as the basic idea behind this diagram is not necessarily applicable on modified bitumens. Nevertheless, comparison with literature data (8) reveal that the Sealoflex binders SFB are effectively modified: The influence on the viscosity is very pronounced.

FIGURE 2: RHEOLOGICAL PROPERTIES ACCORDING TO PFEIFFER AND DORMALEN.



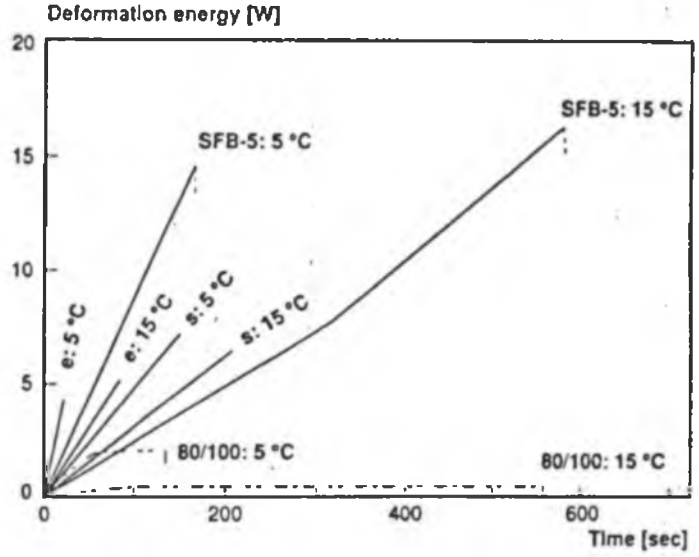
For temperatures between -30 and +80 °C the effective P.I. ≈ 5 (penetration index according to Pfeiffer and Dormalen) is found. This in itself indicates a relatively high insensitivity for temperature. As temperature and loading frequently can de interchanged, the high P.I. also indicates a relative insensibility for frequency to loading. However, the curves indicate clearly the characteristic properties of the binder: There is an increase in the temperature susceptibility above the softening point.

It may be seen that the changes that are achieved by the modification are indeed the one that is strived for: a lower viscosity (or penetration) at temperatures below 0 °C and a higher viscosity at temperatures at which conventional asphaltic mixes are susceptible to rutting (40-60 °C). Of course, the latter effect is accompanied by a higher softening point (≈ 90 °C) and a higher viscosity at temperatures at which normally mixes are laid and compacted. Therefore one should be aware of the effects of the modification on the workability of the mix. These higher viscosities at 100 °C or still higher temperatures, (from a workability point of view) for mixes with a higher bitumen content, can be very effectively used in retarding aging, particularly in drain asphalt mixes with a percentage voids content of more

than 15%. Of course, if rutting has to be prevented, one should not compensate for the eventually reduced level of workability, but one should match the application procedure to its required need.

The rubbery properties of the butadiene become more evident in a ductility test: ASTM D-113. In this test bitumen is applied in two small cylindrical reservoirs. Each reservoir has an opening, which lay adjacent to each other. The reservoirs are separated and through the opening the bitumen or binder is allowed to flow out and form a thread. In these experiments one can observe the force needed to separate the reservoirs, the length of the thread at break and the elastic recovery. By integrating the product of the force and displacement, the so-called deformation energy 'W' is obtained, which is a measure for the energy needed to deform the binder (see Figure 3). It is clear that the SFB-5 bitumen needs much more energy to deform than the conventional or other modified bitumen. In other words, the SFB-5 is much more resistant to deformation.

FIGURE 3: DEFORMATION ENERGY, DETERMINED IN DUCTILITY MEASUREMENTS AT TWO TEMPERATURES.



From Figure 3 the length of the thread at break can be read also, knowing that the deformation speed is constant. It is noted here that the elastic recovery of the Sealoflex binder is about 90% for both temperature levels, whereas for the conventional bitumen it depends on the temperature (from 1% at 5 °C to 10% at 15 °C). Sealoflex SFB-5 and product S (an SBS based product commercially available in the market with two percent more polymer than SFB-5) shows more or less no significant influence of thermal change (almost the same level of deformation energy at 5 °C as well as at 15 °C), while product 'e' (another commercially available SBS modified product with 1% higher polymer than SFB-5) shows a considerable drop in deformation energy with the increase in temperature. All in all this experiment shows the powerful rubber elastic response of the Sealoflex bitumen.

4.0 MECHANICAL PROPERTIES OF MODIFIED ASPHALTIC CONCRETE MIXES

4.1 Micro Structural and Molecular Arguments

A material will respond to stress in an elastic, a viscous or in a plastic way. In many cases all three will occur at once although usually one is dominant. Polymers are visco-elastic and this is the type of behaviour imparted to composites. The elastic response is (under normal conditions) due to the crystallinity and the chain entanglements of the amorphous part. Chain slippage in the bitumen component introduce elements of viscous and plastic flow.

The two main manifestations of visco elastic behaviour are creep and stress relaxation. Both are mechanical relaxations as they involve reordening of the microstructure of the system. Stress relaxation is the decay of stress in a material that has been stressed to a set strain and then allowed to relax at that strain level. This decay in stress occurs due to internal molecular rearrangement or partial disorientation.

Laboratory experiments were performed to validate the application of material science concepts to Sealoflex asphaltic mixes to study stress relaxation and to determine the possibilities of such approaches to pavement design and strength evaluation, including falling weight deflectometer to study geometrical deflection patterns.

This section deals also with the static and dynamic indirect tensile tests, and the preliminary dynamic creep tests. These experiments give a fairly good indication of the level of improvement in the properties of the material achieved by Sealoflex modification. As the basic material behaviour is rubber elastic, a creep compliance test is used for describing the relaxation of the strain in relation to the rubber elastic response.

4.2 Binder Properties

In Table 1 the properties of the binders used in this study are reported. The high softening points combined with the low breaking point of Fraass are characteristic for the modification method applied. They are rather extreme, compared to the values reported in literature (6), indicating a higher degree of modification.

4.3 Mix Composition

The composition of the tested mixes are shown in Table 2a. The mixes denoted by 'A' and 'B' are Sealoflex mixes, they differ in the maximum grain size of the aggregate. The standard mixes are referred to as 'a' and 'b'. The mixes comply with the Dutch specifications for a dense asphaltic concrete (10). In Table 2b are the values shown as a percentage weight of the total composition, except the bitumen quantity which is shown on 100% mineral aggregate.

TABLE 1: PROPERTIES OF BITUMEN AND MODIFIED BINDERS.

Binder properties		SFB-5	80/100	e	s
Softening point temp. R&B [°C]		95	53	63	82
Penetration 25 °C, [0.1 mm]		65	80	65	68
Fraass braking point [°C]		-20	-7	-16	-16
Ductility [cm]	5 °C	29	9	12	29
	15 °C	73	not pos. to det.	26	70
Deformation energy [J]	5 °C	18	2.8	6	7
	15 °C	18	not pos. to det.	3.5	6
Critical cracking [°C]		-47	-8	-20	-31
Storage stability (AT) [°C]		0,3	N.A.	3.5	5.2
Tensile stress 800% elongation		1.8	N.A.	0,7	0,79
Dynamic shear [KPa]	at 45 °C	85.27	28.27	46.96	40.05
	at 55 °C	40.52	9.1	15.05	15.65
	at 65 °C	19.2	2.87	5.19	5.55
	at 75 °C	11.1	1.75	3.01	2.85

TABLE 2A: MIX COMPOSITION

	Dense Asphalt Concrete									
	Sealoflex ®						Conventional			
Mix code	A				B		a			b
Number	1	2	3	4	1	2	1	2	3	1
Stone 0/11[a]	57.0	57.0	57.0	56.2			57.0	57.0	56.2	58.0
Stone 0/16[a]					58.0	57.0				
Sand B[b]	34.5	35.0	34.5	37.3	33.5	35.0	34.5	34.5	37.3	33.5
Filler	8.5	8.0	8.5	6.5	8.5	8.0	8.5	8.5	6.5	8.5
Bitumen 80/100							6.0	6.0	6.0	6.0
SFB-5	6.0	6.0	6.0	6.0	6.0	6.0				

[a] Stones are crushed
[b] Sand B denotes one part natural and three parts crushed sand

TABLE 2B: MARSHALL PROPERTIES

Marshall properties		SFB-5	80/100	e	s.
P_M	[N]	16500	7500	11000	10500
F_M	[mm]	4.8	3.5	5.0	5.0
Q_M	[N/mm]	3440	2100	2200	2100
V_M	[%]	2.4	3.7	2.1	2.2

Table 2b shows the Marshall properties of a mix having binders SFB-5 80/100 'e' and 's'.

FIGURE 4: FATIGUE BEHAVIOUR OF FIVE TYPES OF MIXES AT 15 °C. THE LETTERS INDICATE THE TYPE OF MIX.

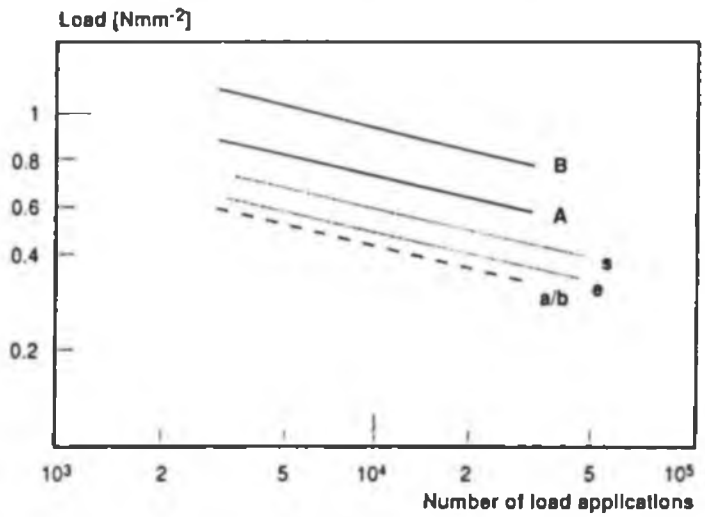


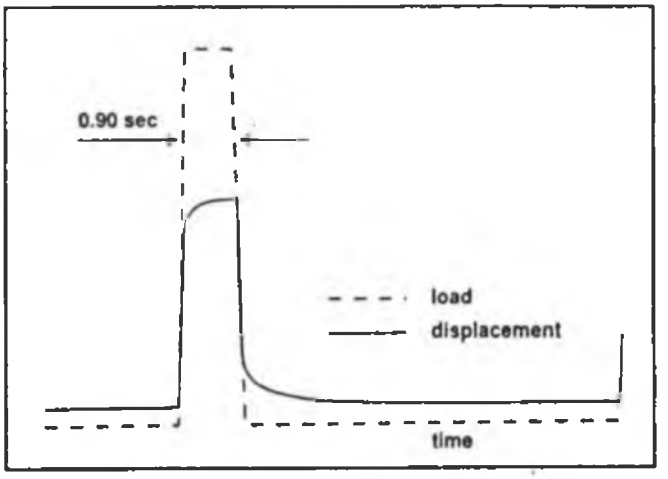
Figure 4 shows the resistance for fatigue in terms of number of load repetitions, independant of applied stress. The data have been obtained using a constant load and at 15 °C. It is clear that, under the given loading conditions, the Sealoflex mixes show a better fatigue behaviour, than 'e', 's' or standard 'a' and 'b' mixes.

4.4. The Dynamic Creep Test

In the (unconfined) dynamic creep test the sample is placed in a loading ring which allows to apply square, compressive force-pulses on the sample. The temperature of the sample was kept constant by using a water bath and a thermostate. The horizontal deformation is measured, thus enabling the calculation of permanent deformation due to repeated loads. In the experiments presented here the pulses were applied during 0.9 sec., followed by a rest period of 5.4 sec. It appeared necessary to precondition - for each sample - the loading/sample system in order to get constant results. As has

been suggested in literature (13) that it is good to allow the specimen to go under a number of load repetitions, for which test results were required. The specimens were subjected to a quasi-static applied load which was constant for at least 10 minutes, followed by a rest period of 10 minutes. Then 10 preconditioning pulses were applied. The mixes tested showed per load pulse response curves as shown in Figure 5. The trapezoidal shape of the load pulse is due to the movement of the penrecorder. On the oscilloscope the pulses were truly square pulses.

FIGURE 5: TYPICAL RESPONSE CURVE OF A SPECIMEN IN THE DYNAMIC CREEP TEST, DUE TO A SINGLE PULSE.



It was assumed that these experiments would allow one to model asphalt concrete's behaviour by a Burgers' model (Figure 6). However, a thorough analysis and modelling is out of scope of this paper.

FIGURE 6: BURGERS' MODEL.

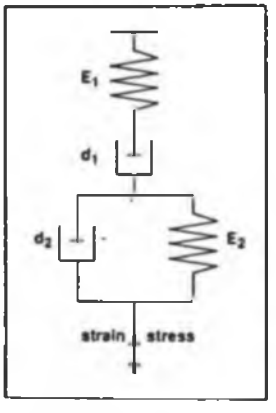
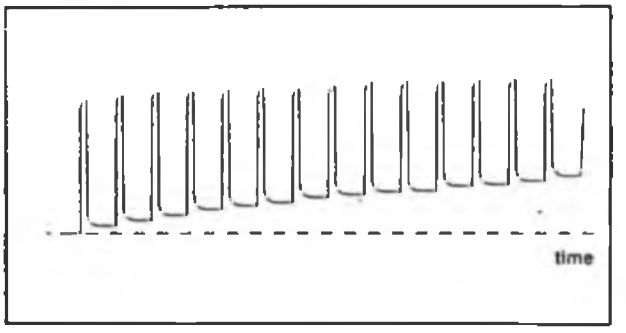


FIGURE 7: TYPICAL TRAIN OF RESPONSE PULSES DUE TO APPLIED SQUARE LOADS.



In Figure 7 a train of pulses is shown, obtained from mix A4 at 40 °C and a load of 2500 MPa. Similar pulses, neglecting smaller differences, have been obtained for mix a3. Here we focus on the increase in the offset of the pulses. This offset shows large differences between the mixes. In Figure 8 the offsets obtained

on 4 different samples are presented. It generally grows with the number of load applications and indicates the sensitivity for permanent deformation. It is evidently clear that the SFB-5 mix is by far the best product in terms of resistance to permanent deformation. This result complies with the findings mentioned above and also with the findings of Australian Accelerated Loading Facility program (ALF).

FIGURE 8: RELATIVE PERMANENT DEFORMATION DUE TO DYNAMIC CREEP LOADS FOR TWO TYPES OF MIXES

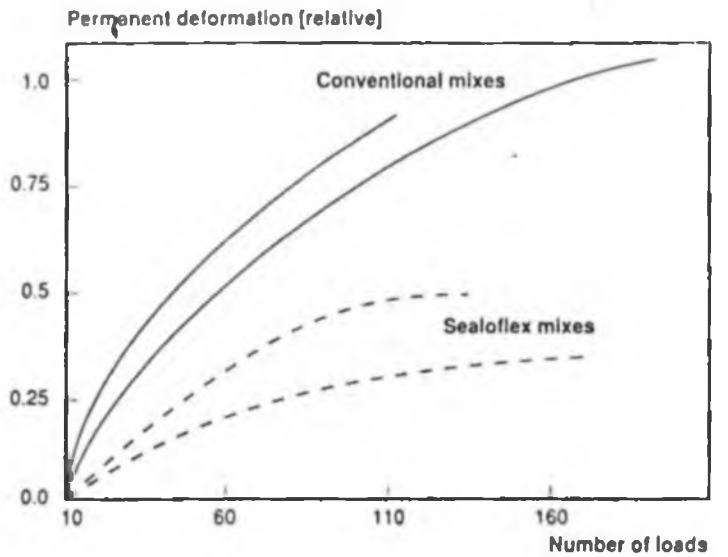


FIGURE 9: DYNAMIC CREEP.

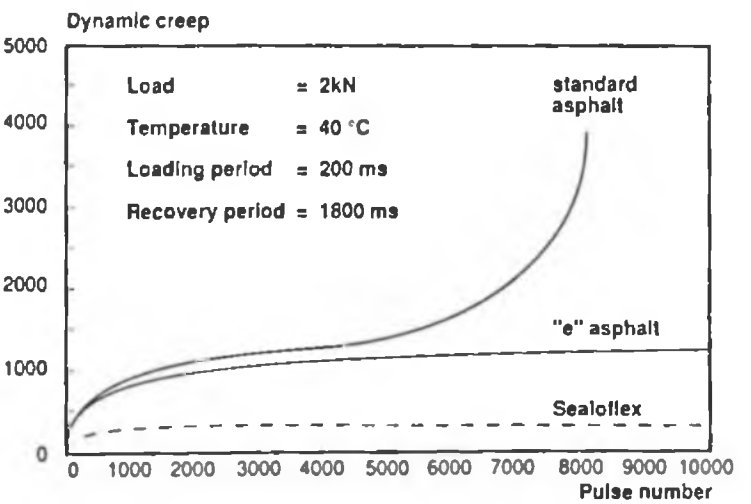
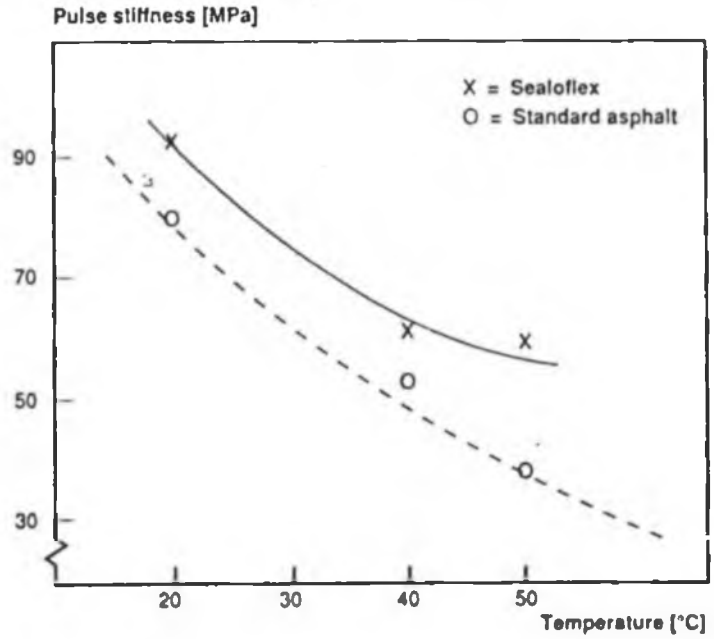


FIGURE 10: STIFFNESS PER PULSE VERSUS TEMPERATURE



In Figure 10 the stiffness per pulse is given as a function of the temperature for the conventional and Sealoflex mixes. It can be seen that under the given loading conditions the Sealoflex mix is 20 to 50% higher than the conventional mix. This confirms the conclusion drawn in the preceeding paragraphs.

5.0 PRACTICAL LOADING TESTS

As it has been mentioned above, excellent performance of the Sealoflex mixes has been observed in the laboratory. The question however is to what extent this superior lab performance is supported by the field performance data. The following paragraphs are being devoted to substantiate the field performance of Sealoflex in various parts of the world.

5.1 Field Experiments

5.1.1 Field Experience in the Netherlands.

In the city of Alkmaar, the Netherlands, on a section of a very highly traveled road with traffic light crossings and situated on the slopes of a bridge over a canal, the conventional asphalt used to last only 6 to 8 months. A field trial with Sealoflex was laid there about 13 years ago. The performance of this section - after 13 years of service - can be considered to be more than satisfactory. Visual condition surveys show no signs of any distress, rutting, corrugation, shoving, cracking or fatigue.

Surely in comparison with the conventional mixes applied before, the behaviour of the Sealoflex mixes is quite phenomenal.
Ever since, several trial sections and many important projects were carried out with Sealoflex in Europe, Australia, U.S.A. and Asia.
In North America, several Highway Authorities in the U.S. are using Sealoflex.

5.1.2 Amsterdam Schiphol Extension Works.

A large reconstruction and extension program was launched by the Amsterdam airport authorities in 1990, to cope with the increasing air traffic volume and for maintaining the pace of developments in the rest of Europe. The main emphasis was laid on reducing the frequency of maintenance by using durable construction materials and to minimise appearance of premature distresses due to increase in number of heavy aircrafts. For this reason it was decided to look into the possibilities of using polymer modified asphaltic mixes. A study program was launched under the supervision of a technical committee (the committee consisted of Prof. Molenaar, University of Delft, Senior Adviser Amsterdam Airport, NACO Airport Consultants and a team of Amterdam Airport's own technical staff.), on the basis of earlier experiences with polymer modified asphalt on EF Platform.
The following binders were included in the study program:
- Cariphalt DM SBS
- Cariphalt HD SBS
- Sealoflex SFB-50 SBS
- Flexxipave 2000 EVA
- Modified bitumen 45/60 and 80/100

The functional properties of the asphalt mixes were considered while drawing up the specifications. These requirements were aimed at resistance to cracking (with the help of tensile tests) and resistance to permanent deformation (dynamic creep test). Also the workability and environmental aspects were included in the final program. The following conclusion could be drawn:
- Mechanical properties:

Only one binder, namely Sealoflex SFB-50, meets the specifications drawn up by the technical committee on all fronts. The other binders failed to meet the specification requirements on one point or several points.
- Environmental study:

The environmental study revealed that the modified binders investigated show a reduction in the volume of PAK's released in comparison with the reference binder. The bitumen vapours released by polymer modified binders in general is volumetrically more due to higher working temperature (160 °C - standard bitumen, 185 °C - Cariphalt and 195 °C - Sealoflex), but the load on the work is well below the standard bitumen and MAC value; with Sealoflex being the least of all.

5.1.3 *Australian Experience.*

Modified binders have been used for many years in Australia. In 1988 a nationwide full scale accelerated'testing program was conducted with the ALF on heavy duty pavements containing modified binders. The pavement loading tests consisted of continuous loading of short pavement sections with dual wheel trolley of twice the legal load limit, i.e. with a total wheel load of up to 8 tonnes, the equivalent of 16 tonnes axle load. About 100,000 to 300,000 wheel passes were applied to each pavement section within a period of 1 - 3 weeks. During the trials the pavement deformation, deflections and temperatures were continually monitored (see Figure 11).

FIGURE 11: MEAN DEFORMATION VERSUS LOADING CYCLES (TAKEN FROM LITT. 13)

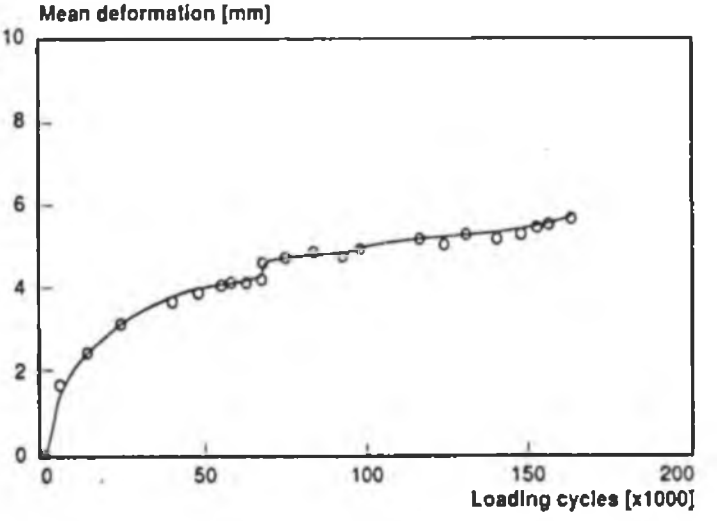
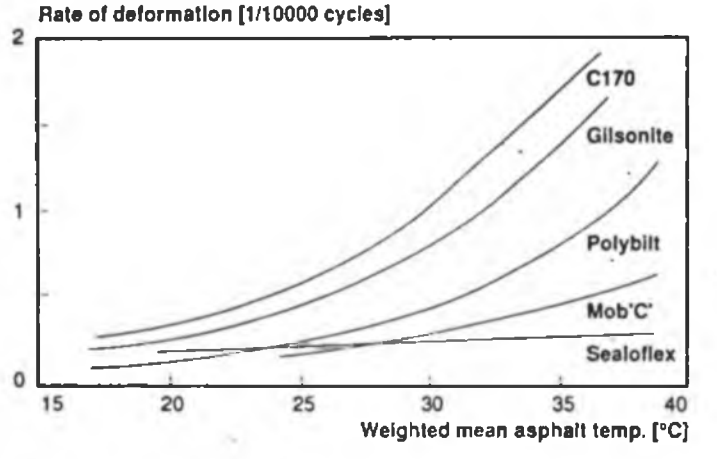


FIGURE 12: RATE OF DEFORMATION VERSUS WEIGHTED MEAN ASPHALT TEMPERATURE FOR VARIOUS MIXES.



A laboratory testing program followed the field trials, concentrating on creep and resilient moduli of the asphalt mixes.

The analysis highlighted the reduced temperature susceptibility of the

modified binders, and provided a ranking of these, reflecting their rut resistance as a function of pavement temperature. Out of several modified binders Sealoflex proved to be the least prone to rutting under hot temperatures (see Figure 12).

Since then Sealoflex products gained substantial acceptance, and were used on several major freeways, airport taxiways as well as on bridges.
The increasing use of modified binders coincided with the introduction of techniques for measuring the engineering properties of asphalt mixes. Resilient modulus and dynamic creep are now routinely measured with a pneumatic loading device, applying repeated load pulses on the specimen. These tests are complemented by workability tests, which are conducted with a gyratory compactor.

As a result of this work, the engineering properties of modified binders (such as the Sealoflex products) could be successfully ranked. The investigations so far indicated that:
- Sealoflex asphalt mixes have outstanding rut resistance;
- Sealoflex products have balanced engineering characteristics, i.e. both stiffness, fatigue, crack growth resistance properties and creep performance are similarly good.

Field data is available to support the laboratory data.

6.0 CONCLUSIONS

Laboratory experiments and full scale testing show the excellent resistance of Sealoflex to rutting and corrugation. There are no indications that the modified binder affects the skid resistance. The nature of modification will prevent the occurance of thermal cracking, whereas the aging will be low.
Theoretical and experimental evidence has been obtained to state that the Sealoflex modified binder has a large resistance to fatigue. Moreover the stress intensity and the crack growth properties are very favourable in terms of overlay design. Combining these two features makes the application of Sealoflex binders for overlay very economical.
The application of Sealoflex as an overlay or in full depth structure material is technically justifiable, whether the overlay is to be applied to strentgthen the pavement structure or to prevent reflection cracking.

The overlay thickness can be reduced substantially, up to 50%, depending on the requirements that are put on the overlay design: with overall cost of maintenance 20 to 40% less than when the design is carried out with conventional products.
Ever since the first trial section, Sealoflex performance worldwide has been very satisfactory.

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Polymeric Additives And Their Role In Asphaltic Pavements : PART I: Effect of Additive Type On The Fracture And Fatigue Behavior.

By

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Polymeric Additives and Their Role in Asphaltic Pavements. Part I: Effect of Additive Type on the Fracture and Fatigue Behavior

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ABSTRACT: The effect of polymer modifier type on the fracture and fatigue behavior of AC-5 asphalt mixture was studied. Three polymer modifiers which belong to the general group of thermoplastic polymers; styrene-butadiene-styrene block copolymer (Kraton), ethylene vinyl acetate (Elvax) and polyethylene (Novophalt) were considered. Beams were prepared from AC-5 asphalt binder containing 6% of each polymer modifier by weight and the same gradation. Flexural static tests were performed to evaluate the three polymer modifiers in comparison with unmodified AC-5 asphalt mixture. It was found that in general all three polymers increase the strength and the modulus of the asphalt pavement. SBS (Kraton) exhibits the highest flexibility and strength at room temperature (70°F). Invoking the modified crack layer model, fatigue crack propagation analysis revealed the superiority of the Kraton modified asphalt mixture to both Elvax and Novophalt mixtures. The modified crack layer model analysis of asphaltic pavements yields important information since it accounts for a combined comparison on the basis of crack speed, measured energy release rate, and the change in work expended on damage formation and history dependent viscous dissipative processes.

KEY WORDS: polymer modifiers, asphaltic pavements, fracture and fatigue behavior.

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INTRODUCTION

THE DURABILITY OF asphaltic pavements is greatly influenced by the environmental changes during the year, especially between summer and winter and between day and night when the daily average temperature change can be considerably large. In summer, the high temperature can soften the asphalt binder and consequently reduce the stiffness of the paving mixture. On the other hand in winter, the low temperature can stiffen the asphalt binder and reduce the flexibility of the paving mixture. As a result, thermal cracking of the pavement surface may develop which adversely affects the performance of the paving mixture, resulting in frequent and costly repairs and maintenance. Thus, high temperature stiffness and low temperature flexibility are essential properties for durable asphaltic pavements. Since the main ingredients of asphaltic pavements are aggregate (limestone) and asphalt binder, it is the asphalt binder which dictates these two performance-related properties.

The inadequacy of conventional asphalt cements to provide these properties has led to the incorporation of various additives, in particular polymeric ones. Various workers for example [1–3] have reported that polymer additives can improve the interfacial adhesion between the asphalt binder and the aggregate, the cohesion of the binder, temperature susceptibility, modulus, resistance to rutting and resistance to fatigue cracking. Little et al. [4] reported that the selection of the best additive for improved pavement performance in various climates, pavement structures and traffic loads is not an easy task. Some polymers can improve one or more properties but probably none can improve all properties. Thus it appears to be that the most effective modifier to improve the overall performance of asphalt pavements is far from being available.

Polymer modifiers vary in function and effectiveness. Elastomers, which are at least to some extent derived from a diene chemical structure, have the ability to toughen asphalt and improve temperature viscoelastic properties. Plastomers, which come from non-diene chemicals, can improve the high temperature viscoelastic properties of softer asphalts which have good intrinsic low temperature properties [5]. The properties of asphalt mixtures can be improved by selecting modifiers in the proper molecular weight range and mixing the modifiers with asphalt mixtures with an appropriate emulsion blending procedure. Low molecular weight polymers are easily blended yet do not contribute much to the asphalt's properties, whereas high molecular weight polymers, which are very difficult to disperse, substantially enhance the properties.

One of the critical factors that should be considered for better rubber modified asphalt is the air void percentage in the total mix. The performance of the rubber modified asphalt mixture will be improved as this percentage is reduced [3,6]. In general, the air void percentage depends on the load capacity of the transportation facility being designed. Lower air void percentages can be obtained by increasing both the modifier and the asphalt binder content until the required value is reached [6].

In the current study focus is placed on three commonly used polymer modifiers, namely, a styrene-butadiene-styrene copolymer (Kraton), ethylene vinyl acetate (Elvax), and a polyethylene (Novophalt), since they have been found to be among the most useful additives, particularly with low penetration asphalts such as AC-5. The performance of asphalt mixtures modified with these polymers will be evaluated in view of a recently developed methodology – the modified crack layer model. Parameters controlling the fracture process characteristic of the mixture's resistance to crack propagation and its dissipative character will be established and used as performance-related criteria. In addition comparison will be made based on the mechanical behavior of asphalt mixtures modified with each additive.

FATIGUE ANALYSIS

The development of pavements with superior resistance to fatigue cracking necessitates the thorough understanding of the combo-viscoplastic behavior of the binders (asphalt) and the polymers (modifiers) which have been shown to be the major constituents influencing the pavement's performance. Recently a methodology, the modified crack layer (MCL) model [7], has been developed to characterize the resistance of materials to fatigue crack propagation (FCP). The capability of this approach to discriminate the subtle effects introduced by different chemical structures and processing conditions in asphaltic mixtures has been demonstrated [8–11]. The MCL model essentially addresses the difficulties encountered in the general applicability of the crack layer model [12–14]. These difficulties are the identification and quantification of damage species associated with fatigue crack propagation in materials.

For stress control fatigue, the modified crack layer model is expressed as

$$\frac{da}{dN} = \frac{\beta' \dot{W}_t}{\gamma' a - J^*} \tag{1}$$

where da/dN is the cyclic crack speed, a is the crack length, γ' is a candidate material parameter characteristic of the mixture's resistance to FCP and β' is the energy dissipative character of the pavement. The change in work W, and the energy release rate J^* will be discussed in detail below.

The J-integral proposed by Rice [15] can be used to evaluate the crack tip elastic-plastic field. Invoking the deformation theory of plasticity, Rice formulated mathematically the energy release rate for materials displaying elastic-plastic response. For a cracked body subjected to a two-dimensional deformation field, the J-integral is expressed as

$$J = \int_{\Gamma} \left(w dy - T \frac{\partial u}{\partial x} ds \right) \tag{2}$$

where Γ is a closed contour surrounding a crack tip in a stressed solid. w is the strain energy density $w = w(x, y) = \int \sigma_{ij} d\varepsilon_{ij}$, T is the traction vector perpendicular to Γ, u is the incremental displacement in the x direction and ds is an element of Γ. Rice has also shown that the J-integral around a crack tip is the change in potential energy for a crack increment Δa. The path independent J-integral proposed by Rice was viewed by Begley and Landes [16] as a measure of the crack tip elastic-plastic field and can be evaluated from the load displacement curve associated with crack extension during monotonic loading. The deformation theory of plasticity upon which the J-integral is founded does not permit unloading, therefore the J-integral evaluated by Begley and Landes strictly speaking cannot be used to characterize the crack tip elastic-plastic field in pavement during fatigue crack propagation (FCP).

Little et al. [4] have modified the J-integral analysis to include unloading effects. On this basis, the energy release rate for an elastic-plastic crack tip field can be evaluated from the change in potential energy (the area above the unloading curve) with respect to the crack length divided by the thickness of the specimen. Little et al. stated that "this modified J-integral (J^*) should be suitable in a comparative analysis of energy release rates among various asphalt binders." This J^* will be evaluated experimentally from the hysteresis loops at various crack lengths and used with the modified crack layer theory in the current fatigue crack propagation (FCP) analysis. Thus,

$$J^* = \frac{1}{B} \left(\frac{dP}{da} \right) \tag{3}$$

where P is the area above the unloading curve and B is the specimen thickness.

The quantity $\dot{W}_i$, which is the "change in work," is measured directly as the area of the hysteresis loop at any crack length, H_i, minus the area of the loop just before crack initiation, H_o, divided by the specimen thickness, B [17].

$$\dot{W}_i = \frac{H_i - H_o}{B} \tag{4}$$

In viscoelastic materials, $\dot{W}_i$ includes work expended on damage processes associated with crack growth and history dependent viscous dissipation processes which are both irreversible.

The specific energy of damage γ' and the dissipative coefficient β', extracted from fatigue crack propagation experiments using the MCL model, will be employed to study the effect of additive type on the fatigue resistance of AC-5 asphalt concrete mixtures.

EXPERIMENTAL

Materials

MODIFIERS

Three polymer modifiers (Kraton, Elvax and Novophalt) were studied. These modifiers belong to the general group of thermoplastic polymers and are claimed to improve the engineering characteristics of the asphalt cement and ultimately of the asphalt concrete mixtures.

Kraton(R) D4463 (thermoplastic rubber of styrene-butadiene-styrene block copolymer) is supplied in pellets that melt at the prescribed mixing temperature between 320 and 380°F.

Elvax (ethylene vinyl acetate) is supplied in free-flowing pellets that melt at a prescribed mixing temperature between 275 and 300°F.

Novophalt modified asphalt cement is a bi-phase binder consisting of a small percentage (4–6%) polyolefin additives. The polyolefin phase is primarily low density polyethylene. Virgin or recycled polyethylene can be incorporated in preparing the Novophalt. The exact chemical composition of Novophalt is proprietary. Its prescribed melting point is between 290 and 310°F.

ASPHALT CEMENT

The following asphalt binder physical properties (Table 1) were determined by the supplier. Prior to specimen preparation the optimum

Table 1. Physical properties of the unmodified AC-5 binder.

Physical Property	AC-5
Penetration @ 77°F, ASTM D-5	204
Viscosity @ 275°F cSt, ASTM D-2170	201
Viscosity @ 140°F, Poise, ASTM D-2171	461
Flash. (Clev. Open cup) °F, ASTM D-92	595

asphalt cement content of the asphalt concrete mixtures was determined using the Marshall method of mix design (ASTM 1559-89). The optimum asphalt cement content (AC-5) was determined to be 8%. In addition, the target asphalt concrete unit weight was determined to be 149 pcf, by the same procedure.

AGGREGATE TYPE AND GRADATION

Crushed limestone aggregate and quartizitic sand were selected for the preparation of test specimens. The hardness and abrasion characteristics (Los Angeles Abrasion Test) of the aggregate were such that they met the minimum standards specified by the Ohio Department of Transportation, when used in the preparation of both Portland cement concrete and asphalt cement concrete. The bulk aggregate was initially sieved to accumulate enough material within each size range specified by the gradation requirements. Gradation requirements corresponding to ODOT (Ohio Department of Transportation) specification item 403 [18] were adopted in the preparation of all specimens.

Specimen Preparation

Polymer modified asphalt binders were prepared by mixing asphalt cement AC-5 with Kraton, Elvax or Novophalt. The bulk polymer was first heated to the compaction temperature of 320°F and then blended with the liquefied asphalt. The weight of each polymer modifier was kept constant at 6% of the asphalt cement. Mixing of the asphalt cement and polymer was performed with a high speed electric mixer until a uniform blend was achieved. The mixture of AC-5 asphalt and Novophalt modifier was prepared by Pri Asphalt Technology, Inc., Tampa, FL. The modified asphalt cement was left overnight at 150°F and raised to 320°F before mixing with the aggregate, as recommended by the supplier.

Asphalt concrete beams measuring 15" long × 2" thick × 3.5" deep were prepared using the following procedure. The aggregate, the modified asphalt cement and the mold were preheated to 320°F before

blending and compaction. Beams were compacted by sustaining a 2000 psi pressure through a steel plate for 1 minute, in agreement with ASTM D3202-83. Beams were allowed to cool off in the compaction mold and were usually tested 7 days after preparation and conditioning. Conditioning consisted of subjecting each beam to a constant temperature of 140°F for 1 day.

Lab Testing

STATIC FLEXURE TESTS

Unnotched asphalt concrete beams were tested under static flexure in order to determine the ultimate flexural strength and the flexural modulus E. A four-point bend test was used. The support span was equal to 10.2" and the distance between the midspan loading points was 3.4". The beam deflection was measured with an LVDT and the load-deflection curve was recorded by means of an X-Y plotter. The load was applied gradually at a constant rate of 0.16 in/min until failure was reached.

FATIGUE CRACK PROPAGATION TESTS

Four-point bending fatigue crack propagation tests were performed under stress control in a laboratory environment at a constant temperature of about 70°F using an invert haversine load. The load application period was 0.2 sec followed by a 2 sec rest period between repeated loads. The same loading configuration was used as in the static flexural tests except that an initial straight notch 0.25" deep was inserted at the middle of the specimens with a 0.156" saw with a round tip of radius 0.094". A maximum load of 65 lb was used with continuous cycle load applications from zero to the maximum load. A hysteresis loop (load vs. deformation) was recorded at 0.25" intervals of crack growth using the X-Y plotter.

RESULTS AND DISCUSSION

The effect of three modifiers (Kraton, Elvax and Novophalt) on the static flexural behavior (ultimate strength and flexural modulus) was examined. These were also compared with the static flexural behavior of unmodified AC-5 asphalt mixtures. In addition, fatigue crack propagation analysis was performed to evaluate the effect of the additives on the fracture toughness in view of the modified crack layer model.

Static Flexural Behavior

The load versus the load point displacement response for a typical un-

notched specimen of each of the three modified AC-5 mixtures and for unmodified AC-5 mixture are shown in Figure 1. The experimental conditions as well as the additive loading (6% of the asphalt cement by weight) were kept the same. It is seen in Figure 1 that all three polymer modifiers have increased the maximum load and the stiffness of the AC-5 asphalt mixture. The Kraton modified mixture exhibits the highest maximum load, followed by the Elvax and the Novophalt mixtures. It is also observed that the Kraton modified mixture is the most compliant in comparison with the Elvax and the Novophalt modified mixtures. The load deflection curve for the Kraton modified mixture exhibits an initial linear response up to about 75% of its maximum load, followed by a more compliant nonlinear response. This deviation from linearity is observed prior to the maximum load. The Elvax modified AC-5 mixture then exhibits a linear response up to about 85% of its maximum strength after nonlinearity takes place. After the maximum load is reached the load decays very slowly. Finally complete rupture occurs, indicative of the brittle nature of the Elvax modified mixture at

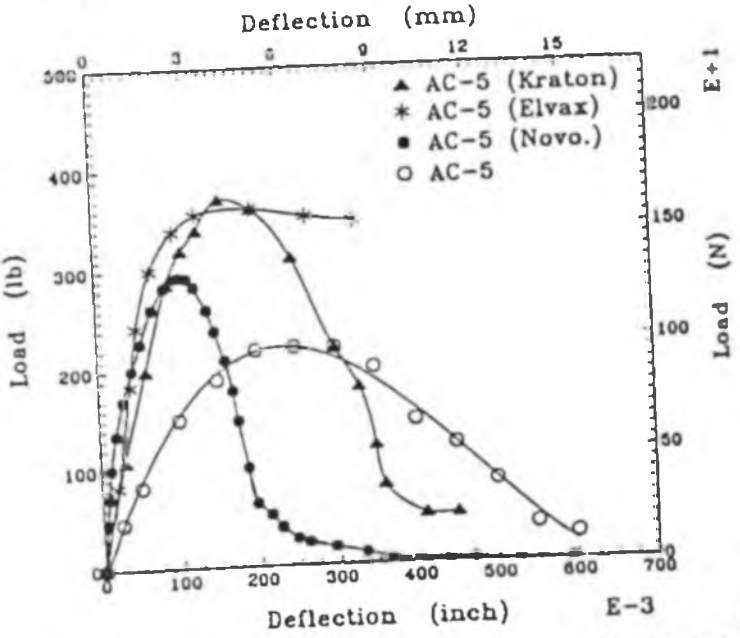


FIGURE 1. Load versus load point displacement of the three polymer modified AC-5 asphalt concrete mixtures together with unmodified AC-5 mixture.

Table 2. Mechanical properties of the modified AC-5 with Novophalt, Elvax and Kraton additives.

Mixture	E (psi)	Ultimate Bending Strength (psi)
AC-5 + 0% additive	4,960	95
AC-5 + Novophalt 6%	16,560	118
AC-5 + Elvax 6%	10,142	139
AC-5 + Kraton 6%	7,200	151

room temperature. The binder holding power appears higher in the Kraton mixture than in the other three mixtures.

Average values of the flexural modulus and ultimate flexural strength for the Kraton, Elvax, Novophalt and unmodified AC-5 mixtures are given in Table 2. It is seen from Table 2 that among the three polymer modified mixtures, the Kraton mixture has the highest ultimate strength and the lowest flexural modulus at 70°F. These two properties are desirable for asphaltic pavements with improved performance. The high ultimate strength can be attributed to the strong elastic three-dimensional network formed by the polystyrene endblock domain of the Kraton modifier. It is not known if the behavior of the Kraton mixture will change with temperature in comparison with the other mixtures tested. This will be reported in a later article.

Fatigue Fracture Behavior

The effect of additive type on the fatigue resistance of the three modified asphalt concrete mixtures is examined in view of the modified crack layer model. The crack length a, versus the number of cycles N for typical specimens of the Novophalt, Elvax and Kraton modified AC-5 mixtures is shown in Figure 2. It is observed from Figure 2 that the Novophalt is inferior with respect to both crack initiation and propagation when compared to both the Elvax and Kraton modified mixtures. An attempt was made to test specimens from the unmodified AC-5 mixture, however due to the softness of the beams, permanent deformation prohibited the completion of the experiment. The crack speed was calculated at intervals of crack length from the slope of each curve in Figure 2, to be employed in the MCL model.

The energy release rate J^*, evaluated based on the potential energy principle [Equation (3)] is plotted against the crack length in Figure 3. The value of J^* for the Kraton modified specimens is always higher than its counterpart for the Novophalt and Elvax modified specimens.

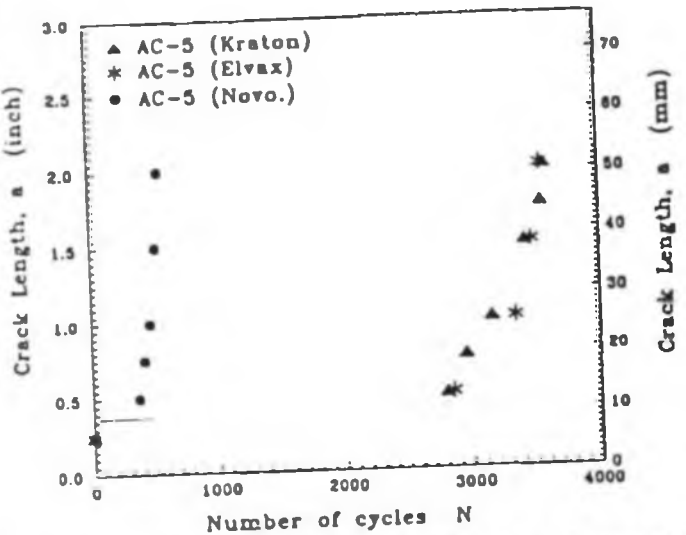


FIGURE 2. Crack length versus number of cycles for the three polymer modified AC-5 asphalt concrete mixtures.

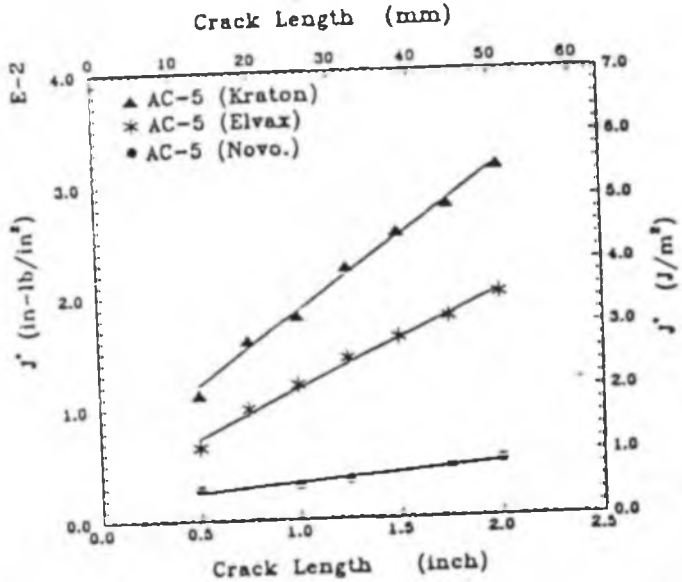


FIGURE 3. Energy release rate versus crack length for the three polymer modified AC-5 asphalt concrete mixtures.

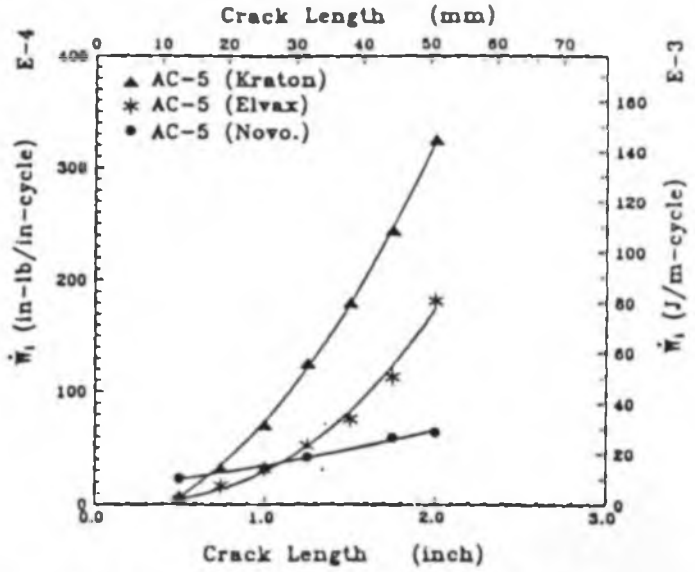


FIGURE 4. Change in Work, $\dot{W}_i$, versus the crack length for the three polymer modified AC-5 asphalt concrete mixtures.

at the same crack length. Again, a higher value of J^* indicates the fracture resistance superiority of the Kraton modified AC-5 to the Novophalt and Elvax modified AC-5 mixtures. The value of J^* at each crack length will be employed in the present analysis to extract γ' and β' for each mixture from Equation (1).

The change in work, $\dot{W}_i$, versus the crack length for typical beams tested from the Novophalt, Elvax and Kraton modified mixtures are shown in Figure 4. The value of $\dot{W}_i$ for the Kraton modified mixture is in general higher than that for the Elvax and Novophalt modified mixtures. Thus, more work has been expended on damage formation and history dependent dissipative processes within the active zone of the Kraton modified mixture. These relationships between $\dot{W}_i$ and the crack length will also be employed in the current analysis [Equation (1)] to evaluate γ' and β'.

In order to extract γ' and β' for various polymer modified mixtures Equation (1) is rearranged as,

$$\left(\frac{J^*}{a}\right) = \gamma' - \beta' \left(\frac{\dot{W}_i}{a\left(\frac{da}{dN}\right)_i}\right) \tag{5}$$

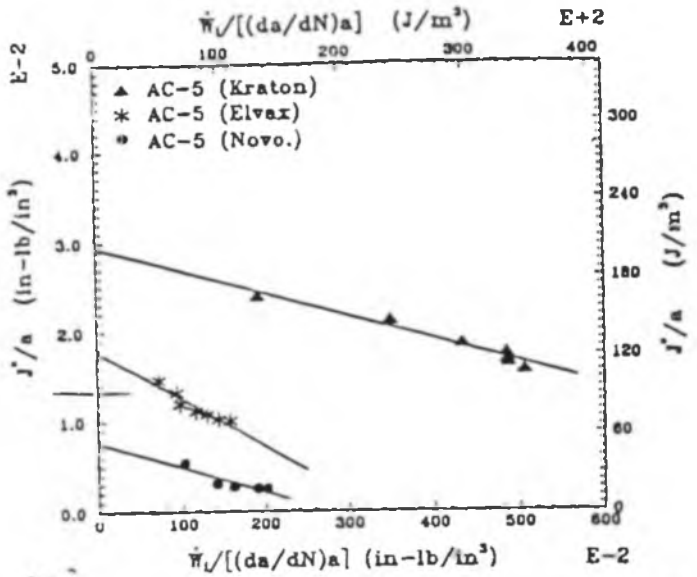


FIGURE 5. Fatigue crack propagation behavior of the three polymer modified AC-5 asphalt concrete mixtures plotted in the form of the MCL model to obtain γ' and β'.

The results of a typical specimen from each mixture are plotted, on the basis of Equation (5), in Figure 5. It is evident from Figure 5 that the experimental points for all of the mixtures define a good straight line, where γ' is the intercept and β' is the slope. The average values of γ' and β' based on three identical specimens of each mixture are given in Table 3. The value of γ' for the Kraton modified AC-5 mixture is higher than that for the Novophalt and Elvax modified mixtures, while the value of β' is lower than those for the Novophalt and the Elvax based mixtures. A higher value of γ' and a lower value of β' make the Kraton mixture more resistant to crack propagation, i.e., tougher than the other mixtures. The fracture toughness superiority of the Kraton modified mixture has been attributed to better adhesion between the binder and the aggregate as well as better cohesion within the binder. This has been substantiated through SEM analysis [11] which revealed microstretching of the Kraton modified asphalt binder.

The theoretically predicted crack speed is plotted versus the energy release rate, using the values of γ' and β' for each mixture and is shown in Figure 6. Also in Figure 6 the experimental results are plotted together with the theory. Again the theory describes the experimental results very well. For a constant crack speed the value of J^*

Table 3. γ' and β' for Novophalt, Elvax and Kraton modified AC-5 mixtures.

Mixture	γ' (in-lb/in^3)	β'
AC-5 + Novophalt 6%	0.83×10^{-4}	3.10×10^{-3}
AC-5 + Elvax 6%	1.79×10^{-3}	2.97×10^{-3}
AC-5 + Kraton 6%	2.13×10^{-4}	2.61×10^{-3}

for the Kraton modified mixture is always higher than the other two mixtures. This indicates that more energy is required to drive a crack in the Kraton than in the other two mixtures.

CONCLUDING REMARKS

Analysis of controlled stress fatigue experiments conducted at room temperature (70°F) on Kraton, Elvax and Novophalt modified AC-5 asphalt mixture revealed the fracture resistance superiority of the Kraton (SBS) modified asphalt mixture to those modified with Elvax and Novophalt. All three polymer modifiers have increased the maximum

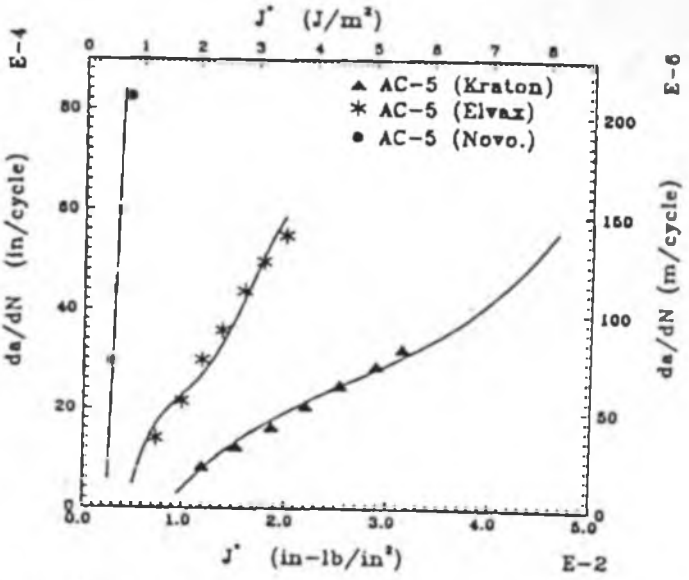


FIGURE 6. The theoretically predicted fatigue crack propagation speed based on the HCL model (together with the experimental data) for the three polymer modified AC-5 asphalt concrete mixtures.

strength and stiffness of the AC-5 asphalt mixture at room temperature, however, the Kraton based mixture possesses relatively higher flexibility and higher strength. These two combined properties in comparison with Elvax and Novophalt modified mixtures are desired for improved asphaltic pavement performance.

ACKNOWLEDGEMENTS

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PREPARATION AND EVALUATION OF POLYMER-MODIFIED ASPHALT BINDERS

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INTRODUCTION

An asphalt is composed of many different molecules which interact to form a viscoelastic fluid. Since the specific chemical composition depends upon both the crude oil source and the refining process, the rheological properties vary markedly from one bitumen to another. Asphalt is not a continuous, isotropic, homogeneous material, but is traditionally characterized as colloidal, with micelles of several thousand Angstroms (asphaltenes) suspended in a high viscosity oily phase (maltenes)[1-7]. Newer research also points to tiny microcrystalline domains that are theorized to be aliphatic, waxlike interactions which extend only a few microns [8]. The microstructure is, therefore, defined by the concentration of micelles (and possibly microcrystals), by their size distribution, and by any chemical or physical interactions between them. These interactions are responsible for a more or less well developed three-dimensional network which determines the elastic nature of the material [9]. The addition of a polymer to a bitumen creates a new microstructure, and therefore modifies the physical properties of the binder [10-17].

The resulting physical characteristics of the polymer modified asphalt (PMA) depend upon the base asphalt, the type

and percentage of polymer, the compatibility of the constituents, the manufacturing technology, and the thermal history of the material. Currently, there are two principal types of PMA, those obtained by mechanical blending, and those involving a chemical reaction between the components. Research and development of PMA involves characterization of the microstructure of the asphalt-polymer system, and of the resultant physical properties of the modified binder. The last step before commercialization is to identify applications which utilize the unique properties of PMA to best advantage [18-20].

This paper discusses methods for the evaluation of various PMA's by microstructure and physical property characterization.

EXPERIMENTAL

Unless otherwise noted, polymers used in this study are styrene-butadiene block copolymers of varying geometries, including diblock, linear triblock, and radial multiblock systems. The polymer modified asphalts discussed here were prepared by slowly adding measured quantities of ground or pelletized polymers to constantly agitated asphalt in jacketed glass reaction vessels. A thermostatically controlled oil bath insured a constant temperature (normally 180°C) throughout the mixing. The blending was considered complete when the polymer particles disappeared, the material appeared homogeneous, and there was no visual separation of phases when sieved. In some cases, a chemical reactant was added to crosslink polymer and

asphalt molecules in-situ. This reaction increases the average molecular weight and improves compatibility in the blend[21,22].

Microstructure Evaluation

The PMA's were evaluated for microstructure using both optical and electron microscopy methods specially developed for this application.

In the scanning electron microscopy technique [23], the PMA must first be reacted with osmium tetroxide. The materials are quickly mixed and then all agitation is stopped while the reaction takes place. This chemical presumedly fixes the geometry of the polymer network by crosslinking the olefinic sites on the butadiene chains. OsO_4 further serves as a marker which is visible to a scanning electron microscope. After the reaction is complete, the asphalt is extracted from the polymer network with a suitable solvent. The reacted polymer matrix is then placed under a scanning electron microscope for structure evaluation.

As reported in 1975, reflective fluorescence microscopy is effective at demonstrating the polymer matrix without extraction [24]. Here the PMA (with its microstructure intact) is frozen and fractured. The newly exposed surface is bombarded with blue light, and the fluorescent re-emitted yellow light is observed with an optical microscope. Under these conditions, there is a dramatic visual difference between the two phases; the oils swelling the polymeric phase fluoresce yellow light, whereas the bituminous phase remains dark. The microstructure is characterized by the composition of the

continuous phase, the nature of the dispersed phase, the apparent relative concentrations, and the dimensions of the particles in the dispersed phase.

In some cases the microstructure is very fine and barely observable by fluorescent optical miscroscopy, but can be seen in somewhat more detail by newly developed transmission electron microscopy techniques. Thin wafers of PAC are prepared by cryofracture. They are then toned with OsO_4 to color the polymer. In this case the polymer phase is dark and the bitumen phase is light. Like the optical microscopy method, this procedure has the advantage of not disturbing the material structure by extraction of the asphalt.

Physical Property Characterization

The most significant improvements in asphalt by polymer modification are: increased elasticity and tensile strength, reduced variation in consistency with changing temperature, and increased non-newtonian rheology (pseudoplasticity). For this study, ASTM Standard Test Method D 4957-89 [25], "Apparent Viscosity of Asphalt Emulsion Residues and Non-Newtonian Bitumens by Vacuum Capillary Viscometer" at 60°C; D 2170-85 [26], "Kinematic Viscosity of Asphalts (Bitumens)" at 135°C; and D 36-86 [27], "Softening Point of Bitumen (Ring-and-Ball Apparatus), differentiate consistency at elevated temperatures. ASTM D 5-86 [27], "Penetration of Bituminous Materials" at 25°C demonstrates consistency at ambient temperature. (All viscosities at 60°C cited are interpolated to a shear rate of 1 sec^{-1}.) When a PMA shows a significant rise in the high

temperature consistency (viscosities, softening point) over the base asphalt, with little change in the 25°C penetration, there is an improvement in the temperature susceptibility of the asphalt [28]. This should translate into less rutting and tenderness of asphalt pavements at high temperatures, and less cracking and brittleness at low temperatures [29,30].

Aging was simulated by ASTM test method D 2872-88 [27], "Effect of Heat and Air on a Moving Film of Asphalt (Rolling Thin Film Oven Test)".

To determine the susceptibility to phase separation, a storage stability test was developed. A thin-walled aluminum tube (such as that used for toothpaste) was filled with 50 g of the PMA. The open end was rolled down and sealed to eliminate any airspace and possible surface oxidation. The tube was then placed vertically in a metal testtube holder in a 163°C oven. After a specified time (e.g. 48 hours), it was removed from the oven and placed in a freezer. Care was taken that the tube always remained vertical and undisturbed. When frozen, the tube was cut into three equal sections with a spatula and knife. The foil was removed from the top and bottom sections, which were separately placed in 50 ml beakers. The samples were then tested by ASTM D 36-86 (Softening Point) [27]. A difference of 2°C in the softening point was considered evidence of phase separation.

RESULTS AND DISCUSSION

To evaluate PAC's, effective modification of asphalt must first be defined. The first criteria is the integrity, or compatibility, of the asphalt/polymer system. If conventional asphalt storage, handling and usage are to be employed, the material must not phase separate. The second criteria is a cost-effective improvement in binder physical properties. If the polymer modification has little effect on end-use behavior, it is trivial.

Compatibility

A polymer may be incompatible, slightly compatible, or compatible. Incompatible polymers, when mixed with the majority of asphalts, result in a heterogeneous mixture without cohesion or ductility. The modifier destroys the colloidal equilibrium of the asphalt, and therefore the cohesion of the material. Slightly compatible polymers require special mechanical, thermal or chemical processes to successfully improve asphalts [10].

It is important to note that compatibility refers to the polymer-asphalt system, and not just the polymer. A polymer may be incompatible with the majority of asphalts, but compatible with a particular asphalt (one that is highly aromatic, for example). Chemical additives and reactions, such as those used by the rubber industry, are very effective at compatibilizing asphalt-polymer mixtures by imparting a desirable microstructure and then improving their stability

during storage and aging, even when using polymers that fall in the slightly compatible category.

Compatible materials yield physically stable blends using conventional mixing techniques. These may or may not improve the asphalt's physical characteristics; there may be a synergistic effect where the asphalt swells the polymer to an extent where the polymer modulus becomes important. Or the polymer may be simply dissolved in the asphalt with little effect on the asphalt's microstructure, and therefore physical properties.

Figures 1 - 4 represent scanning electron photomicrographs of polymer networks after being reacted with OsO_4 and extracted from several PMA's. As previously reported by Wolfe [23], the structure of the polymer depends upon the chemistry of the polymer and the asphalt. He identified five separate types of networks simply by incorporating the same SBR polymer into different asphalts. With SBS, even more polymer conformations can be identified. The structure which seems to provide the best overall stability vis-a-vis storage, dependence on thermal history, and consistency of physical properties seems to be the honeycomb-like structure as seen in Figure 1. It is not clear whether this network must be continuous throughout, or if it can also exist in small localized domains when the polymer concentration falls below some critical level. Figure 2 represents a perfect example of an incompatible physical blend of SBS in asphalt. Here the polymer has not established a network, but instead has collapsed to produce microballs which

will separate from the asphalt on standing. The physical properties of such a system show improvement over the base asphalt as long as the polymer is kept in suspension, but the polymer is obviously not being used to greatest advantage. When slightly incompatible systems are encountered, it is often possible to create a favorable microstructure by chemically crosslinking the polymer in-situ. Numerous reactions common to the rubber and plastics industries can be used. The internal compatibility is particularly improved if some of the asphalt molecules are also chemically bonded to the polymer chain. Figure 3 represents a photomicrograph of a PMA made from the same asphalt used in Figure 2. By beginning with an SB block copolymer of lower initial molecular weight, and then chemically crosslinking it in-situ before incorporating the OsO_4, the desired honeycomb network can be developed. This latter product is found to be stable to separation and demonstrates more consistent physical properties. Figure 4 shows that the polymer concentration can be doubled in this same asphalt and still remain compatible if the system is chemically stabilized. Although these micrographs are consistent with the available physical and storage stability data, it must be remembered that the asphalt was extracted before these micrographs were made. If the extraction disturbs the actual microstructure, the resulting micrograph may not accurately represent the structure of the polymer as it exists in the PMA.

Figure 5 is an optical reflective fluorescence photomicrograph of a polymer completely dissolved (compatibly) in an asphalt. Normally, polymer agglomerations less than 1 micron in size do not migrate from the asphalt matrix. However, such small polymer domains will have minimal effect on the structure, and hence on the resulting rheological properties. The polymer in this case is too compatible with the asphalt, probably because the styrene endblocks are so well solubilized by the maltene fraction. They can not interact with one another to increase the effective molecular weight of the polymer. Figure 6 shows a photomicrograph for an incompatible blend. The polymer forms rather large spherical clusters which separate from the asphalt quickly. Figure 7 represents a photomicrograph of a polymer which is completely dispersed in and swollen by the asphalt. However the microstructure is obviously much coarser and hence more visible than the fine and almost invisible dispersion seen for the completely compatible system. This coarse structure may exist as a polymer dissolved in a continuous asphalt phase, or as asphalt suspended in a continuous polymer network, depending upon the concentration and dispersion (swelling) of the polymer. A coarse, continuous polymer phase usually exhibits the most positive influence on physical properties, but this may be at the expense of thermal and storage stability.

Figure 8 is a transmission electron photomicrograph of a polymer chemically reacted to the asphalt. The very fine microstructure (less than 1 micron) correctly predicts that

this material shows no sign of separation in the storage stability tests.

According to Stoke's law, a coarse microstructure and large differences in density between polymer and asphalt will result in separation of the two materials, and therefore poor storage stability. Styrene-butadiene polymers are less dense than asphalt, and tend to rise to the surface. Halogenated polymers such as polychloroprene are heavier than asphalt and tend to migrate to the bottom. Visual observations are not sufficient to detect this instability, so the storage stability test described above was developed to guarantee the homogeneity of PMA's during shipping, storage, and use.. Physical blends of SBS and asphalt usually show good stability when the polymer concentration is low. As the polymer concentration increases, the microstructure becomes coarser and separation may result. This is often caused by poorly swollen polymers with regions of lower density, or other chemical incompatibilities which cause the polymer molecules to cluster. Hence, the asphalt compatibility problem becomes more critical as we increase polymer levels to augment performance. The roofing industry has dealt with this problem for years, because typical single-ply roofing membranes require 12-15% SBS. At such dosages, very few asphalts are sufficiently compatible to meet their stringent specifications.

Figure 9 shows the viscosity at 135°C of physical blends of an SB block copolymer in four different asphalts. With no polymer, the viscosities of the four asphalts are similar. As

the level of modification increases, however, so do the differences in viscosity. Similarly, the polymer's chemical composition, structure, average molecular weight, and molecular weight distribution determine the homogeneity. The temperature, mixing time, shear, and ancillary chemical processes during PAC preparation are also parameters which can change the finished product's properties.

In-situ chemical reaction of the physical blends of SBS and AC can enhance stability by either reducing the coarseness of the polymer domain or by crosslinking asphalt molecules to the polymer chain for enhanced solubility. Even chemical modification of the physical blend can not always guarantee a stable product. Table I shows the 3 day storage stability results for a chemically reacted 3% SB diblock polymer in 13 different asphalts with widely varying chemical composition and polymer compatibility. These asphalts include the eight core asphalts from the federally funded Strategic Highway Research Program (SHRP) which were specifically selected for their diversity. Although several of these asphalts are only slightly compatible with SBS polymers, the chemical modification resulted in very stable blends which showed no significant separation, with two very dramatic exceptions. SHRP asphalt AAM-1 is a very unusual Texas asphalt known for its extreme incompatibility with all styrene-butadiene systems. This asphalt has almost no asphaltenes and very few saturated hydrocarbons in the maltene phase. Although most existing literature would predict such chemistry to be very favorable

for SBS compatibility, just the opposite is true. Even though the specific gravity of this asphalt is less than one, which is well below other known bitumens, the polymer always separates to the surface within minutes after agitation is stopped. Additional study is currently underway to investigate the unusual characteristics of this bitumen and its unexpected response to polymer modification. The second example of separation is a classic asphalt instability problem. Heavy Italian crudes have such high asphaltene concentrations that they yield paving grade bitumens simply upon atmospheric distillation. The maltene phase is barely sufficient to maintain colloidal stability within the asphalt itself. Upon addition of SBS, some of the oils leave the continuous phase of the asphalt to swell the polymer. The peptizing power of the maltene phase is then insufficient to maintain a uniform dispersion of the micelles, and they precipitate as asphaltenes. The consequent concentration of these very polar aromatic molecules in the bottom of the storage container results in very high softening points in the bottom fraction, rather than in the upper fraction as was the case for the polymer separation from asphalt AAG-1. Bitumen refineries do use this Italian crude as a blending stock for lighter crudes, and the resulting asphalts can normally be used effectively with polymers. Asphalt blends including significant quantities of AAM-1 are much more difficult to use with SBS.

Stability

Another important component of PMA quality closely related to compatibility is the evolution of physical properties upon storage or aging [12]. It is important that the polymeric network remain stable after reasonable periods of storage in tanks, and that the performance benefits of the modification be maintained after the hot mixing process with aggregates. The effects of storage can be studied by extending the time of the storage stability test, and then comparing physical properties of samples taken from both the top and bottom of the sample to results obtained for the original freshly prepared product. The effects of aging in the hot mix plant can be studied with routine laboratory simulated aging tests. The rolling thin film oven test (RTFO) is preferred, because separating polymer can form a skin on the surface of a thin film oven test (TFOT) specimen which prevents additional exposure to atmospheric oxygen. One linear and two radial SBS polymers, each differing in molecular weight, styrene content, and structure, were added to an asphalt and reacted using the chemical process mentioned above with just enough reagent to prevent polymer separation. The PMA's were then subjected to RTFO aging and long term oven storage. Results are reported in Table II. None of these products showed a significant separation even after two weeks of storage at 325 F, but the linear SBS did show a small but significant decrease in softening point. The results after the aging test were surprising. This RTFO aging test will usually increase the viscosity of this asphalt by two to three times.

The decrease in viscosity observed for Radial #2 and the linear system suggests that the polymer is degrading or that there is a significant rearrangement of the network during the aging process. In fact, the polymer network in this marginally compatible state is very sensitive to sample preparation conditions such as rate of cooling and other variables related to thermal history. A structure rearrangement can occur simply by cooling the polymer at different rates in the testing device. Blend h was prepared by mixing equal amounts of the PMA's made with radial #1 and the linear SBS as described above. A second product, blend g, was prepared by using exactly the same components, but the in-situ chemical reaction was carried out only after the two polymers were blended, rather than reacting each separately and then postblending the products. This polymer combination showed a significant evolution in properties with time, with the order of preparation having little influence on the final result. The combination of Radial #2 with this same linear polymer (blends i & j) was much more stable with time, but again the order of blending and reacting made little difference in long term storage results. However, the initial viscosities did vary quite a lot with method of preparation.

CONCLUSIONS

The properties of the PMA depend upon the bitumen, the polymer, the compatibility of the constituents, the level of modification, and the technology for manufacturing the mixture.

The chemical composition, aromaticity, colloidal stability, and rheology of the asphalt are important variables, as are the chemical and structural parameters of the polymer. A marked difference in the microstructure and therefore physical compatibility can be readily observed by microscopic analysis. These variations can be confirmed by routine physical measurements.

The optimum bitumen improvement is attained not when the polymer is dissolved in the bitumen, but, rather, when the polymer is swollen by the binder. A polymer dissolved in the bitumen implies the loss of polymer-polymer interactions in favor of polymer-bitumen interactions, meaning that the only change in the asphalt is a higher viscosity of the oily phase. Polymer modified asphalt microstructure is defined as the relative organization of the two phases: the polymer phase consisting of polymer micelles swollen by the asphalt's oils, and the bitumen phase consisting of the fraction of the asphalt not involved in the swelling of the polymer. At low polymer levels, the polymer particles are globules (swollen by oils of the bitumen) dispersed in an asphalt matrix and, therefore, the modification of properties is attributed to the compositional change of the bituminous phase (drop in concentration of the oily fraction and consequent rise in the number of micelles). Raising the polymer concentration to a critical level results in a phase inversion, where the polymer becomes the continuous phase, and a dramatic change in physical properties is observed as the improved bituminous properties evolve towards polymer

properties. The critical point is dependent upon the polymer, its concentration, the asphalt, and the manufacturing process (mixing temperature, time, shear, etc.). The evolution of the structure, and therefore of the physical properties, also depends strongly on the thermal history. For example, the inversion from a polymer matrix to an asphalt matrix can occur in particularly sensitive systems by a simple heating to 60°C, resulting in a dramatic change in physical properties. An in-situ chemical reaction can cause the same type of changes as the phase inversion. The polymer is chemically linked to the asphalt, thereby extending the polymer matrix, and diminishing the possibility of phase separation.

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TABLE I

Storage Stability Test

Ring and Ball Softening Points for 13 asphalts modified with 3% SB di-block polymer and chemically reacted in-situ.

Base asphalt	Pen[a] @ 25°C, 1/10 mm	Ring and ball softening points[b], °C			
			After storage stability test[c]		
		°C	Top	Bottom	Difference
SHRP[d] AAA-1	121	48.1	49.5	49.3	0.2
SHRP AAB-1	77	52.5	52.7	52.5	0.2
SHRP AAC-1	87	49.2	49.3	50.0	-0.7
SHRP AAD-1	96	50.6	52.3	52.1	0.2
SHRP AAF-1	47	52.7	53.6	53.6	0.0
SHRP AAG-1	50	49.1	49.9	49.6	0.3
SHRP AAK-1	52	58.3	60.7	59.7	1.0
SHRP AAM-1	63	51.9	62.5	52.5	10.0
Arabian Heavy	54	56.7	58.2	58.1	0.1
Venezuelan	77	50.6	52.4	52.1	0.3
Mexican	46	60.6	60.7	60.7	0.0
French	64	54.6	55.1	54.7	0.4
Italian Heavy	45	63.0	60.9	67.0	-6.1

[a]ASTM D 5, Penetration of bituminous materials.

[b]ASTM D 36, Softening point of bituminous materials (ring and ball apparatus).

[c]Three days in a sealed vertical tube at 163°C, samples taken from top and bottom thirds of tube.

[d]Strategic Highway Research Program core asphalts.

TABLE II

Evolution of Properties with Prolonged Storage and RTFOT[a] Aging

One southwestern U.S. asphalt modified with 3% SBS Block copolymers and chemically reacted in-situ.

				Viscosity[b] 60°C, Pa·s		Storage Stability[c] Softening Point[d], °C			
	SB	ave. Molec.	Pen[e]	before	after	1 week		2 weeks	
Polymer	ratio[f]	weight	25°C	RTFO	RTFO[a]	Top	Bottom	Top	Bottom
Radial#1	30:70	180000	122	1370	1460				
Radial#2	20:80	140000	100	500	350	48.3	48.3	47.8	47.2
Linear	30:70	120000	95	1940	560	58.9	58.9	55.0	55.6
Blend[g]			105	1290	570	64.4	65.6	58.9	58.9
Blend[h]			109	960	650	66.1	65.6	58.3	58.9
Blend[i]			95	1610	730	50.0	50.0	48.9	48.9
Blend[j]			98	830	640	50.6	51.1	48.9	48.3

[a]ASTM D 2872, rolling thin film oven test at 163°C, 75 mins.

[b]ASTM D 4957 viscosity interpolated to a shear rate of 1-sec^{-1}.

[c]In a sealed vertical tube in a 163°C oven for specified time.

[d]ASTM D 36, softening point (ring and ball apparatus).

[e]ASTM D 5, penetration at 25°C, in 1/10 nm.

[f]Ratio of styrene to butadiene in block co-polymer.

[g]50/50 Blend of linear and radial #1 (co-reacted).

[h]50/50 blend of linear and radial #1 (independently reacted).

[i]50/50 Blend of linear and radial #2 (co-reacted).

[j]50/50 blend of linear and radial #2 (independently reacted).

FIGURE CAPTIONS

Fig. 1. Scanning electron photomicrograph of a compatible polymer-asphalt blend.

Fig. 2. Scanning electron photomicrograph of an incompatible polymer-asphalt blend.

Fig. 3. Scanning electron photomicrograph of a compatibilized polymer-asphalt blend.

Fig. 4. Scanning electron photomicrograph of a high polymer-asphalt blend.

Fig. 5. Optical reflective fluorescence photomicrograph of a compatible polymer-asphalt blend.

Fig. 6. Optical reflective fluorescence photomicrograph of an incompatible polymer-asphalt blend.

Fig. 7. Optical reflective fluorescence photomicrograph of a swollen polymer-asphalt blend.

Fig. 8. Transmission electron photomicrograph of a chemically reacted polymer-asphalt blend.

Fig. 9. Viscosities of physical blends of an SB block copolymer in four different asphalts.

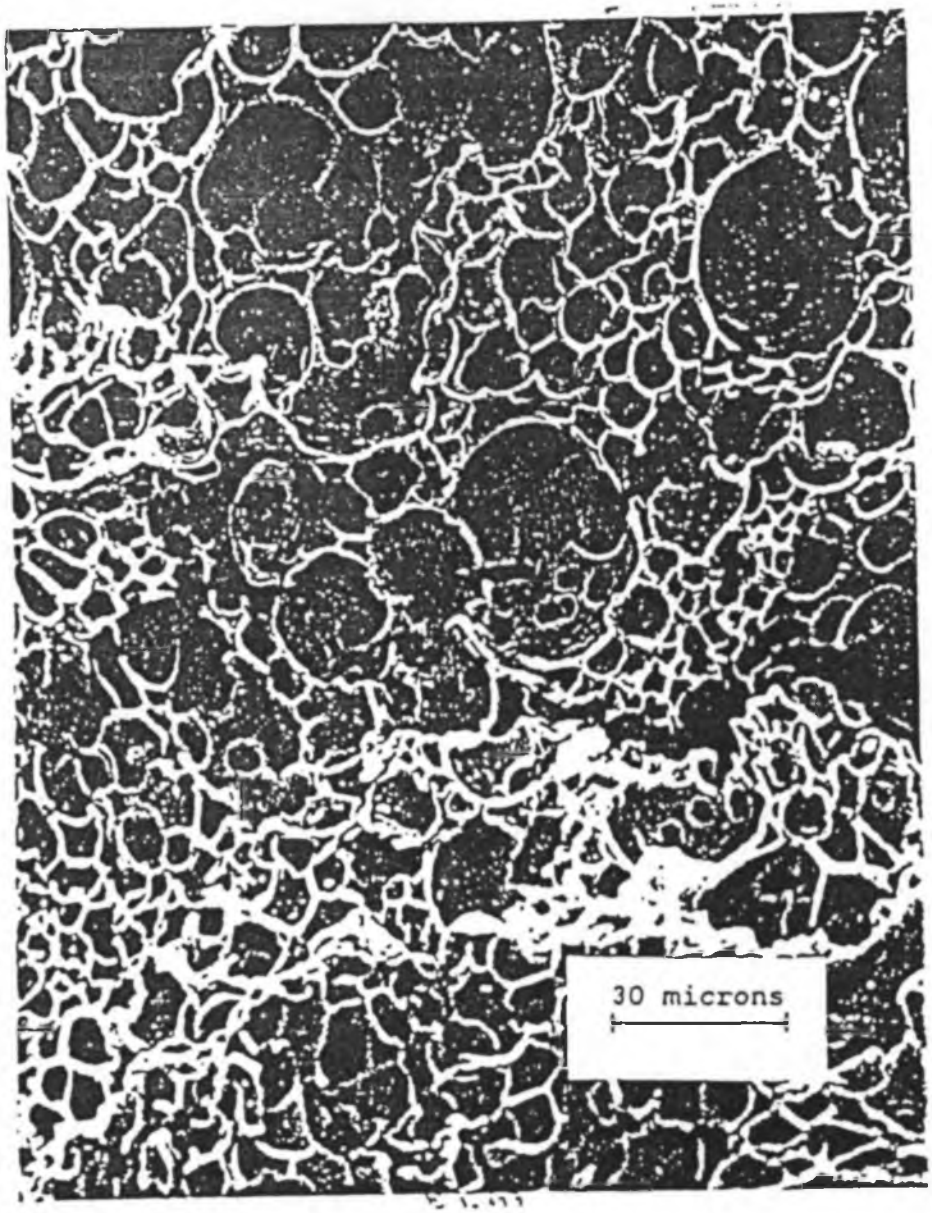


Fig. 1. Scanning electron photomicrograph of a compatible polymer-asphalt blend.

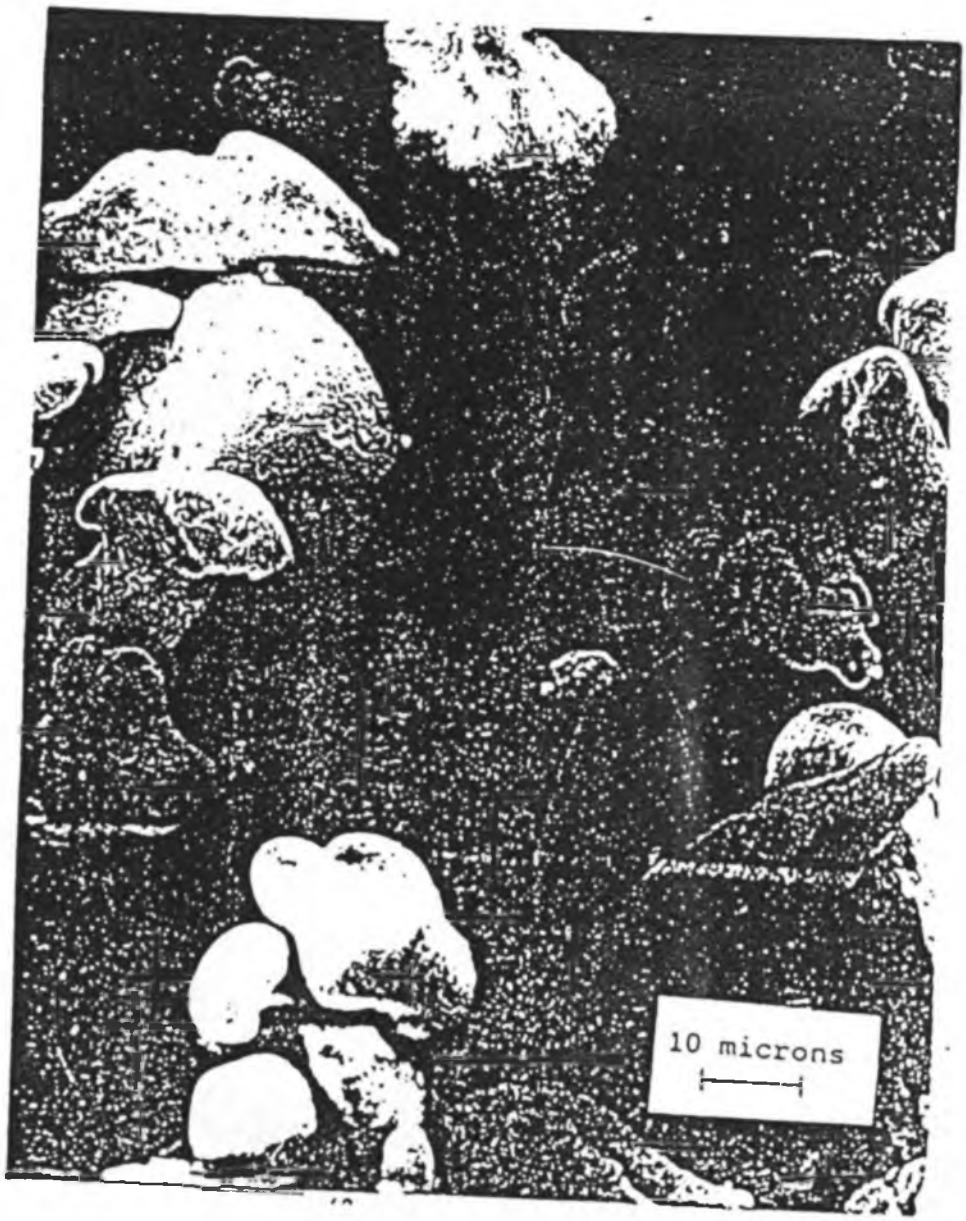


Fig. 2. Scanning electron photomicrograph of an incompatible polymer-asphalt blend.



Fig. 3. Scanning electron photomicrograph of a compatibilized polymer-asphalt blend.

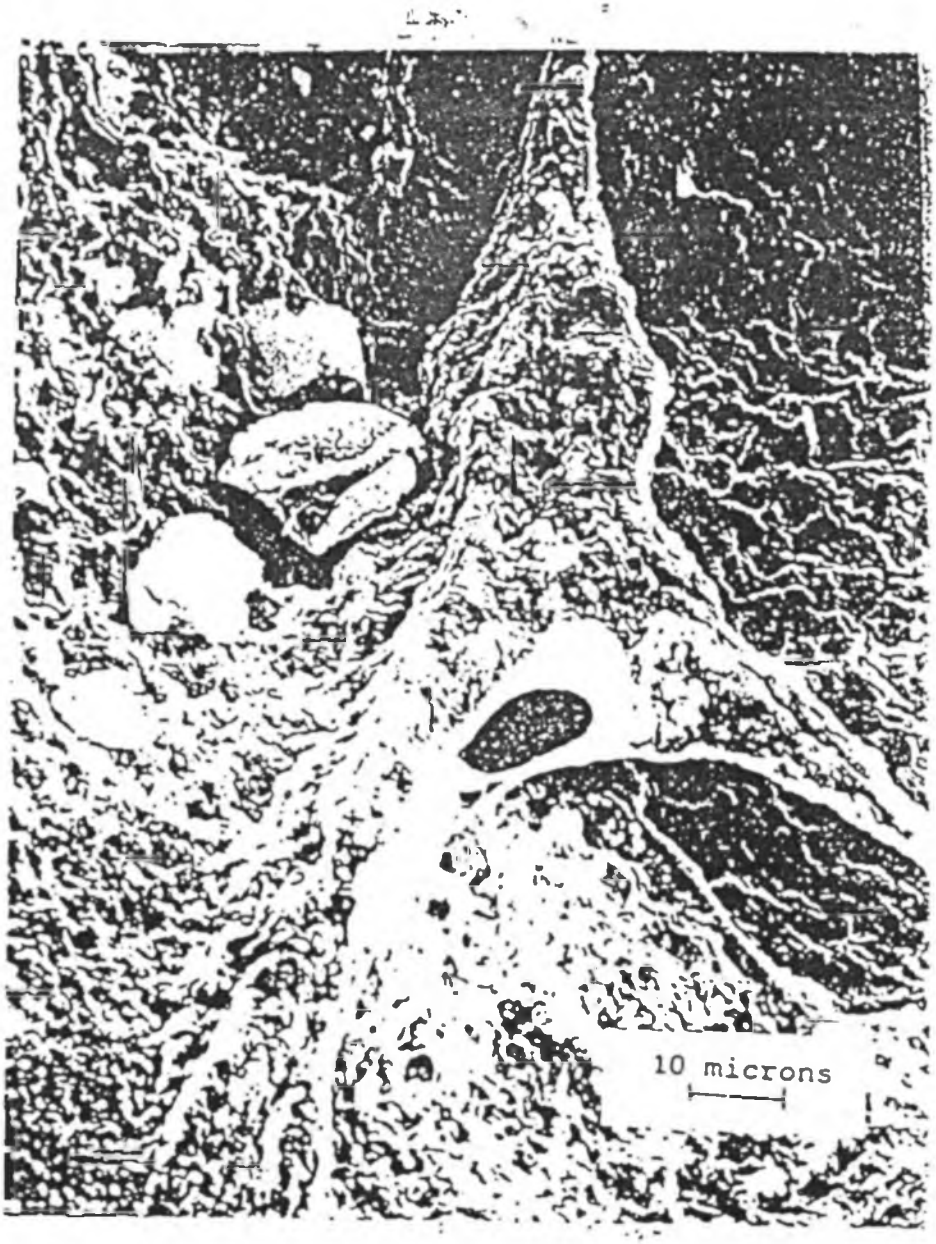


Fig. 4. Scanning electron photomicrograph of a high polymer-asphalt blend.

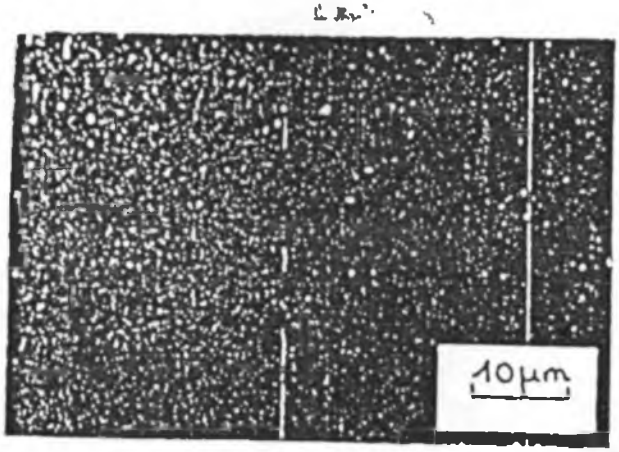


Fig. 5. Optical reflective fluorescence photomicrograph of a compatible polymer-asphalt blend.



Fig. 6. Optical reflective fluorescence photomicrograph of an incompatible polymer-asphalt blend.

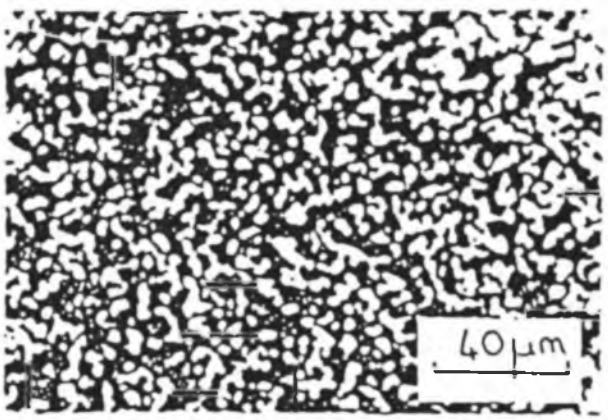


Fig. 7. Optical reflective fluorescence photomicrograph of a swollen polymer-asphalt blend.

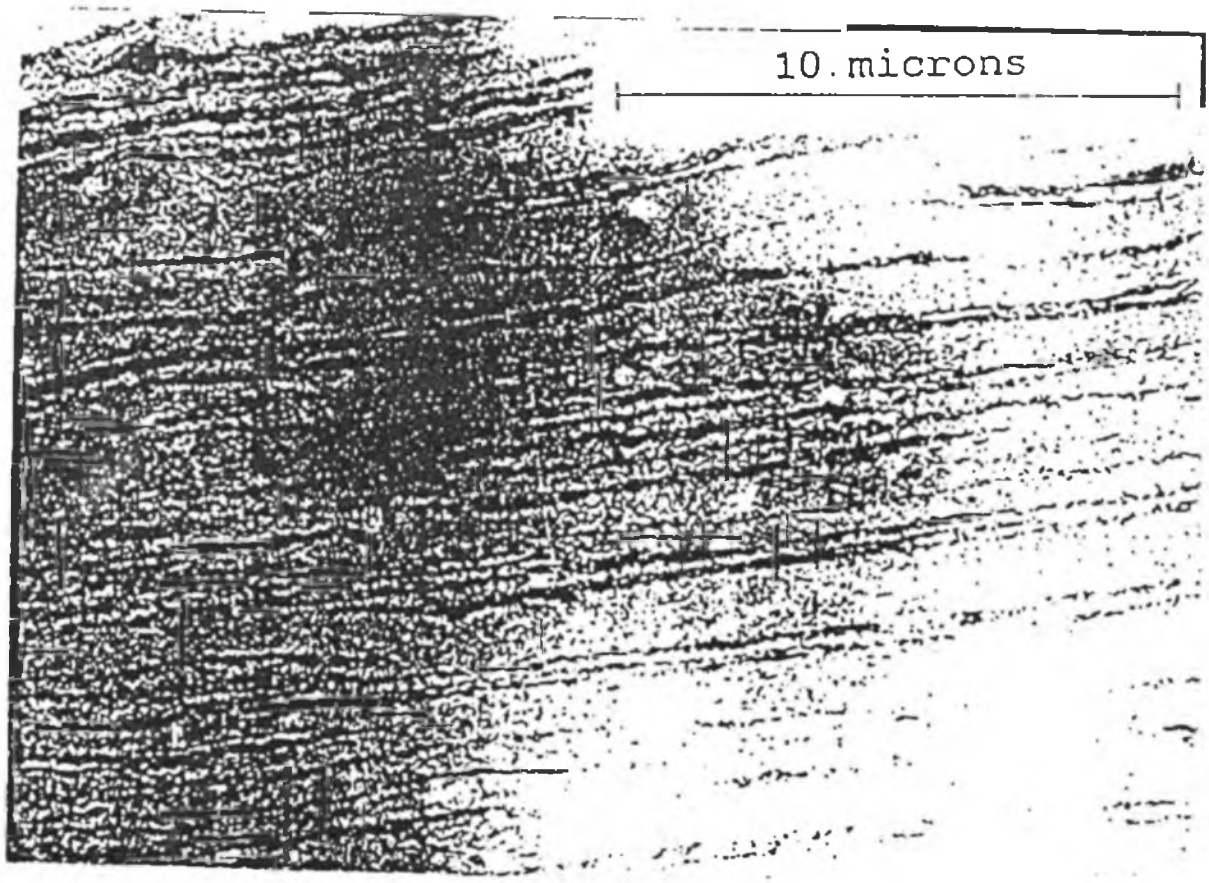
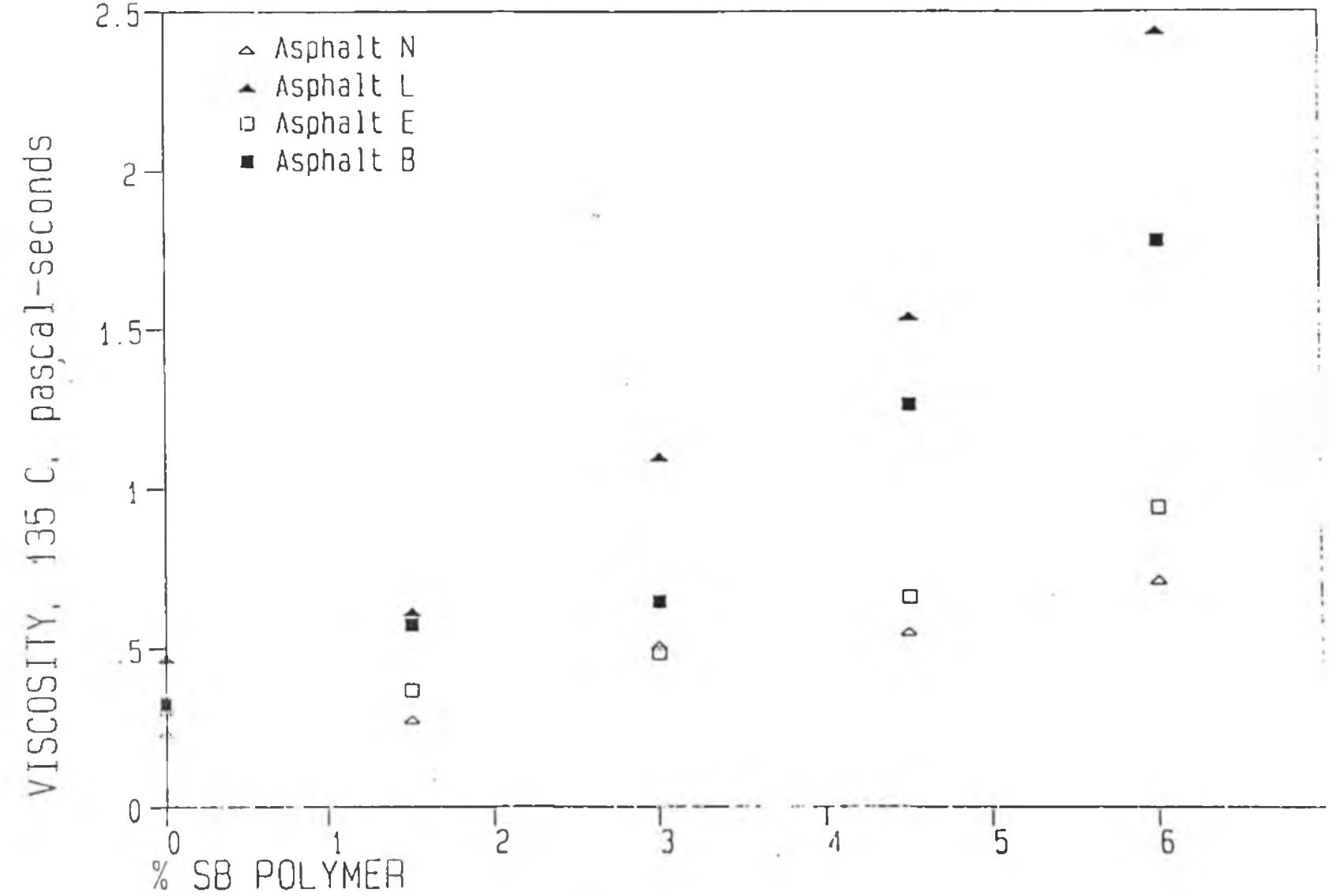


Fig. 8. Transmission electron photomicrograph of a chemically reacted polymer-asphalt blend.

Fig. 9. Viscosities of physical blends of an SB block copolymer in four different asphalts.



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Properties of Rubberised Bitumen from Reclaimed Rubber†

AZEMI BIN SAMSURI*

This paper discusses the properties of rubberised bitumen prepared by physical blending of bitumen with reclaimed rubber powders obtained from either rejected rubber gloves or scrap tyres. Besides reclaimed rubbers, natural rubber latex and synthetic polymer such as ethylene methyl acrylate were also used to prepare the rubberised bitumen. Properties such as penetration number, softening point, work done to break and tenacity were measured; results showed that the properties improved with the addition of rubber. The softening point, tenacity and energy to break increased progressively while penetration number decreased with increasing rubber content. Rubberised bitumen prepared by using glove crumbs produced overall better properties than that using tyre shavings. The properties of rubberised bituminous mixes were also evaluated and compared with those of ordinary bituminous mixes. The results showed that rubberised bituminous mixes produced higher resistance to permanent deformation and dynamic cracking compared with ordinary bituminous mixes.

Some materials are easy to recycle while others are difficult. Thermoplastic products are easy to recycle and can be moulded into products again simply by the application of adequate heat and pressure. In contrast, most rubber products and thermoset plastics are not easy to recycle and cannot be moulded directly into products again because of the three dimensional crosslink network which prevents flow. Thus, most of the scrap rubber products such as used tyres or rubber discards are presently burnt or buried in designated landfill areas. Both methods are environmentally unfriendly. However, by means of a suitable reclaiming process, reclaimed rubber in the form of fine powders (40 mesh or 420 microns) can be produced from these scrap rubber products (tyres, examination gloves, toy balloons, *etc.*). These fine powders can be used to aid processing such as in extrusion and calendering to reduce extrudate swell and shrinkage and thus provide an overall better dimensional stability. Besides processing aids, reclaim rubbers can be used as extenders to cheapen the compounding costs at the expense of slightly poorer physical properties of the final vulcanisates.

Another important area where fine rubber powders find a wide application is in the construction of flexible road pavement. Currently, an ordinary unmodified bitumen which serves as a binder (a substance used to hold the aggregate structure firmly together or to a substrate) in a wearing course is not adequate to meet the ever increasing traffic/

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axle loads. It is well established that flexible pavements need relaxation time for recovery, a phenomenon known as healing[1]. If the traffic is not heavy (off-peak traffic hours), the small stress cracks within an asphalt pavement will tend to heal or close with time. However, under a very heavy traffic condition, the cracks have little time to heal, thus accelerating pavement failure. Apart from heavy axle loads, climatic factors such as high temperatures and intense heat can also accelerate pavement failure through rapid ageing of bitumen. An aged and degraded bitumen is a hard and brittle material which may form cracks easily due to cyclic stresses associated with traffic loads and expansion and contraction due to thermal changes. The cracks formed will eventually lead to premature failures of road surfaces. If precautions and means of overcoming premature road failures are not carried out, the Public Works Department and Highway Authority will continue to pay a very high cost for road maintenance and repairs. Furthermore, driving on defective road surfaces is both uncomfortable and unsafe.

Increasing demands on road surfacings posed by higher traffic density, heavier loads and faster speeds emphasise the need for binders with improved performance. It is in this area that rubberised binders have a role to play. Quite small quantities of rubber improve the cohesive strength of bitumen; the latter becomes tougher and more tenacious than unmodified bitumen[2]. Rubber makes the bitumen less brittle and increases the range of temperatures over which it remains serviceable; the flexibility which rubber imparts allows it to hold more securely to aggregate against displacement forces[2]. The addition of rubber particulate increases the viscosity of the bitumen cement and, thereby, improves the bitumen's film thickness on the aggregates, allowing the hot mix to hold more binder content and at the same time reduce the absorbency of aggregates[1]. This, in turn, can help optimise the binder content to the advantage of the pavement design-engineer.

The studies on the incorporation of rubber and synthetic polymer into bitumen to improve the properties of the binder for road pavement date back to the 1930s[3]. The usage of polymer-modified bitumen to improve the performance of pavement system is now widely adopted in Europe, United States of America and Australia. However, the knowledge and technology regarding the use of natural or synthetic rubber as an additive to bituminous binder are still relatively new in the South East Asian regions. In view of this scenario, colloborative work was undertaken by the Rubber Research Institute of Malaysia (RRIM) and Public Works Department Research Institute (IKRAM) with a view to provide knowledge and information to the local road engineers on the use of natural rubber additive to modify the bituminous binder as a means or an alternative to overcome the problems of premature failure of road pavement.

This paper discusses some of the laboratory studies and limited service trial of rubberised-bituminous mix to explore the usage of fine rubber powders as bitumen modifier in making road pavements. The fine rubber powders were produced from natural rubber examination glove rejects and tyre shavings, respectively. Apart from reclaimed rubber, natural rubber latex concentrate and polyethylene-co-methyl acrylate (EMA) were also used to modify the bitumen. The performance of rubberised-

bitumen based on fine rubber powders obtained from scrap rubber goods was compared with that of rubberised bitumen based on natural rubber latices and also with that of unmodified bitumen.

EXPERIMENTAL

Materials

Four different types of rubber were used *viz.* natural rubber (NR) latex concentrate, pre-vulcanised NR latex, fine rubber powders reclaimed from rejected examination gloves (particle size of 0.5 mm) and tyre shavings (particle size of 0.5 mm). Commercial grade EMA was also used to modify the bitumen (details of technical specifications were not disclosed). Bitumen of 80/100 penetration number was used throughout unless stated otherwise.

Mixing

Mixing was carried out on a laboratory scale using a Hobart mixer at a temperature of 160°C for about 1.5 h. First, the solidified bitumen was heated until it melted and in liquid form. On reaching the required temperature, the bitumen was blended with rubber at rotor speed of 80 r.p.m. The quantity of rubber was varied from 2 parts per hundred of bitumen (p.p.h.b.) to 10 p.p.h.b. Large scale mixing was carried out in a blending tank of 10 metric ton capacity; only the fine rubber powders reclaimed from reject examination gloves were used in the large scale mixes.

Road Trial

A rubberised-bitumen road trial using fine rubber powders from reject gloves and NR latex concentrate was carried out on the N1 Rembau road, Negeri Sembilan. The amount of rubber used was five percent of the binder content. The quantity of rubberised bituminous binder used was five percent by weight of the total mix aggregates. There were two methods of producing the mix. In the first case, the rubberised bitumen was first prepared by preblending fine rubber powders with bitumen in a 10 metric ton capacity tank mixer (as decribed above). Then, the preblended rubberised bitumen was mixed with the aggregates of different sizes at different proportions in accord with gradation SHRP mix design. Mixing of rubberised bituminous binder with the aggregates was carried out in a pugmill by using the batch process. In the second case, instead of preblending the rubber with bitumen, the rubber was added directly to bitumen and aggregates where they were mixed in the same pugmill. Samples were taken from the bituminous mix to prepare the cylindrical test-pieces by using a gyratory compactor which simulated field compaction. A pressure of 240 kPa was applied for 200 revolutions at 135°C. In this investigation, sample designated by SX 20 denoted a dense bituminous mix where unmodified bitumen was used as the binder. SX 20 + NR latex denoted a dense mix prepared by the second method where rubberised bitumen (based on NR latex) was used as the binder. SX 20 + glove crumbs denoted a dense mix prepared by the second method where rubberised bitumen (based on glove crumbs) was used as the binder. SX 20 + preblended glove crumbs denoted a dense mix prepared by the first method where rubberised bitumen was used as the binder based on preblended glove crumbs.

Physical Tests

Penetration number. The penetration number was determined according to *BS 2000: Part 49*, 1983. It is a measure of consistency of a

bituminous material expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known conditions of loading, time and temperature. In this test, the sample was melted and filled in a penetration cup (diameter 55 mm, internal depth 35 mm). Later, the sample was cooled and placed together with a transfer dish in water bath at 25 ± 0.1°C for 1.5 h. The penetration was measured with a penetrometer by means of which a standard needle was applied to the sample under a fixed known load (100 g). The distance (depth) of penetration was measured after 5 seconds of loading.

Softening point. The softening point was determined using ring and ball apparatus according to *BS 2000: Part 58*, 1983 specifications. In this test, a steel ball of specific mass was placed upon a disk of bitumen contained within a metal ring of specified dimensions. The assembled apparatus was placed in a bath of liquid and the softening point was taken at which the bitumen surrounding the steel ball just touched the base of the apparatus.

Energy at break and tenacity. Rubberised-bitumen sample was melted by heating at a temperature of 120°C. The molten sample was poured into three mould brickets until it excessively filled the mould cavity and allowed to cool at 23°C. Once the sample solidified, the excessive material was removed with a hot knife. The sample was conditioned at 23°C for 24 h before testing. The stress-strain measurements on rubberised bitumen samples in a moulded bricket were carried out by using an Instron tensile machine at a temperature of 23°C. The crosshead speed was 500 mm per min. The typical load-deformation curve is as shown in *Figure 1* and *Figure 2* for unmodified bitumen and rubberised bitumen, respectively. The energy to break was determined by integrating the area under the load-deformation curve OYE. In the case of unmodified bitumen, it is difficult to locate the breaking point since the bitumen just continued to flow as shown in *Figure 1*. To overcome the problem, the breaking point was referred to that of the breaking point of the rubberised bitumen.

The tenacity was determined by integrating the shaded area as shown in *Figures 1* and *2*. A straight line was extrapolated from the straight portion of the curve to meet the x-axis. The tenacity is defined by the area bounded by the straight line and the curve in the flow region (unmodified bitumen) or the curve in the 'rubbery' region (rubberised bitumen) as shown by the shaded portion in the two figures.

Marshall Test. The test was originally developed by Bruce Marshall and is described in *BS 598: Part 3*, 1985. This test is used to measure the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus. In this test, a cylindrical specimen (diameter 100 mm, length 60 mm) was compressed diametrically at a constant rate (50.8 mm per minute), at 60°C until failure. The maximum load developed during the test, known as Marshall stability, and the deformation at the maximum load, known as the Marshall flow were measured. Marshall quotient was determined by dividing Marshall stability by Marshall flow.

Indirect tensile modulus and fatigue tests. Both tests were carried out using the materials testing apparatus for asphalt (MATTA) machine as shown in *Figure 3*. The machine consists of a loading frame which has a heavy,

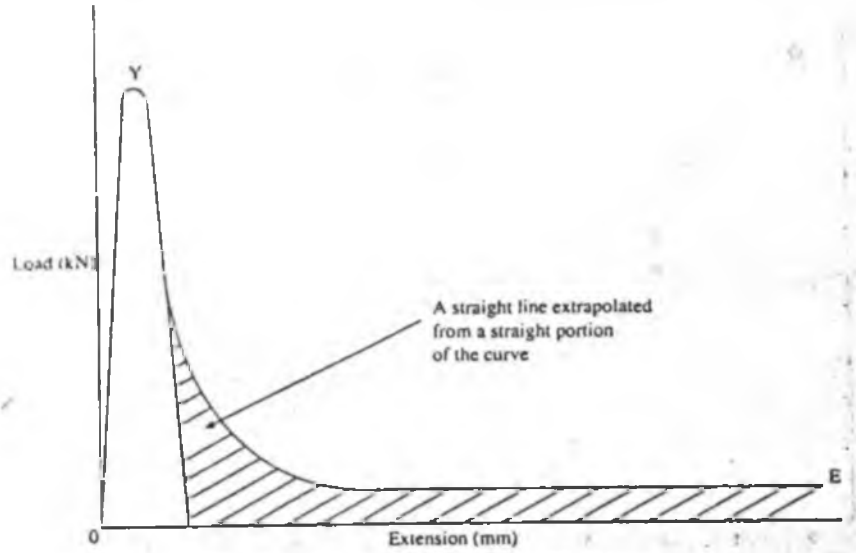


Figure 1. Load-deformation curve of unmodified bitumen.

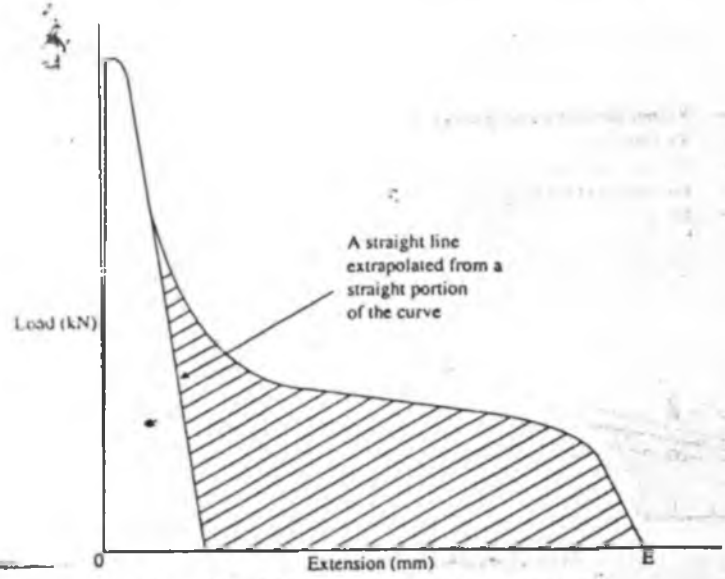


Figure 2. Load deformation curve of rubberised bitumen.

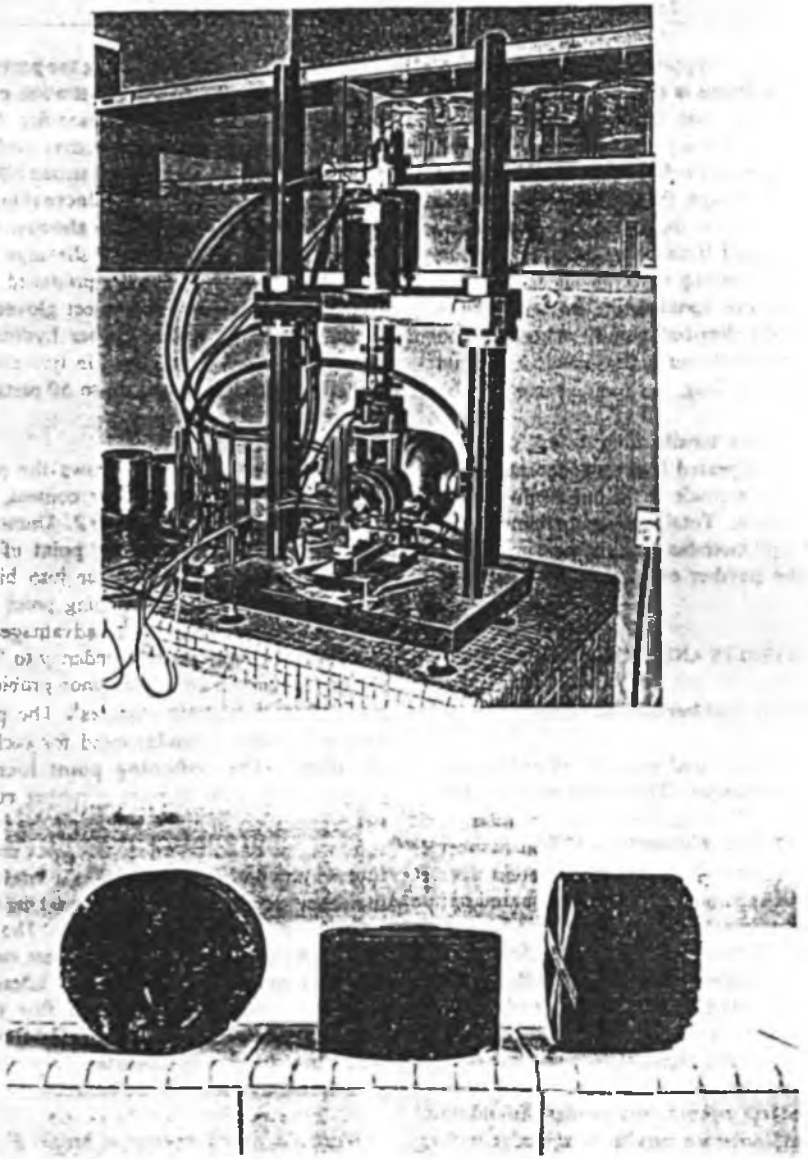


Figure 3. Photographs showing MATTA machine and test-specimen.

flat, baseplate, supported on four levelling screws. The frame is of heavy construction to limit deflection and vibrations which could influence the accuracy of measurements during dynamic repeated loading tests. Loading forces are applied through the shaft of a pneumatic actuator mounted in the centre of the crosshead. A strain gauged force transducer, mounted in line with the loading shaft, measures the force applied to the specimen. The cylindrical specimen (as decribed above) is mounted in jigs that enable either indirect tensile or axial compressive loading.

The indirect tensile fatigue test provides facilities for repeated loading of the sample in indirect tensile mode for a maximum of one million pulses. Total and permanent strain together with modulus are continuously plotted against the number of pulses on logarithmic scales.

RESULTS AND DICSUSSIONS

Properties of Rubberised-bitumen

Effect of type and quantity of rubber on penetration number. The effect of type and quantity of rubber on penetration number is shown in *Figure 4* where penetration number is plotted against rubber content, based on the data shown in *Table 1*. Unmodified bitumen is a soft and viscous material as reflected by its high penetration number, *i.e.* 85.8. The penetration number was affected both by the type and quantity of rubber. All types of rubber showed a similar trend, *i.e.* the penetration number decreased progressively with increasing amount of rubber indicating the material became more viscous and harder. Blending rubber with bitumen results in a binder with improved hardness similar to harder grade bitumen. At more than 5 p.p.h.b. EMA was the most effective in decreasing the penetration as reflected by the lower penetration number compared with rubbers as the modifier. Among the rubbers, fine rubber powders reclaimed from reject gloves and prevulcanised NR latex were very effective in decreasing the penetration. The result also showed that it required twice as much tyre shavings to get the same penetration number produced by the fine rubber powders from reject gloves. This might be due to higher rubber hydrocarbon content in reject gloves than in tyre shavings since the latter contained 40 to 50 parts p.h.r. of carbon black.

Softening point. Figure 5 shows the plot of softening point *versus* rubber content, based on the data shown in *Table 2*. Unmodified bitumen has a low softening point of about 44°C. Incorporation of rubber into bitumen generally increases the softening point of the modified binder which has an advantage of the possibility of reducing the tendency to 'bleed' in hot weather which is a common problem for pavements in warmer climates[4]. The plot in *Figure 5* shows a similar trend for each type of rubber. The softening point increased progressively with increasing rubber content. EMA modified bitumen produced the highest softening point followed by NR latex and fine rubber powders (reject gloves), while tyre shavings modified bitumen produced the lowest softening point among the rubbers. The result again showed that it required at least twice as much or more tyre shavings to obtain the softening point produced from fine rubber powders of reject gloves which might indicate that, it is the rubber hydrocarbon content which predominantly modifies the bitumen.

Work done and energy at break. Figure 6 shows the load-deformation characteristics of rubberised bitumen as well as the unmodified

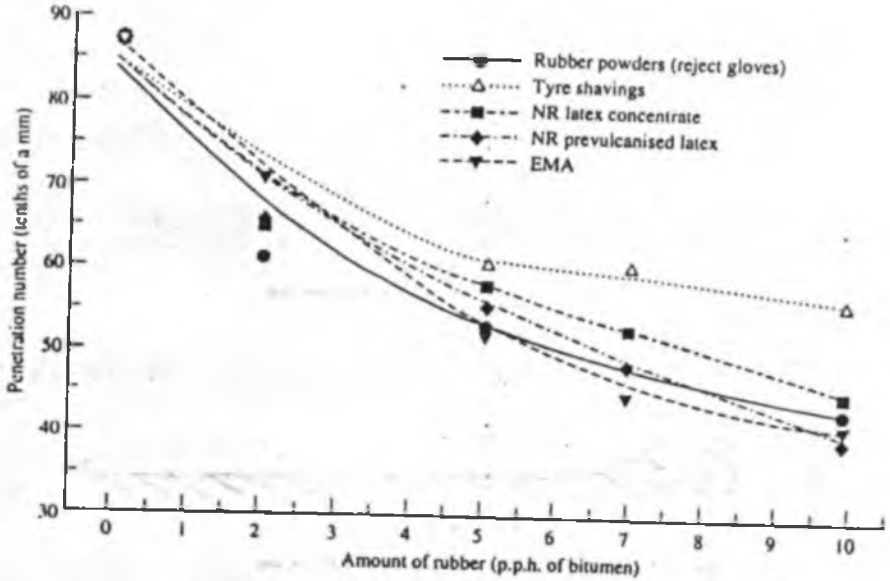


Figure 4. Penetration number vs amount of rubber.

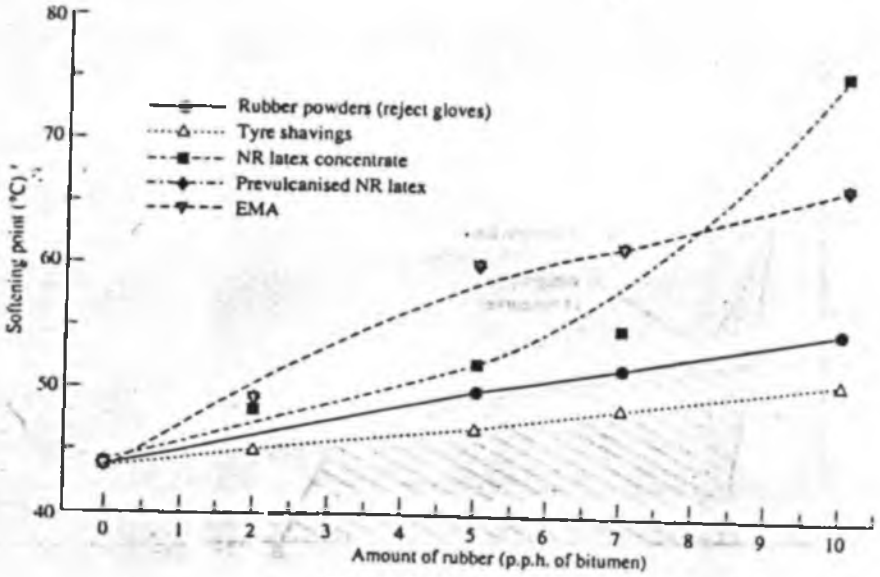


Figure 5. Softening point vs amount of rubber.

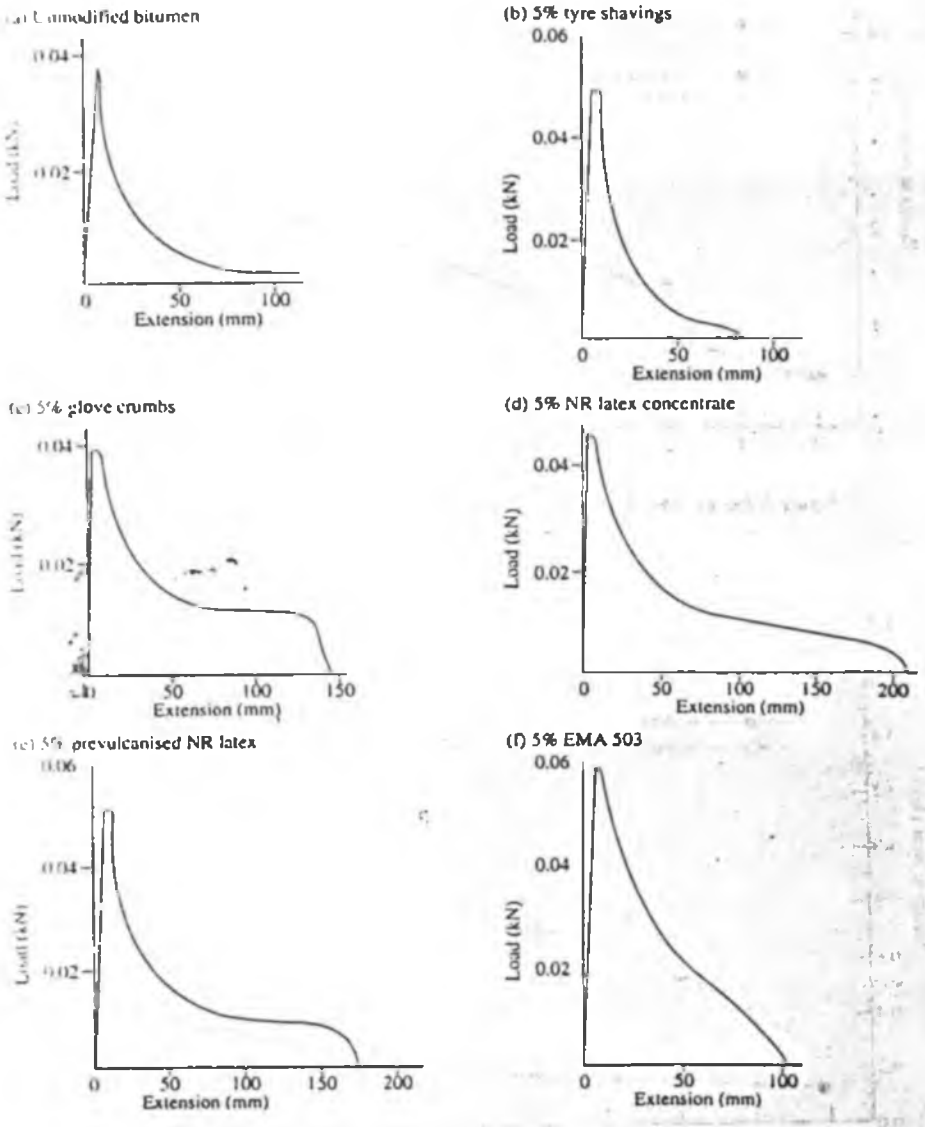


Figure 6. Load displacement characteristics of different types of rubberised bitumen reproduced from the chart recorded during the experiment.

TABLE 1. PENETRATION NUMBER (TENTH OF A MM) OF RUBBERISED-BITUMEN

Amount of rubber (p.p.h. of bitumen)	2	5	7	10
Rubber powders (reject gloves)	60.4	52.0	47.6	42.6
Tyre shavings	64.4	60.2	59.4	54.6
NR latex concentrate	64.4	57.0	51.8	44.4
Prevulcanised NR latex	64.8	54.8	47.6	39.4
EMA	69.2	51.2	44.2	41.0

Penetration number of unmodified bitumen = 85.8 (tenths of a m.m.)

TABLE 2. SOFTENING POINT (°C) OF RUBBERISED-BITUMEN

Amount of rubber (p.p.h. of bitumen)	2	5	7	10
Rubber powders (reject gloves)	47	50	52	55
Tyre shavings	45	47	48	50
NR latex concentrate	47	52	56	75
Prevulcanised NR latex	48	60	62	66
EMA	48	60	62	66

Softening point of unmodified bitumen = 44°C

bitumen and EMA-modified bitumen. The work done or energy to break was determined from the area under the load-deformation curve. The load-deformation curve was affected by the type of rubber (the amount used in each case was 5 p.p.h.b.). Unmodified bitumen produced a low maximum load after which the load decreased continuously producing a curve that looks like a rectangular hyperbola which asymptotes with the x-axis as the unmodified bitumen just continue its flow during deformation. In the case of rubber-modified bitumen, the maximum load increased markedly after which the load decreased progressively to a value about one third of its maximum load (in the cases of fine rubber powders from reject gloves and NR latices) before producing a 'rubbery' plateau region as a consequence of some degree of resistance to deformation attributed to the elastic behaviour of the rubber. Bitumen modified with tyre shavings and EMA did not produce broad plateau region; perhaps these materials are less rubbery since tyre shavings are filled with high concentration of black fillers and EMA is a plastic. Nevertheless, all modified bitumen binders

showed a definite breaking point unlike unmodified bitumen which continued to flow like a thin thread even after the crosshead had reached its maximum permitted distance travelled.

The plot of work done or energy to break *versus* quantity of rubber is as shown in *Figure 7*. The unmodified bitumen when compared at the same breaking deformation as that of rubberised bitumen has the lowest energy, about 0.46 J, indicating that the material is weak and easily deformable. Addition of rubber into bitumen improved the energy to deformation significantly as reflected by the increase in the work done (energy) to break. Among the rubbers used, NR latex concentrate is the most effective in enhancing the energy to deformation, followed next by fine rubber powders from reject gloves. Addition of 5 p.p.h.b. of fine rubber powders from reject gloves, increased the energy to deformation by a factor of about four compared to that of unmodified bitumen. Thus, the results show that rubberised bitumen is very effective in enhancing the energy to deformation.

Effect of the rate of deformation on energy to break. The viscoelastic behaviour of rubber-modified bitumen was investigated by performing tensile stress-strain measurements at different rates of deformation at 23°C. This study is useful since in practice, the road pavements are subjected to different rates of cyclic loading as a consequence of different masses and accelerations of traffic axle loading. In this study, rubberised bitumen containing 5 p.p.h.b. of fine rubber powders reclaimed from reject gloves was subjected to different rates of deformation by pulling a sample in a mould bricket at different crosshead speeds ranging from 10 to 500 mm per minute using an Instron tensile machine. A similar exercise was also carried out for the unmodified bitumen. The results are shown in *Figure 8* where the energy to break is plotted against crosshead speed. Generally, the energy to break increased with increasing rate of deformation. The energy to break for both unmodified bitumen and rubberised bitumen increased by a factor of about four by increasing the crosshead speed from 10 mm per minute to 500 mm per minute. This is clearly a manifestation of the viscoelastic effects of the material. At any rate of deformation, the energy to break of rubberised bitumen is always higher than that of unmodified bitumen by a factor of about two at the lowest rate and by a factor of about four at the highest rate of deformation.

Tenacity. High tenacity is required for bitumen to be used in drainage mixes for good and long service performance[5]. A plot of tenacity *versus* amount of rubber is as shown in *Figure 9*. Unmodified bitumen produced a low tenacity value, 0.17 J. Addition of rubber into bitumen improved the tenacity of the modified binder. NR latex concentrate appears to be the most effective in enhancing the tenacity of the modified binder, followed by fine rubber powders from reject gloves.

Properties of Rubberised-bitumen Mix

Marshall test. The Marshall test can be used to predict the resistance to permanent deformation of bituminous mixes on the basis of empirical relationships. The Marshall quotient has been found to correlate with permanent deformation better than either the individual value of stability or flow. The results of the Marshall test are shown in *Table 3*. The addition of rubber give rise to an increase in the Marshall stability and quotient. The increase varies with the form of rubber used and the method of incorporating the rubber into

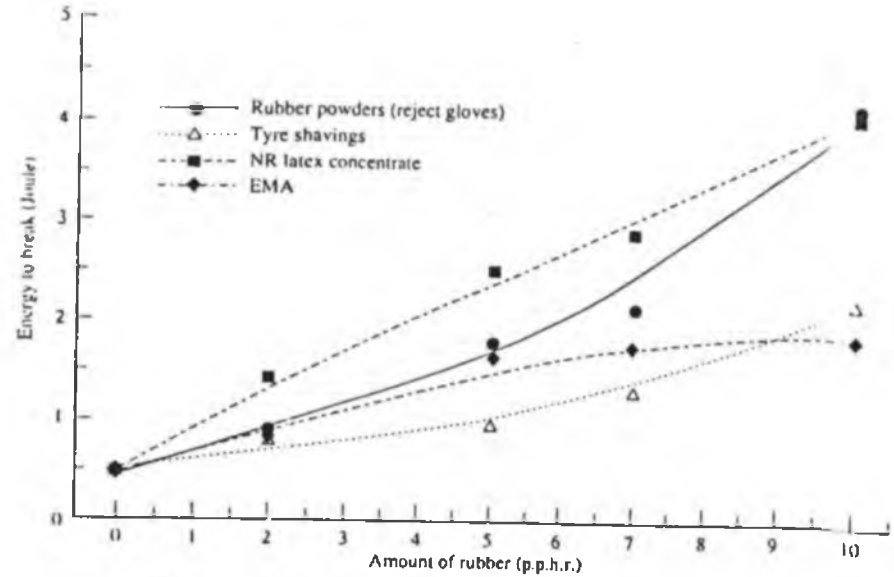


Figure 7. Energy to break vs amount of rubber (crosshead speed 500mm/min at 23°C).

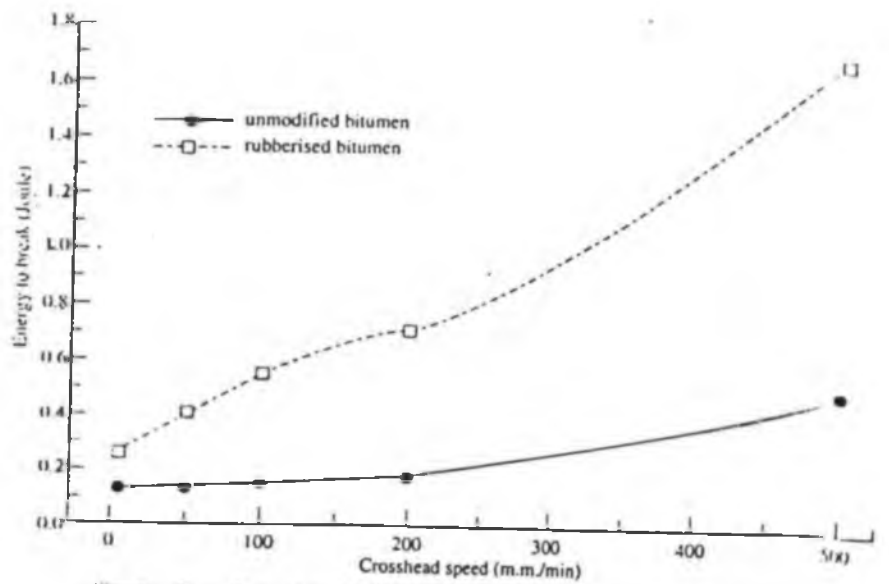


Figure 8. Energy to break vs crosshead speed (effect of rate on energy to break at 23°C).

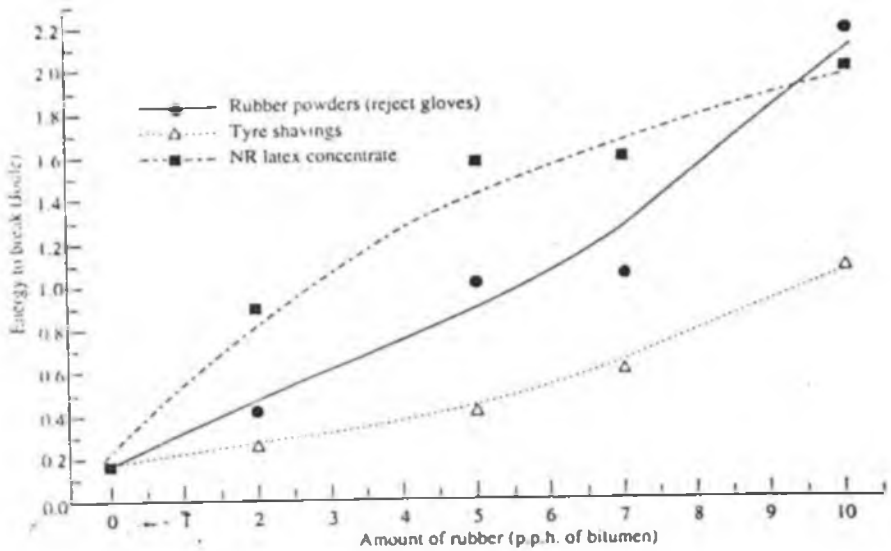


Figure 9. Tenacity versus *amount of rubber (crosshead speed 500 mm/min at 23°C).*

bitumen. Mixes produced using bitumen pre-blended with fine rubber powders clearly show the greatest improvement, causing an increase in the Marshall stability by more than two folds and in the Marshall quotient by nearly three folds compared to the normal unmodified bituminous mix (SX 20). Direct mixing of rubber with bitumen and aggregates (*i.e.* mixing *in situ*) in the pug mill produced rubberised bituminous mixes with an increase in Marshall stability by 1.4 times and in the Marshall quotient by 1.7 times higher than unmodified bituminous mix. Thus, pre-blending of bitumen with rubber is a necessary step in order to produce an efficient rubberised bitumen binder probably due to adequate and efficient rubber dispersions in the bitumen phase.

Indirect tensile modulus test. The indirect tensile modulus test is a quick, non-destructive method of measuring the stiffness of bituminous mixes under dynamic loading conditions to which the material is subjected in practice. In general, the higher the stiffness, the better is its resistance to permanent deformation. *Table 4* shows the results of indirect tensile modulus test. The effectiveness of the pre-blended fine rubber powders is again evident in the indirect tensile modulus test. The elastic modulus of the samples produced using the pre-blended rubberised bitumen is approximately three times greater than that of the unmodified bitumen samples which is in accord with the Marshall quotient results. Thus, the presence of binder modified by preblending with fine rubber powders improved the

TABLE 3. RESULTS OF MARSHALL TEST

Mix	Marshall stability (kN)	Marshall flow (mm)	Marshall quotient (kN/mm)
SX 20	7.62	5.77	1.32
SX 20 + NR latex	13.42	5.44	2.47
SX 20 + glove crumbs	10.90	4.76	2.29
SX 20 + pre-blended	16.12	4.89	3.30

TABLE 4. RESULTS OF INDIRECT TENSILE MODULUS TEST

Mix	Elastic modulus (MPa)
SX 20	2 379
SX 20 + NR latex	2 932
SX 20 + glove crumbs	3 175
SX 20 + Pre-blended glove crumbs	6 579

resistance to permanent deformation by nearly three times than that of unmodified bituminous mixes.

The high elastic modulus of rubberised bituminous mixes has another advantage, *i.e.*, it improves the resistance to rutting. Rutting is accumulation of permanent strain which occurs in two phases. Initially, it is that of densification of the mix, followed by plastic flow of the mix. Rutting usually occurs while climbing lanes and also near roundabouts where vehicles travel at a very low speed. Rutting of road surfaces is hazardous as it disturbs the control of vehicle passing over it. It was reported by the Public Works Department that the addition of natural rubber as an additive to bituminous binder improves the resistance to rutting in the wheel tracking test by a factor of about six compared to unmodified bituminous mix[6].

Indirect tensile fatigue test. The results of indirect tensile fatigue test are shown in *Table 5*. When subjected to repeated indirect tensile loading of 2000 Newton, all samples that had been modified with rubber show higher resistance to fatigue stress. The preblended fine rubber powder samples again performed the best in this fatigue test. While it required more than twice and four times the number of load pulses to reach a permanent strain of 10^{-3} for the directly added latex and rubber powder samples, respectively in comparison to the unmodified bitumen samples (200 pulses); no

TABLE 5. RESULTS OF INDIRECT TENSILE FATIGUE TEST

Mix	Appropriate number of load pulses to reach permanent strain of 10^{-3}
SX 20	200
SX 20 + NR latex	550
SX 20 + glove crumbs	950
SX 20 + Pre-blended glove crumbs	*

*Test terminated after 1000 pulses. No permanent strain was recorded by then.

permanent strain was induced in the pre-blended rubber powder samples after 1000 pulses. Thus the results again shown the better performance of rubberised bituminous mixes than unmodified bituminous mixes in terms of resistance to permanent deformation and fatigue cracking.

Cost effectiveness. Table 6 shows an estimated cost to produce a road pavement section having a length of 200 m, width of 7 m and thickness of 0.05 m base on different types of modified binders and that of unmodified bitumen. The amount of pre-mix required is about 168 metric tons based on 5% binder (by weight). The cost shown in the table includes the labour, processing, construction, raw materials, and overheads, but excludes transportation cost.

The total cost to make that section of road pavement using unmodified bitumen is about RM14 280 (RM = Malaysian dollar) or about US$5712. If fine rubber powders reclaimed from reject gloves are used to modify the bitumen, the total cost is about RM16 113 (US$6445.20). An increase in cost of about 13%. The cost of rubber powders reclaimed from reject gloves is about RM1.80 per kg.

If NR latex concentrate is used to modify the bitumen, the total cost to make a similar road pavement is about RM19 645 (US$7858). An increase in cost of about 35% compared to unmodified bitumen.

IF EMA is used to modify the bitumen, the total cost is about RM25 045 (US$10 018). An increase in cost of about 75%.

Among the three modifiers, rubber powders reclaimed from reject gloves is the most cost effective. The Marshall quotient of preblended rubberised bitumen is about three times higher than that of unmodified bitumen indicating that the life span of rubberised bitumen pavement is about three times longer than unmodified bitumen pavement[6]. Thus, the effective cost of rubberised bitumen pavement is actually RM5371 (*i.e.*, RM16 113 ÷ 3), about 2.7 times cheaper in terms of maintenance cost.

DISCUSSIONS

The results discussed above favour the use of rubberised bitumen as an alternative bmder instead of unmodified bitumen because of the improvement in the physical properties of both

TABLE 6. ESTIMATED COSTS TO PRODUCE ROAD PAVEMENT SECTION (200 m × 7 m × 0.05 m) USING DIFFERENT TYPES OF MODIFIED BITUMINOUS BINDER

Type of binder	Cost	
	RM	$US
Unmodified bitumen	14 280	5 712
Rubber powders (reject gloves)	16 113	6 445
NR latex concentrate	19 645	7 858
EMA	25 045	10 018

RM = Malaysian ringgit (dollar) RM2.50 = US$1.00

the modified binder and that of the rubberised bituminous mixes. Rubberised bitumen has a better temperature susceptibility and less susceptible to temperature changes compared to unmodified bitumen. Rubberised bitumen also has a better resistance to deformation and higher tenacity compared to unmodified bitumen. Rubberised bituminous mixes are predicted to last at least three times longer than unmodified bituminous mix based on the Marshall quotient and elastic modulus results. The question now is the type of rubber most appropriate to use to modify the bitumen. Among the rubbers used, it appears that both NR latex concentrate and pre-vulcanised NR latex are the most effective in enhancing both the physical properties of the modified binder and rubberised bituminous mixes. However, other relevant factors such as the environment, ease of processing and cost should be considered before deciding the suitability of the rubber.

On a laboratory scale it is easy to blend NR latices with bitumen where the experiment can be easily controlled and monitored. However, on a large factory scale, it is not very easy to control and handle the problems associated with foaming, steaming, liberation of ammonia gas and furthermore, if improper stabilisers are used, gellation of the latex may occur due to heat at high temperatures and mechanical agitation. If gellation of latex occurs pre-blending with bitumen is not possible. The liberation of ammonia gas mentioned earlier will also cause pollution to the environment and needs proper effluent treatment to combat the problem.

On the other hand, fine rubber powders reclaimed from reject gloves offer a few advantages if they are used as modifier. The advantages with regards to the environmental factors are that it helps to minimise the problems associated with disposing reject gloves and it reduces the problems of pollution associated with burning, burying or disposing discarded gloves into rivers or seas.

The advantages concerning processing and cost are that it is easy to blend rubber powders with bitumen without any problems provided that care is taken to choose the correct temperature and speed of mixer; and the cost of rubber powders obtained from reject gloves

is cheap, about three times cheaper than NR latex concentrate.

In view of the greater advantages of rubber powders than NR latices in terms of environment friendly, ease of processing and handling and cost of material, rubber powders reclaimed from reject gloves is a very suitable material to modify the bitumen to improve the physical and mechanical properties of the binder and the rubberised bituminous mixes.

CONCLUSION

Addition of rubber into bitumen improves both the physical and mechanical properties of the binder and rubberised bituminous mixes, in particular, in terms of temperature susceptibility and resistance to permanent deformation. Thus, this will lead to an improvement in the service life of the road pavement and hence the overall maintenance cost will be very low.

ACKNOWLEDGEMENT

The author wishes to convey his sincere appreciation to Ir. Hj. Ab. Latif and Ir. Mohd Hizam of IKRAM for useful discussions and comments and also for road trials and testings on bituminous and rubberised bituminous mixes at the Pavement Laboratory of IKRAM.

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Stress Relaxation Behaviour of Natural Rubber Vulcanisates Containing Non-rubber Constituents

A.B. OTHMAN*#, G.A.W. MURRAY** AND A.W. BIRLEY**

Natural rubber (NR), which is derived from latex of Hevea brasiliensis *tree, contains about 3%–5% of non-rubber constituents. The presence of these non-rubber constituents, which are mostly proteinaceous materials, affect the sensitivity of rubber to water, thereby affecting properties such as elastic modulus and stress-relaxation.*

Studies using vulcanised unfilled NR showed that changes in relative humidity of the sample gave variations in elastic modulus and stress-relaxation of vulcanisates. The variability was due to the presence of certain types of amino-acid; their presence increases the elastic modulus and reduces the rate of relaxation of NR vulcanisates. These were due to the formation of ionic crosslinks; drying the rubber intensifies the ionic interactions and effectively increases the apparent crosslink density, thereby reducing the rate of relaxation.

Commercial natural rubber is produced in different grades; this arises from the different sources of latex coagulum and different methods of handling rubber. Conventional grades (*e.g.* Standard Malaysian Rubber) are processed by coagulating the latex using acids followed by washing and drying the rubber, whilst the processing of deproteinised rubber (DPNR) involves an extra step whereby the naturally occurring proteins are largely removed prior to coagulation[1,2]. Hence, DPNR contains lower amounts of nitrogenous non-rubber constituents than conventional grades.

It has been reported that rubber which has been processed in different ways show a marked variation in properties due to the presence of different types and/or amount of non-rubber constituents. For instance, proteins are believed to affect creep; Smith observed that the removal of proteins from DPNR reduces the rate of creep[3]. Knight and Tan[4] reported that the presence of proteins caused the modulus of rubber vulcanisates to increase, while amino-acids affect the storage hardening of the raw rubber[5]. Storage hardening is also affected by inorganic materials[6]. Certain nitrogenous bases and fatty acids take part in the sulphur vulcanisation reaction which subsequently affects the properties of rubber vulcanisates[7]. The presence of non-rubber constituents also affect the sensitivity of the rubber to water, thereby properties such as elastic modulus and stress relaxation[8].

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Recycled Rubber With Asphalt As A Membrane For Pavement Rejuvenation A Progress Report.

By.

ROBERT E. (BOB) Winters.

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PAPER NO. 56

RECYCLED RUBBER WITH ASPHALT AS A MEMBRANE FOR PAVEMENT REJUVENATION

A PROGRESS REPORT

BY

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TO BE PRESENTED AT:

112TH MEETING OF THE
RUBBER DIVISION
AMERICAN CHEMICAL SOCIETY
CLEVELAND, OHIO
4 - 7 OCTOBER 1977

INTRODUCTION

In the early 1960's a new method for utilizing recycled scrap tire rubber with asphalt was conceived. This paper is a progress report on the growth of this concept.

The material, known as OVER-FLEX®, was invented by Charles H. McDonald of Phoenix, Arizona. During his years as a civil and materials engineer for the Bureau of Public Roads (now the Federal Highway Administration) Mr. McDonald searched for an effective procedure to correct flexure cracking in pavements. This type of distress is manifested by a map pattern or "alligator" cracking. The cracks will reflect through a conventional overlay of asphalt concrete. The only sure solution to the problem is complete and costly reconstruction with a new base and surface engineered for todays traffic and wheel loadings.

PREVIOUS CONCEPTS

Most rubber-asphalt technology had heretofore been directed toward making conventional overlays more elastic by the addition of small percentages (in the range of 2 to 5 percent by weight) of virgin polymers, reclaimed rubbers or ground vulcanized scrap. The fact that these concepts never became widely used is testimony to their lack of sufficient improvement in in-place properties to justify the cost of the added rubber.

A SOLUTION IS FOUND

McDonald reasoned that high percentages of rubber were needed to be effective (25 percent plus, by weight of the asphalt). He found that this concept was not only effective but could also be very economical if the composition were placed as a thin but very elastic membrane over severely cracked pavements. The performance of these membranes in full scale field tests of over nine years duration has proven that it is an effective procedure for correction of flexural cracking in pavements. When used as a surface treatment, or seal coat, a dressing of rock chips is added to the fresh surface to protect the membrane from the action of traffic, as well as providing a non-skid, all-weather surface. When used as a membrane between a badly cracked pavement and an overlay or leveling coarse, not only flexure cracking but thermal or shrinkage cracking is also arrested.

The granulated vulcanized scrap rubber is primarily an SBR-NR blend ground to a minus 16, plus 25 mesh size. The rubber granules and paving grade asphalt are reacted at high temperature to form a composition that is tough and elastic.

This very viscous material required the development of specially designed distributors with internal mixing equipment for proper placement and workmanship. The Sahuaro Petroleum and Asphalt Company of Phoenix, Arizona developed this

equipment and the technology for proper field application. They are responsible for marketing this product nationwide.

GOVERNMENTAL SUPPORT

Mr. McDonalds' process is the subject of a Federal Highway Administration Implementation Package titled "Rubber-Asphalt Binder For Seal Coat Construction". Exhaustive research of the test projects placed by the Arizona Department of Transportation, the City of Phoenix and other Arizona communities, led to this publication which encouraged other states and user agencies to test this remarkable new material for themselves. Demonstration Projects funded by the Federal Highway Administration with the support of the Environmental Protection Agency, entitled "Project No. 37, Discarded Tires in Highway Construction" have been placed in 18 states to date with many more scheduled for completion next year. Several other rubber-asphalt products were proposed for this Demonstration Project, but were disqualified as unproven and experimental when compared to the McDonald Composition.

CRYOGENIC AND AMBIENT RUBBER GRINDING

The vulcanized crumb rubber from worn tires is processed to the desired mesh size by several methods. Cryogenic grinding is one method used. The tire rubber, which has been reduced to minus 7mm in size by ambient equipment, is sprayed with liquid nitrogen in an insulated conveying chamber. The frozen

rubber is then ground in a high speed hammermill and subsequently sized with any extraneous materials such as tire carcass residue removed by air separation. Conventional screening equipment can be employed as long as care is taken to prevent the buildup of moisture from condensation as the frozen rubber particles thaw. Moist rubber and hot asphalt are to be avoided for obvious reasons. Conventional cracker mills, rotary cutters and hammermills have all been successfully employed for ambient size reduction. Magnets and other de-contamination equipment as well as screening machines are employed. The machinery in a conventional rubber reclaiming plant can be used as long as the granulated crumb rubber is left in its vulcanized state. The rubber granules for use in this product are not to be de-vulcanized. De-vulcanization adversely affects the elasticity of the in-place product.

CORNER CUTTING TO BE AVOIDED

Some ease of application can be obtained through the use of a portion of de-vulcanized (or de-polymerized) rubber crumb, at the expense of product quality. This compromise is unnecessary and ill-advised. Previous compromises of in-place properties in this field appear to have retarded or arrested the wide spread use of such products. The specially designed distributors together with the addition of a small percentage of a high boiling point diluent to the reaction product have provided for ease of application without a compromise of properties.

OTHER USES

The performance of the material as a water barrier has been demonstrated on bridge decks, pond and canal linings and roofing. Other uses and potential justifying experimental projects include its use:

1. As an effective crack sealer for maintenance.
2. For control of expansive clay subgrades under existing highways.
3. As a low volume road placed directly on compacted native soils.

VOLUME USE AND ADVANTAGES

To date almost 5000 kilometers (over 3000 lane miles) of the rubber-asphalt composition have been applied to highways, city streets, airports and other paved surfaces. Almost 16 million kilograms (over 35 million pounds) of granulated vulcanized scrap rubber from tires has been used. The increasing demand for this product will not only provide an outlet for the millions of scrap tires discarded each year, but will improve the life expectancy of our roads and highways in the bargain. These savings can be translated into tax dollars we all must pay to support the maintenance of our paved surfaces.

SUMMARY

The savings in asphalt and other job related fuels and energy is an impressive two-thirds, when compared to the thicker sections of conventional materials necessary to provide comparable service. The petroleum and energy savings when added to the other attributes of this product, add up to a very attractive incentive for the use of this proven material.

We will now screen a film on the subject which was produced for the public works field. I trust it will help to illustrate the subject.

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Reinforcement Of Asphalt & Tar By Elastomer Addition. I

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Rubber world December 1969

Reinforcement of asphalt and tar by elastomer addition

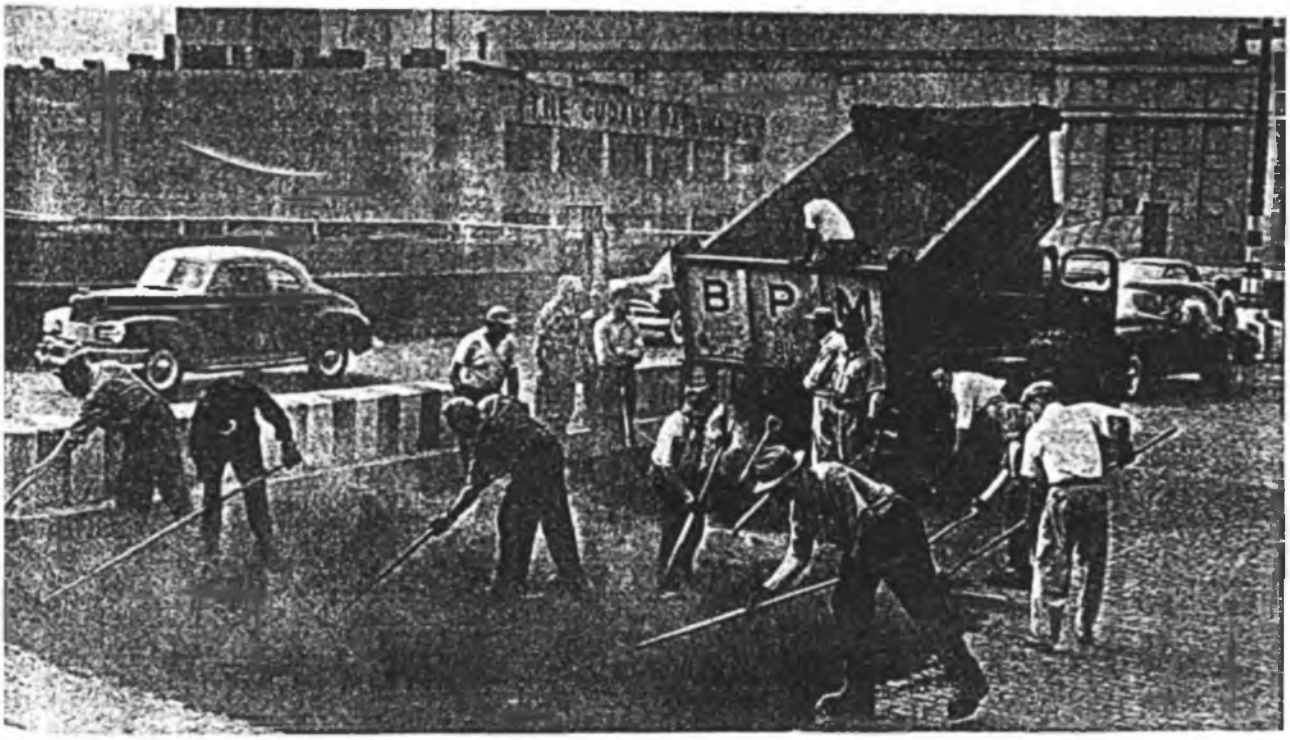
E. A. Sinclair and K. E. Bristol
The Goodyear Tire & Rubber Co.
Akron, O.

In the U.S., at least 5,000 miles of city streets, township roads, and county, state, and federal highways have been resurfaced with bituminous materials containing rubber. Data collected to date from these resurfacings clearly show that rubber increases durability and decreases maintenance. A project in King County, Wash. is typical: 10 years ago county officials resurfaced a 12-mile stretch of road, half of it with ordinary asphalt; the rest with rubberized asphalt. The rubberized section still does not require maintenance; while the other section has twice needed resurfacing.

In addition to a longer use-life, rubberized bituminous surfaces can also be applied thinner than conventional surfaces. In 1965 in Huntington, Ind., two bridges were repaired with a SBR-in-asphalt binder composition, which did not add much weight to the arches spanning the river. Although nearly 9,000 vehicles cross the bridges daily, the surfaces have required virtually no maintenance. This is also important for city streets where repeated resurfacings have significantly reduced curb height. Other benefits derived from rubber-in-bitumin road surfaces:

- Skid resistance is improved through increased aggregate retention and elimination of bleeding.
- Traffic disruptions are minimized because rubberized surfaces may be reopened substantially quicker than conventional asphalt pavements.
- There is less pavement cracking, probably owing to increased ductility at low temperature and decreased temperature susceptibility.

Tars are also being reinforced with rubber. For example, butadiene-acrylonitrile copolymers (NBRs) reinforce coal tar and provide a binder for paving that will resist the solvent action of jet fuel, gasoline, and oil. NBR is also helping the U.S. Air Force overcome a major maintenance problem, reduce upkeep cost, and protect expensive equipment at sev-



Smoke, men, and rubber, a theme catching on with highwaymen. Here, pavers resurface the cobblestones of N.Y.'s West Side Highway with an NR-asphalt mix.

Table 1. Evaluation of different polymers in asphalt cement from Smackover Crude.

Type Polymer	None	NR[a]	NR[a]	Reclaim[b]	Reclaim B[c]	CR[d]	IR[e]	IR[e]	SBR[f]	SBR[f]	SBR[g]
% Polymer (dry)	None	3	5	5	5	3	3	5	3	5	5
Penetration at 25°C	72	58	47	76	66	70	65	66	65	60	57
Ductility at 4°C, cm	5.5	8.5	7.2	7.0	6.5	23	9.0	6.5	150 +	150 +	150 +
Softening Point, °C	47.8	55.6	61.5	49	49.5	50	57	62	53	63.5	61.5
Toughness, in.-lb	23	75	122	30	35	66	42	46	68	115	164
Tenacity, in.-lb	8	50	83	11	17	46	15	16	41	76	130
Elongation, in.	26 +	4.2	3.2	3.3	6.8	7	26 +	26 +	26 +	26 +	26 +

[a] High solids, high gel NR latex.
[b] 50/50 natural/synthetic reclaim.
[c] Non-staining whole tire, peptizer-type reclaim.
[d] Polychloroprene latex, Neoprene 735.
[e] Cis-polyisoprene latex, Shell 700.
[f] High solids, high Mooney, low (4%) gel, cold SBR latex, Pliopave L170.
[g] Same SBR, different lot of Smackover Asphalt than used for other blends.

eral military and domestic air fields. The rubber provides the cohesiveness that prevents the surface from breaking up and releasing aggregates, which could be sucked into jet engines.

Rubber-in-bituminous cost

Installation cost of asphaltic concretes range from $10–20/ton, depending upon location, size of project, type aggregate, and other factors. The rubber increases material costs $1.50–2.50/ton, depending upon asphalt content and % rubber used. In asphalt (emulsion) seal coatings, addition of latex increases the initial cost by about $0.02 per sq yd, resulting in a total seal coat cost of $0.10–0.15 per sq yd.

Maintenance costs for non-rubberized asphalt pavement have made it possible for officials in King County (Wash.) to amortize a rubberized pavement in 2–3 years. Further, the rubberized paving is proving to be good with little maintenance for a decade, resulting in substantial additional savings.

Bitumen classification

Asphalt and tars are used extensively in highway paving, roofing, paper lamination, and other industrial uses. By chemically or physically treating these unmodified materials, their behavior and usefulness can be improved considerably.[1] In fact, certain polymers can improve bitumens having a wide range of physical properties and chemical composition.

Actually, the term bitumen designates a wide range of mineral substances consisting principally of mixtures of complex hydrocarbons varying from liquids to solids. Our work mainly involved paving-grade bitumens: asphalt cements of petroleum origin —i.e., the distillation residues of crude oil refining; and naturally occurring deposits. Coal tar is produced by the destructive distillation of bituminous coal.

Asphalt cements vary considerably in consistency and composition. And although no successful method of classification has yet been devised for crude oils (1),[2] they are roughly grouped as paraffinic or asphaltic base, or mixtures of these. There is a general chemical classification of asphalts as paraffinic, naphthenic, and aromatic.

Gruse and Stevens (2) report that changes in temperature susceptibility and weathering correlate with the source of asphalt. Heat and exposure change the aromatic type most, the naphthenic next, and the paraffinic least. Geographically, Californian crude oils undergo the greatest change, followed by Gulf Coast and Mexican, with Mid-Continent having the least change. Traxler reports that the ratio of "resin + cyclics" to "asphaltenes + saturates" appears to be helpful in explaining the resistance of paving asphalts to hardening by oxidation and volatilization (3).

Several methods are used for chemically fractionating or analyzing asphalts (4, 5, 6). Rostler and White have calculated ratios of chemical fractions to durability for 119 asphalts (4, 7, 8, 9). They report a low ratio (less than 1.4) of "most reactive" to "least reactive" components for asphalts having good durability.

Asphalt manufacturers, the paving industry, and ASTM use physical properties rather than chemical analysis to characterize asphalts. Cements are specified by penetration grade or viscosity; these properties are related to average molecular weight. Penetration is inversely proportional to viscosity; however, a given penetration-grade asphalt will vary considerably in absolute viscosity, depending upon crude source. Therefore, asphalts are also classified as high or low viscosity types, and there is a trend toward replacing penetration specification with viscosity. Rubber improves the different penetration grades, high and low viscosity types.

Coal-tar properties also range widely owing to variations in composition.[3] Principally, they are classified by viscosity and specific gravity. A federal specification calls for blending rubber with "high temperature, straight run residual coal tar of the coke oven variety." This type of RT-12 tar and acrylonitrile-butadiene rubber (NBR) was used for most of our work with tar.

Blending methods

Rubbers tested in bitumen have taken about every conceivable form: crumb, powder (10), solution, latex, and even liquid polymers. Blending time varies from 18 hrs,

Article presented at May '69 meeting of Rubber Chemistry.

[1] Two main deficiencies are temperature susceptibility and durability.

[2] Numbers in parentheses refer to bibliography at end of article.

[3] Specifications for 14 tars are listed in ASTM D490-47 (1951).

as recommended by one crumb supplier (11), to 5 min for a liquid rubber (12). When the rubber, aggregate, and binder are added directly to a pug-mill, mixing time is limited to about one min to conform with hot mix preparation procedures. However, the mixture remains hot for a much longer time.

Very thorough and rapid dispersion can be obtained by adding latex to the hot bitumen. In the laboratory we added the latex dropwise from a separatory funnel while stirring with a propeller stirrer. Depending upon rubber solids, temperature, and batch size, all the water was expelled, and the blending completed in 30–120 min. A similar system can be used for latex-modified, production-size batches and for powders, liquid polymers, and rubber cements.

For production batches (Fig. 1) we recommend introducing the latex into the hot bitumen line just ahead of the line's discharge into an open tank (13). This one-tank system with a spray bar has been very satisfactory, but a separate defoaming tank can be used. The latex may be added by pump, or air pressure, or by gravity feeding into the suction arm of an eductor. The bitumen is recirculated until all the latex is added; agitation is continued until all the water is expelled, and periodically during storage.

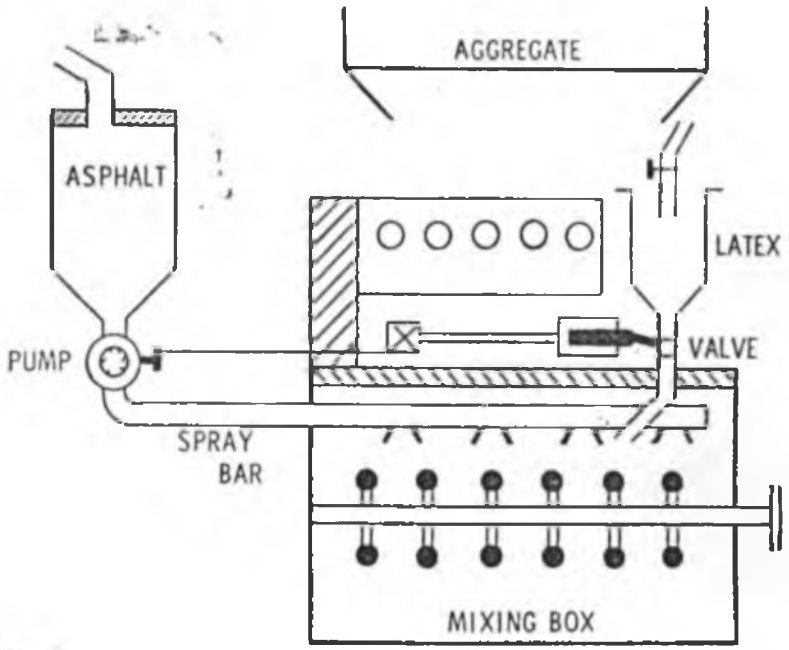


Fig. 1.

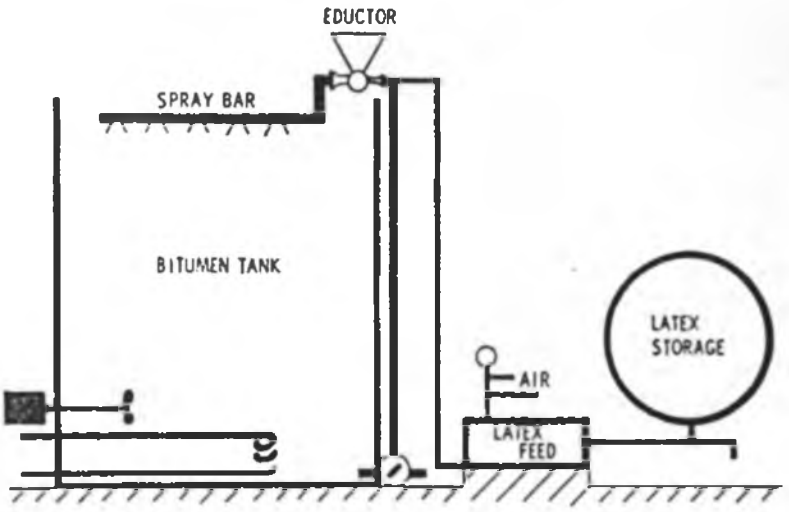


Fig. 2.

Rubberized bituminous concrete is produced by adding rubber to the aggregate and bitumen in the pug-mill (Fig. 2) (14, 15), or by using preblended rubber and bitumen. For best dispersion the latex should be added at the start of the wet mix cycle. In contrast, rubber powder is added to the dry aggregate and mixed a few seconds before adding the asphalt.

Adding latex or rubber powder after the asphalt and aggregate are mixed shortens the time available for blending the rubber and gives poorer dispersion and effectiveness. Longer mixing times give a greater decrease in penetration or hardening of the asphalt.

Rubberizing bituminous emulsions with latex is quite simple. There are anionic latexes that are compatible with anionic bituminous emulsions, and cationic latexes compatible with cationic emulsions. Blends are prepared by mixing the latex into the finished emulsion, or by adding the latex to the emulsifier solution during preparation of the emulsion. A preblended rubber-bitumen can be used for the emulsion, but this is more time consuming.

Mixing conditions, especially time and temperature, affect blend properties and even change the properties of straight bitumen. In general, prolonged heating and high temperature harden the material—penetration, ductility, and flexibility decrease; while viscosity, softening point, and toughness increase. Most laboratory mixing was for one hr at 150–163°C when using high solids latex or fine powder in asphalt cement. Coal tar is more volatile than asphalt, so mixing conditions should be less severe—e.g., 75 min at 107–121°C or 30–45 min at 135–150°C.

Rubber-bitumen behavior

Bitumen properties improved by an effective rubber are temperature, susceptibility, ductility at low temperature, toughness and tenacity, softening point, impact resistance, adhesion and cohesion, recovery, and bleeding resistance. (See p. 70 for tests used to measure physical properties.) These

Some tests used to measure the physical properties of bitumens.

• Penetration: asphalt cements are bought or specified by penetration value—i.e., the depth in 1/10 mm that a standard needle will penetrate asphalt under specific conditions. This test (ASTM D5-65) employs a 100-gm load for 5 sec at 25°C.

• Viscosity: the viscosity of bitumens has been measured over a range of temperatures with many instruments—e.g., Saybolt-Furol, kinematic, Brookfield, and sliding plate. Some state highway departments have adopted viscosity specifications for asphalt, and a Federal Specification (MIL-STD-620A-1965) for rubberized tar includes Brookfield viscosity at three temperatures.

• Softening Point: determined by the ring and ball method (ASTM D36-66T).

• Ductility: determined according to ASTM D113-44 (1961). A briquet of regular asphalt is elongated at a rate of 5 cm/min at 25°C; the results are reported as centimeters of elongation at rupture. When ductility is measured at lower temperatures (4°C to 7.2°C), speed is usually reduced to 1 cm/min or less. When an effective rubber is added to the asphalt, a large increase in ductility at low temperature occurs, and the higher rate of extension must be used to obtain the data.

• Toughness and Tenacity: rubber imparts some unique properties to asphalt that are not measured by conventional tests—e.g., the capacity of rubberized bitumen to hold aggregate; which is a combination of increased adhesive and cohesive strength. A test was developed to measure this property, called toughness—i.e., the resistance an material offers to deformation. A cup and ball arrangement was used for the test specimen (Fig. 3); an Instron or Scott instrument was employed to separate the half submerged ball from the cup of bitumen. The area under the curve, force (lb) vs. elongation (in.), represents the toughness in inch-pounds. Elongation, peak load, and tenacity may also be obtained from the plot. Tenacity (in.-lb) is the area bounded by a line drawn tangent to the down side of the curve from the peak to the axis and the high elongation portion of the curve. This test has been standardized at 25°C with a ⅞-in. diameter ball, and extended at a rate of 20 in./min.

• Temperature Susceptibility: one method involves the relationship of the penetration at 25°C and the softening point. It is a rating of the change in consistency by change in temperature. Normal Type asphalts have a susceptibility index of − 1.0 to + 1.0; the more highly susceptible or Z Type has an index of less than − 1; while those with low susceptibility and less brittleness, called R or Blown Type, have an index greater than + 1.0. Rubber reduces temperature susceptibility, increases index number, and indicates an increase in useful temperature range. Ductility at 4°C also demonstrates the improvement at low temperature; the bleeding resistance test and softening point are further proof of the improvement at elevated temperatures.

• Resistance to Bleeding: addition of rubber on seal coat applications reduces or eliminates bleeding. This is demonstrated by the bleeding resistance test, ASTM D917-49 (1961). Kraft paper is laminated with the bitumen and placed between white paper and then subjected to pressure of 0.5 psi for 5 hr at 65.6°C. The white paper is then examined for the size of the stain (Fig. 4).

• Fuel Immersion (rubberized tar), this test is covered by Federal Specifications LY 197-6 and MIL-STD-620A, Method 107. The specimen is in a 3-oz ointment box (penetration cup), and the penetration and volume and weight change are measured after 18 hr at 37.8°C in 70/30 isooctane/toluene.

• Flow (Rubberized tar): the flow specimen, 4 cm wide by 6 cm long by 0.32 cm deep on a metal panel, is mounted at an angle of 75 degrees with the horizontal and placed in an oven maintained at 37.8°C (100°F) for 60 minutes. Change in length is recorded in centimeters.

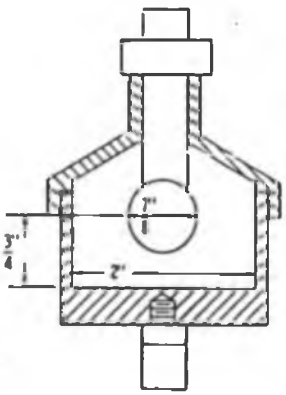
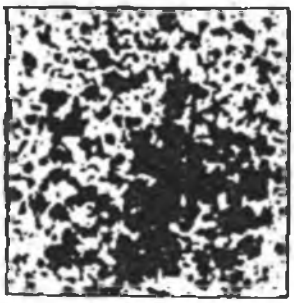


Fig 3, right, and Fig. 4, for right.





properties normally increase in direct proportion to rubber concentration. A low concentration increases low-temperature ductility of some asphalts to the 150 cm limit of our ductilometer. Penetration at 25°C is normally decreased by an increase in rubber; while penetration at 0°C may be increased.

Endres (16) demonstrated the advantage of a rubber over a resin by plotting butadiene/styrene ratio vs. softening point of

Table 2. Evaluation of different polymers in asphalt from New Mexico Crude.

Type polymer	None	SBR[a]	SBR[b]	AI#14[c]
% Polymer (dry)	None	3	5	5
Penetration at 25°C	100	82	161	86
Softening point, °C	45.5	54.5	41	47.8
Ductility at 4°C, cm	6	63	26	6
Toughness, in.-lb	21	105	8	20
	Data after thin film oven aging			
Penetration at 25°C	51	51	68	48
% Retained pen.	51	62	42	56
Ductility at 4°C, cm	0.8	21	6.8	3.7

[a] High Mooney SBR, Pliopave L170.
[b] Liquid SBR, 3800 poises, Flosbrene.
[c] Enjay Adhesive Intermediate #14.

Table 3. Effect of SBR powder and latex on asphalt from New Mexico Crude.

Source SBR	None	Powder[a]	Latex[b]
% SBR	0	2.4	2.4
Penetration at 25°C	120	109	112
Softening point, °C	43	48	48
Toughness, in.-lb	20	75	74
Ductility at 4°C, cm	5	90	105

[a] Pliopave S180. [b] Pliopave L170.

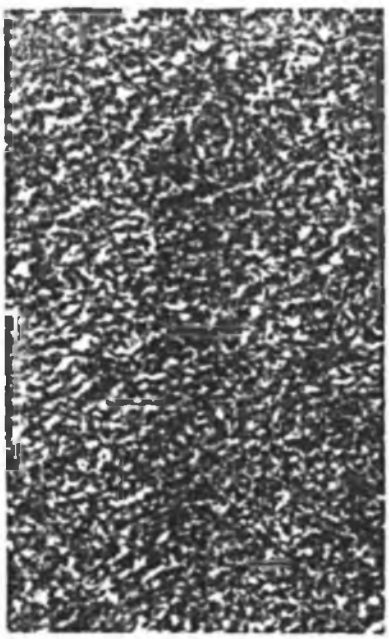


Fig. 5.

the polymer-asphalt blend.[4] The increase in softening point was directly proportional to polymer butadiene content.

SBR[5] continues to be the best polymer for upgrading asphalt, with the best overall improvement resulting from an SBR having high molecular weight and little or no gel content.

An ideal rubber-asphalt combination appears to be one which, at a high mixing and application temperature (150–175°C), has a single-phase system appearance that, upon cooling, develops a network phase of reinforcing rubber fibrils.

An insoluble or high gel polymer may remain as individual particles; while a low molecular weight polymer, especially liquid or semi-solid polymers, may not form the reinforcing network phase. The highly swollen rubber (Fig. 5) has a light grey network with the asphalt appearing as a dark grey background. In a color photograph, or with a microscope,[6] the rubber is a light yellow network; asphalt, a reddish-brown background.

The combination of high molecular weight and low gel is difficult to obtain in polymers and places polymers such as natural, reclaim, and liquid types at a disadvantage. This disadvantage is readily apparent when comparing the effects different polymers have on asphalt properties (Tables I and 2).

Essentially, a better balance of properties derive from a high-Mooney, low-gel SBR. NR latex has no appreciable effect on low-temperature ductility, and although softening point and toughness are improved, elongation is poor. Cis-polyisoprene latex or cement has little effect on ductility; toughness is lower than with natural rubber. The two reclaimed rubbers did not disperse satisfactorily, even when mixed with an homogenizer. They had only a negligible effect on asphalt's properties. Polychloroprene did not give the desired increase in ductility at low temperature; toughness was good in this asphalt, but was better in more highly aromatic asphalts.

The high-Mooney, low-gel SBR, however, was outstanding in its effect on low-temperature ductility (150+ cm). It also improved other asphalt properties. In fact, this SBR gives the best combination of property improvements.

The liquid, low molecular weight SBR (Table 2) acted as a plasticizer and increased penetration, but decreased the softening point. And while ductility increased, it was no higher than for some equally soft, straight asphalts. Addition of low molecular weight Adhesive Intermediate #14 yielded a small increase in softening point, but no improvement in ductility or toughness. (The more effective, high Mooney SBR is included in Table 2 for comparison purposes.) Also observed from tests on mixtures using asphalt from New Mexico crude petroleum was that there is no significant difference in property improvements between the latex or powder version of a polymer, provided they are both well dispersed (Table 3).

[4] He also reported the importance of polymer sol-gel characteristics.

[5] Pliopave L170, a high solids (67+% TS), cold polymerized (about 24% bound styrene), high Mooney (100+ ML), low gel (6% max) SBR latex, was used to obtain data shown in the remainder of this report unless indicated otherwise. This polymer disperses well in practically all asphalts except some made by the propane extraction process.

[6] Microscope slides were prepared by placing a drop of hot rubberized asphalt on one end of a heated slide, removing the slide from the heat source, and then spreading the drop before the slide cools to approximately 0.002-in. thickness. Tar contains many carbonaceous particles that prevent obtaining a good microscope specimen.

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Reinforcement of Asphalt & Tar by Elastomer Addition - Part I.

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Rubber world January 1970.

Reinforcement of asphalt and tar by elastomer addition—II

Only 5,000 miles of the nation's 3.7 million miles of road have been resurfaced with rubberized bituminous materials. The results thus far, however, indicate a potentially vast market for rubber suppliers. This is the second of a two-part report that began in RW, Dec., 1969, p. 67.

. A. Sinclair and K. E. Bristol
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With few exceptions the proper rubber polymers are dispersed by and improve the properties of penetration-grade asphalts for highway application. These asphalts usually are between 60 and 200 penetration units. For example, two Canadian crude-derived highway grades (85–100 and 120–150, Table 4) are both improved considerably by 3% dry weight of SBR polymer from latex. In fact, each property generally accepted as being descriptive of quality is improved: softening point, ductility at low temperature, toughness, and temperature susceptibility. The harder asphalts—lower penetration grades used for roofing and industrial products — have fewer solvating constituents and do not disperse the rubber so well as the softer asphalts.

Basically, both high- and low-viscosity types of asphalt are improved by the proper rubber (Tables 5 and 6). As little as 1.5% SBR increases the ductility of high viscosity asphalt by some 135+ cm, from 15 cm to 150+ cm, the limit of the machine. The increase in softening point, toughness, tenacity, and temperature susceptibility index is directly proportional to SBR concentration.

More than 1.5% SBR was required to increase the ductility of low-viscosity asphalt (Table 6) to 150 cm; but 1.5% SBR increased toughness by 200% and viscosity by over 100%. Additional rubber provides further improvement. Amount usually recommended: 2–5%.

The importance of increased viscosity for low-viscosity asphalt was reported by Traxler in one of his research projects (Table 7) for the National Bituminous Concrete Association, now the National Asphalt Paving Association. He stated that low viscosity asphalt contributed to "tenderness" in hot-mix paving (17). (See Part I for Bibliography.) That is to say, that an asphalt cement with a Saybolt-Furol viscosity of less than 135 sec at 135°C will contribute to excessive cutting, shoving, and deformation during application and early life of the pavement. In contrast, as little as 1.5% SBR will raise the viscosity from the "contribute to tenderness" classification to the safe, desirable range—greater than 160 sec, Saybolt Furol viscosity (Table 6).

Tests on the effect of SBR concentration on the temperature susceptibility index of low- and high-viscosity asphalt (Table 8) further demonstrate that rubber improves this property and extends the useful temperature range of the binder. A disadvantage of bituminous binder is that it becomes soft at elevated temperatures and hard and brittle at low temperatures. Rubber is the best method for improving this behavior.

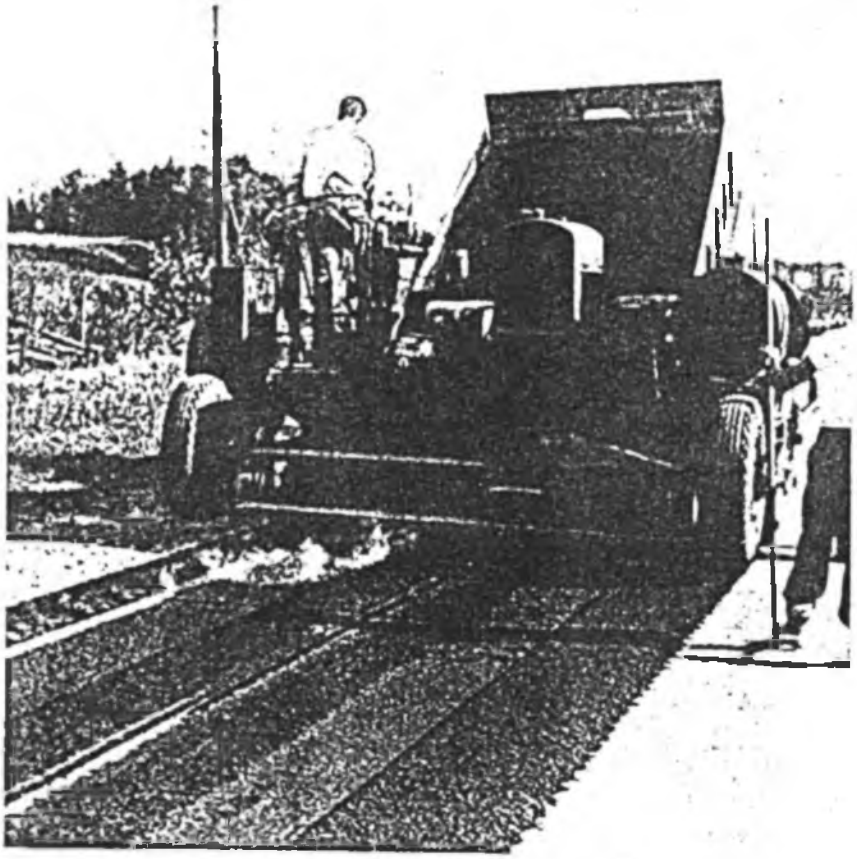
One method of determining durability is to measure the proper-

ties before and after thin film oven aging (Table 9). In this test, similar to ASTM D1754-63T, film thickness is approximately 1/8-in.; exposure, 5 hr at 163°C. While penetration is the usual test made after aging, many believe low-temperature ductility is more meaningful.

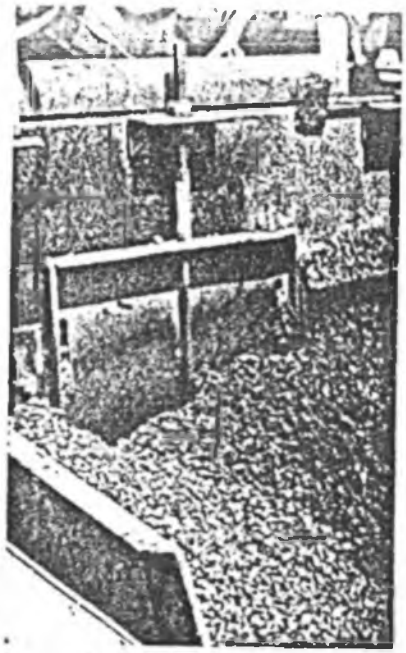
Doyle (18), Standard Oil Co. of Ohio, reported to the Highway Research Board that penetration did not correlate with cracking, but that ductility measured at 7.2°C and 1 cm/min did. When the pavement was cracked or ravelled, ductility was less than 8 cm; for a no-cracks pavement, ductility was greater than 8 cm. These findings emphasize the large improvement in low-temperature ductility gained by adding SBR. This improvement is ample for the expected decrease in ductility during long-term aging and weathering.

The ductility at 7.2°C of low- and high-viscosity asphalts were measured at a speed of 5 cm/min. The improvement in aged ductility due to SBR is a measure of improved durability, indicating a longer pavement life due to a reduction in cracking.

The asphalt cements from the Bureau of Public Roads (Table 10) represents a wide range of chemical composition (4). The ratio "most active-to-least active" (Table 10) represents the proportion of nitrogen bases + first acidaffins to second acidaffins + paraffins; du-



Maintenance costs for the nation's roads and highways will reach some $4.3 billion in 1970. Expenditures for all purposes will top $19.8 billion.



SBR, nitriles and natural rubber appear to be best suited for asphalt and for reinforcement. Nitriles are especially suited to applications in garage, airfield, parking lot tar-concrete surfaces because of oil resistance properties.

Table 4. Different penetration grade asphalts from same crude.

Penetration grade	85–100		120–150	
% SBR	0	3	0	3
Penetration at 25°C	78	68	128	108
Softening point, °C	52.5	62.5	49.5	59.5
Ductility at 7.2°C, cm	5	150 +	16.5	150 +
Toughness, in.-lb	22	92	12	63
Susceptibility index	+ 0.6	+ 2.4	+ 1.4	+ 3.3

Table 5. Effect of concentration of SBR on high viscosity asphalt (Venezuelan).

% SBR	0	1.5	3.0	4.5
Penetration at 25°C	85	77	70	64
Softening point, °C	45	48	55.5	70.5
Ductility at 7.2°C, cm (5 cm/min)	15	150 +	150 +	150 +
Toughness, in.-lb	31	66	87	156
Tenacity, in.-lb	11	43	63	125
Susceptibility index	– 1.2	– 0.7	1.0	3.7

Table 6. Effect of concentration of SBR on Low Viscosity Asphalt (Canadian).

% SBR	0	1.5	3.0	4.5
Penetration at 25°C	78	74	68	65
Softening point, °C	52.5	56	64	71
Ductility at 7.2°C (5 cm/min)	5	38	150	150 +
Toughness, in.-lb	22	66	120	180
Tenacity, in.-lb	6.5	47	85	145
Susceptibility index	0.6	1.3	2.6	3.8
Viscosity at 135°C Saybolt Furol, sec	87	191	800	—

Table 7. Data from "Viscosity of Asphalt Cement from a Construction Standpoint" by Dr. R. N. Traxler.

Viscosity at 135°C		Contribute to tenderness
Stokes	Saybolt Furol, sec	
3.5 or above	160 or above	no
3.1–3.4	136–159	doubtful
3.0 or below	135 or below	yes

rability rating is based on the weight loss during an abrasion test on sand-asphalt mixes. The lower rating number derives from lower weight loss and indicates better durability. Durability rating correlates with the "most reactive-to-least reactive" ratio and substantiates the earlier statements to this effect.

Because of the limited supply of these asphalts, rubberizing was limited to one polymer, SBR, and one concentration, 4%. New control data were developed from three original tests and two aged tests using straight asphalts, because the asphalt samples had been in storage for 12 years and had been reheated. Original and aged properties of all five asphalts were improved by SBR (Table 10). Asphalt No. 56 had the lowest amount of "most reactive" fractions, and the lowest toughness; asphalt No. 91 contained the highest amount of "most reactive" fractions, and much lower asphaltenes content, and had the highest toughness.

Asphalt No. 91 is the only one of the series that did not show a separate rubber phase in the microscope; nor did it have 150+ cm low-temperature ductility after adding SBR. The phenomenon of

Table 8. Effect of SBR on temperature susceptibility of asphalt cements.

	Temperature Susceptibility Index			
	Low Viscosity AC		High Viscosity AC	
% SBR	85–100 Pen.	120–150 Pen.	85–100 Pen.	120–150 Pen.
0	0.6	1.4	– 1.2	0.1
1.5	1.3	1.6	– 0.7	1.1
3.0	2.6	3.2	1.0	2.2
4.5	3.8	3.5	3.7	3.2

Table 9. Effect of thin film oven aging on low-temperature ductility of asphalt and rubberized asphalt.

	Ductility at 7.2°C (5 cm/min)			
	Low visc. asphalt		High visc. asphalt	
% SBR	Orig.	Aged	Orig.	Aged
0	8	3.3	15	5
1.5	28	13	150	150
3.0	150	29	150	150
4.5	150	34	150	150

Table 10. Effect of SBR on asphalts from the Bureau of Public Roads.

Asphalt BPR No.[a]	56	56	3	3	105	105	91	91	92	92
% SBR	0	4	0	4	0	4	0	4	0	4
Ratio most reactive[b] / least reactive	0.7	—	1.12	—	1.21	—	1.55	—	1.78	—
Durability rating[c]	I	—	II	—	III	—	VI	—	VIII	—
Source of crude[a]	Konsas		Mexico		Wyoming		Calif.		Calif.	
Penetration at 25°C	54	48	71	62	78	58	70	64	72	59
Softening point, °C	54	74.5	51	65	46	64	46	59.5	46.5	65.5
Toughness, In.-lb	—	57	—	106	—	105	—	182 +	—	109
Tenacity, in.-lb	—	39	—	64	—	70	—	155 +	—	80
Elongation, in.	—	27 +	—	27 +	—	27 +	—	27 +	—	27 +
Ductility at 4°C (5 cm/min)	2.5	150 +	10	150 +	8.5	150 +	Broke	25	11	150 +
Testing after thin film oven aging										
Penetration at 25°C	39	39	38	46	38	36	41	43	37	42
% Retained pen.	72	81	53.5	74	49	62	58.5	67	51	71
Ductility at 4°C (5 cm/min)	3.1	30	0.5	40	0.5	15.2	0	9.5	Broke	9.5

[a] From ref. 7. [b] From ref. 4. [c] Based on abrasion loss, loss increases with higher number, ref. 4.

Table 11. Effect of polymers on the properties of tar (RT 12).

Polymer	None	3% NBR		3% B/AN/MAN	
% Gel, MEK	—	39	69	18	73
Brookfield viscosity, cps at 105°C	450	5300	2200	5000	2500
Penetration, 1/10 mm	255	120	84	139	85
Softening point, °C	35.5	46	45.5	46	45.5
Flow, cm	4 +	1.0	1.1	0.9	1.1
Toughness, in.-lb	7	120	93	228	86

high toughness and limited low-temperature ductility has been observed with other blends that did not show a separate rubber phase at 100 power magnification. This ductility is lower than expected and may be due to poor aging and abnormally low ductility of the straight asphalt as it broke while the ductility mold was being removed.

Durability determined by low-temperature ductility after thin film oven aging correlates well with the durability rating by abrasion loss. Rubberized blends of Nos. 56 and 3 appear to be out of line. However, this is probably due to the very low penetration and ductility of No. 56 before rubberizing as compared to the values for No. 3.

An important use for tar, especially tar-rubber blends, is for tar-concrete paving and seal coating bituminous pavement around air fields, garages, parking lots, and fuel storage areas. An early Federal Specification called for an oil-resistant rubber in tar, and although this was not specified for many of the recent tar-rubber projects, NBR is favored for these projects.

Advantages of coal tar over asphalt include resistance to fuel and oxidation. Tar is also a better solvent for rubber than asphalt and will disperse a polymer containing some gel. As with the SBR-asphalt system, the sol-gel ratio of NBR is important in tar applications. One method of varying polymer sol-gel characterisitcs is to vary the % conversion of monomer during polymerization. This was done for the 67/33 butadiene-acrylonitrile copolymers (see blends, Table 11). A portion of the latex was discharged at 91% conversion, and the remainder reacted to about 99% conversion; these contained 39% and 69% gel, respectively. Both polymers improved tar properties; however, the blend containing the lower gel NBR had the highest viscosity, penetration and toughness.

Terpolymers of 62 butadiene, 28 acrylonitrile, and 10 of a third monomer such as methacrylonitrile (MAN), ethylacrylate, 2-vinylpyridine, and styrene all improved the properties of tar, but offered no advantage over the copolymer with equivalent solubility (Table 11). Once again, polymer solubility had the expected influence on viscosity, penetration and toughness.

Table 12. Federal specification for rubberized tar.

Test	Specification	3% NBR[1]
Penetration at 25°C		
Non-immersed	100–225	150
Fuel immersed	100–250	165
Difference	50 max	15
Softening point, °C	32 min	42
Brookfield viscosity		
cps at 90°C	4800–18500	12200
cps at 105°C	2050–7600	4900
cps at 120°C	860–3050	1900
Flow, cm	4.0 max	2.0
Volume change, %	± 2.5	± 0.4
Weight change, %	± 2.0	− 0.1

[1] Typical tar-rubber blend containing 3% NBR (Philprene 1360 with 25% gel) in RT-12 tar.

A tar-rubber blend provides a binder resistant to the solvent action of fuel and oil and is being used to overcome a major maintenance problem at military and domestic air fields. (See Table 12 for Federal Specification for rubberized tar-cement along with a typical tar-rubber blend.) As indicated earlier, a medium- to low-gel NBR will meet this viscosity specification at a lower rubber concentration than is required with a high-gel polymer. Time and temperature of mixing, type and concentration of rubber and tar source influence the final properties. These variables can be adjusted to pass the specification with tars from numerous suppliers. □

Rheological Properties of Rubber-Modified Asphalt

By A. A. Zaman,[1] A. L. Fricke,[2] and C. L. Beatty[3]

(Reviewed by the Highway Division)

Abstract: The performance of rubber (from used tires) as an asphalt cement modifier was evaluated by performing experiments on the shear-flow properties and creep-rupture behavior of modified asphalt cements. Results indicate that various asphalt/rubber samples exhibit shear-thickening, Newtonian, and shear-thinning behavior depending on the shear rate. The shear viscosity, linear viscoelastic functions, elasticity, and creep resistance of asphalt cement increased with the addition of rubber. These increases indicate that the addition of rubber will improve the low temperature properties of asphalt cement, and that such modifications are necessary to reduce the tendency of asphaltic-paving materials to crack in cold climates and to increase the life cycle of the road.

INTRODUCTION

The use of ground rubber from tires as an additive to asphalt cement has been developing for more than 30 years. Recently, the emphasis began to focus on the potential of ground rubber as a useful method to minimize the waste-disposal problems. From the engineering and environmental perspective, large-scale use of ground rubber from waste tires appears attractive and promising.

The low cost, inherent cohesive nature, weather-resistant properties, and ease of processing in the molten state are the main reasons for the extensive use of asphalt-cement-based materials as waterproof coatings, sealants, and binders (Nadkarni et al. 1985). In some of its applications, asphalt cement is exposed to a wide range of temperatures (−20°C–60°C) and loading conditions. Pure asphalt cement is a viscous fluid at temperatures higher than 50°C and becomes brittle at temperatures lower than 30°C (Kortschot and Woodhams 1984). It undergoes considerable deformation due to the applied load over a period of time. This is a major problem, which greatly restricts its applications under conditions that warrant its use for extended periods of time. Pure asphalt cement has very poor creep resistance (McQuillen 1988), and it is obvious that this characteristic is greatly reduced at elevated temperatures and when subjected to loads for long periods. To improve the low and high temperature performance (e.g., softening point, crack resistance, elastic modulus, etc.) of asphalt cement, there has been a growing interest in the possible use of various polymers in the recent past. Modification has been attempted by the addition of rubber, thermoplastic elastomers, polyethylene, styrenebutadiene copolymer, etc. Studies (Kortschot and Woodhams 1984) on the viscous properties of asphalt cement indicate that asphalt cement is very temperature-sensitive and, in fact, the drastic change in viscosity with temperature affects the pavement performance considerably. There are several studies on the viscoelastic properties of asphalt cement (Kortschot and Woodhams 1984; Bouldlin and Collins, unpublished paper, 1990; Berker et al. 1990), and some researchers have attempted to overcome the problem of asphalt-cement rutting by the addition of a styrene-butadiene copolymer and styrene-butadiene-styrene thermoplastic elastomer (Van der Poel 1954). An increase in the flexural strength and elongation was reported for asphalt cement modified with polyethylene (Jew et al. 1986). The addition of styrenic-block copolymers to asphalt cement is reported to increase the viscosity, softening point, toughness, and tenacity of asphalt cement. Results indicate that there is an increase in the tensile modulus of asphalt concrete as the temperature is increased (Shuler et al. 1987). The use of polymeric modifiers in asphalt cement results in the reduced flow of asphalt, a substantial increase in softening temperature, improved low temperature flexibility, and higher toughness and tenacity (Fina Oil 1986). Studies on the thermomechanical behavior of modified asphalt (Nadkarni et al. 1985) indicate that conventional air-blowing improves the softening and the modulus at an elevated temperature, but it does not improve the low temperature flexibility.

BACKGROUND

Rheology is the study of the time-temperature response of material to an applied force or stress. Among the rheological properties, the viscosity function is one of the most important characteristics of the fluids because of their complex response under different conditions. At very low shear rates, the viscosity approaches a constant value, called the zero-shear-rate viscosity (η_o) or Newtonian behavior, but at higher shear rates (for most of the fluids), viscosity becomes a function of the shear rate. Asphalt cement (Kandhal et al. 1988) and asphalt cement modified with polymers are among the most complex materials, which show a shear-thickening (an increase in viscosity by an increasing shear rate or "dilatancy") behavior (Mohseen et al. 1992) at low shear rates up to the softening point, Newtonian behavior around the softening point, and shear-thinning (pseudoplastic) behavior at higher shear rates. Viscosity measurements over a wide range of temperatures and shear rates have some advantages over empirical tests and can be used to predict the behavior of asphalt cement at low temperatures (Kandhal et al. 1988; Schweyer and Busot 1969; Moavenzadeh and Stander 1966).

The asphalt-cement binder controls the behavior of flexible pavements at low in-service temperatures (Roque et al. 1987) and the pavement performance is primarily controlled by the rheological properties of asphalt cement. Rheological measurements can be a powerful tool in the characterization and design of viscoelastic blends (Kortschot and Woodhams 1988; Berker et al. 1990). The objective of this work was to investigate the rheological properties of rubber (from used tires) modified asphalt cement at different loadings of rubber. This

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could result in determining the optimum weight percentage of rubber that can be added to asphalt cement to achieve the desired physical properties. Used rubber is an attractive asphalt cement modifier due to its availability and low cost. The world rubber production is of the order of several million tons per year, which eventually results in huge amounts of waste materials. Therefore, the use of waste rubber as an asphalt-cement modifier is beneficial from the engineering, economic, and environmental points of view.

MATERIALS

Chevron AC-30 asphalt cement was used in this study. The physical properties of this grade of asphalt cement are shown in Table 1. Rubber particles (80 mesh) supplied by the Florida Department of Transportation were produced by Rouse Rubber Inc. (Vicksburg, Mississippi) by buffing the car tire treads by the wet process (i.e., the rubber particles were milled under water using milling stones). The exact chemical composition of the rubber particles and their additive concentrations are not known and are expected to vary from particle to particle.

Swelling kinetics of the rubber particles in three boiling-point fractions of the Chevron AC-30 asphalt are being studied by Li and Beatty (personal communication, January 1995) and an image analysis of videotaped swelling experiments will be reported elsewhere by Li and Beatty. Likewise, the incorporation via the roll-milling of these rubber particles in vinyl-styrene-butadiene polymers prior to crosslinking will also be reported by Li and Beatty (personal communication, January 1995) as will the static and dynamic mechanical properties.

Rubber-modified asphalt-cement blends were prepared by adding the rubber in powder form to molten asphalt at 175–200°C over a period of 30 min, with frequent stirring in order to incorporate rubber into the asphalt cement. The molten mixture was poured into a square aluminum mold with the dimensions of 10 × 10 × 0.3 cm. The samples were kept in a refrigerator before testing. For creep-recovery experiments, the samples were cut into tensile dog-bone specimens corresponding to ASTM D 638 specifications.

METHODS

Steady Shear Flow Testing

An Instron capillary viscometer (Model 3211) was used for shear viscosity measurements of unmodified and asphalt modified with different amounts of rubber. The capillary viscometer is perhaps the most popular instrument for studying the flow properties of highly viscous fluids for a variety of shear rates, ranging from 1 s^{-1} to 10^5 s^{-1}, and different temperatures. In this system, the samples are forced through the capillary at different constant volumetric flow rates. The pressure drop through the capillary is determined by measuring the force required to drive the sample through the capillary. The volumetric flow rate and the corresponding pressure drop through the capillary is used to determine the viscosity of the sample.

TABLE 1. Properties of Asphalt Cement (Chevron AC-30) Used in This Study[a]

Property (1)	Value (2)
Absolute viscosity at 60°C	287.5 Pa·s
30 cm of mercury (Hg) Penetration at 25°C	66.00
Flash point	597.1 K
Smoke point	444.3 K
Kinematic viscosity at 135°C	516 × 10^{-6} m^2/s
Thin film ductility at 25°C	1.02 m

[a]Tests were conducted by the Florida Department of Transportation, Gainesville, Florida.

Using a number of sweeping assumptions, the shear rate at the wall of the capillary is (Bird et al. 1987)

$$\dot{\gamma}_w = \frac{4Q}{\pi R^3}\left[\frac{3n' + 1}{4n'}\right] \tag{1}$$

where Q = volumetric flow rate through the capillary; R = radius of the capillary; and $n' = (d \log_e \tau_w / d \log_e Q)$ is the correction for non-Newtonian behavior.

The shear stress at the wall of the capillary, τ_w, can be determined by considering the Bagley (1957) correction for pressure losses due to the end effects, and is equal to

$$\tau_w = \frac{\Delta P D}{4(L + ND)} \tag{2}$$

where ΔP = total pressure drop along the capillary; D = diameter of the capillary; and N = intersection of plots of ΔP versus (L/D) (at a fixed flow rate) with the (L/D) axis. Once the shear rate and shear stress are known, the shear viscosity η is determined as

$$\eta = \frac{\tau_w}{\dot{\gamma}_w} \tag{3}$$

Using this system, at first samples were heated to the melting temperature and then loaded into the barrel. Before starting the measurements, the instrument was allowed to equilibrate to the testing temperature for about 30 min to ensure a constant temperature profile along the barrel and capillary. Tests were conducted at temperatures ranging from 45°C to 60°C.

Dynamic Mechanical Testing

The linear viscoelastic characteristics of the material under consideration were investigated in small-amplitude oscillatory shear flow using a Rheometrics mechanical spectrometer (RMS-800) with a cone-and-plate geometry. In this system, one of the plates is oscillated in the θ direction sinusoidally with a frequency ω and angular amplitude θ^o, while the other plate is stationary. The time-dependent torque, which is required to maintain the stationary position of the plate, is measured. The motion of the oscillating cone can be given by the angular displacement, θ, as a function of time, t (Bird et al. 1987).

$$\theta = \theta^o \sin \omega t \tag{4}$$

The torque, T, required to hold the other plate stationary also varies sinusoidally at the same frequency, ω, but with a phase shift, α, as

$$T(\omega) = T^o \sin(\omega t + \alpha) \tag{5}$$

If $\theta^o \ll 1$ and the cone angle α_o is small (of the order of several degrees), the real (dynamic viscosity) and imaginary parts of the complex viscosity can be determined from (Bird et al. 1987)

$$\eta'(\omega) = \frac{3\alpha_o T^o \sin \alpha}{2\pi R^3 \omega \theta^o}, \quad \eta''(\omega) = \frac{3\alpha_o T^o \cos \alpha}{2\pi R^3 \omega \theta^o} \tag{6, 7}$$

where R = plate radius; and α_o = cone angle (rad). The linear viscoelastic functions η' and η'' can be related to those of the complex modulus as

$$\eta' - i\eta'' = \frac{G''}{\omega} - i\frac{G'}{\omega} \tag{8}$$

where G' = storage modulus.

In this work, the cone angle was 0.1 rad and the radius of the plate was 1.25 cm. The RMS has a torque motor and a transducer, which measure the torque and the normal force, respectively. A crucial requirement for small amplitude oscillatory shear flow is that the experiments be carried out within the linear viscoelastic range, i.e., the material functions such as G' and η' must be independent of the applied strain levels. Frequency sweeps at different strain levels were used to determine if this were the case. If the data are equivalent at each strain level, we may assume that the data are in a linear viscoelastic range over the entire range of frequencies. Otherwise, the strain was reduced until the frequency sweeps of the two smallest strain levels were commensurate. The dynamic viscosity and storage modulus of different samples were measured at temperatures ranging from 35°C to 65°C.

Creep Rupture

The equipment used to conduct creep experiments consisted of a wooden rack from which several samples could be suspended. Other accessories included grips to hold the samples, calibrated weights for loading, measuring equipment to determine the elongation of the specimen, and a stopwatch to record time. In spite of the simplicity of the apparatus, the data obtained were reproducible. For the creep experiments, the samples were cut into tensile dog-bone specimens corresponding to ASTM D 638 specifications.

Samples of pure asphalt and asphalt modified with different amounts of rubber (2.5%, 5%, 7.5%, and 10% by weight) were suspended under constant weights (20, 40, 70, 120, 170, and 220 g) at room temperature using clamps, and elongation was recorded at constant time intervals. Creep rupture represents the ultimate time of a given material and, in this study, was defined as the instant when the sample could no longer support the applied load and broke into two pieces. The samples exhibited considerable flow before failure. The tensile creep data obtained at constant stress are time-dependent displacement values. Strain and tensile creep stress reported in this paper refer to engineering strain (ratio of elongation to the initial length) and engineering stress (ratio of applied load to the initial cross-sectional area). A tensile modulus $E(t)$ is defined as the applied stress to the time-dependent strain. The tensile modulus $E(t)$ is not a material constant, but a time-dependent variable that is also a function of the temperature and environment.

RESULTS AND COMMENT

Shear Flow Properties

Fig. 1 is a plot of shear viscosity as a function of shear rate for unmodified asphalt cement and asphalt cement modified with different amounts of rubber at T = 55°C. As can be observed, the viscosity of unmodified asphalt cement increases with the shear rate till a particular shear rate, remains constant over a small range of shear rate, and then decreases with a further increase in the shear rate. In other words, it shows shear-thickening (dilatant), Newtonian, and shear-thinning (pseudoplastic) behavior. This behavior indicates that the resistance of asphalt cement increases against the loading condition up to the "transition shear rate " (or softening point), stays constant over a small range of shear rate, and then its resistance decreases against the loading condition. From engineering and economical points of view, it is beneficial to process asphalt cement products above the softening point. Plots of viscosity versus shear rate for asphalt modified with 2.5%, 5%, 7.5%, and 10% rubber indicate that the shear viscosity of asphalt-modified rubber will be increased by increasing the amount of rubber. Modified asphalt cements show Newtonian behavior over a wider range of shear rate and their resistance against loading will be higher and more uniform as the amount of rubber is increased. In addition, the degree of shear-thickening and shear-thinning behavior will be decreased by increasing the amount of rubber in asphalt cement.

Fig. 2 represents the viscosity of asphalt cement modified with 10% rubber at different temperatures (45°C, 55°C, and 60°C). The effect of shear rate on viscosity is more significant at lower temperatures and the degree of shear susceptibility will be decreased by increasing the temperature. Asphalt

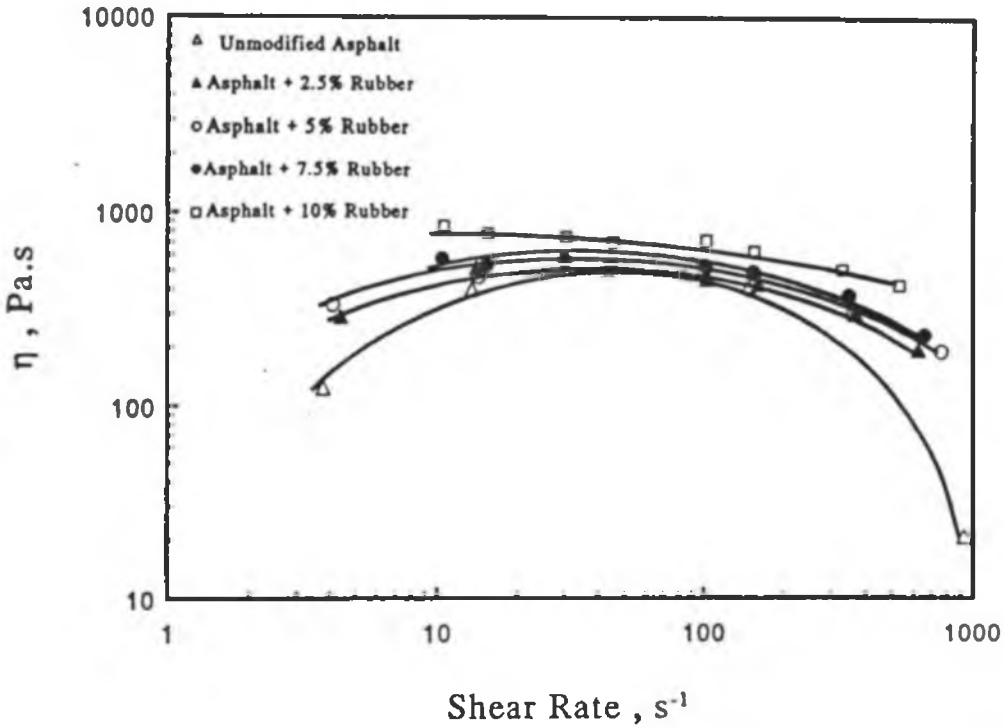


FIG. 1. Viscosity as Function of Shear Rate for Unmodified and Rubber-Modified Asphalt Cement at 55°C

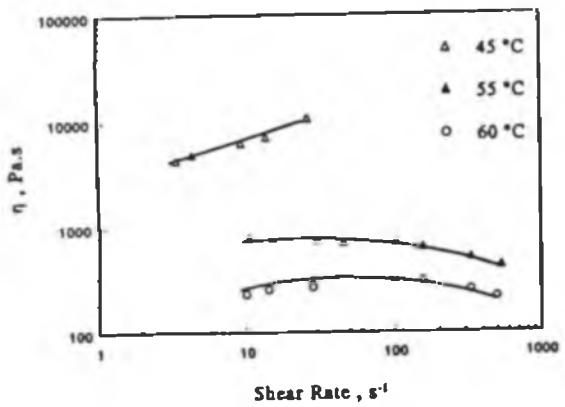


FIG. 2. Effect of Temperature on Viscosity of Asphalt Cement Modified with 10% Rubber

products are very temperature-sensitive and there is a big change in their physical properties as the temperature changes.

Figs. 3 and 4 are plots of dynamic viscosity and storage modulus as a function of frequency in small-amplitude oscillatory shear experiments for asphalt cement modified with rubber at 55°C. The results indicate that the dynamic viscosity and storage modulus will increase as the amount of rubber increases in the asphalt cement. Dynamic viscosity is a decreasing function of frequency and storage modulus is an increasing function of frequency. However, there is an indication of a plateau for dynamic viscosity and storage modulus at higher frequencies.

Fig. 5 is a plot of storage modulus as a function of frequency for asphalt cement modified with 7.5% rubber at different temperatures (35°C, 46°C, 55°C, and 65°C). Fig. 5 shows that storage modulus is a decreasing function of temperature, as might be expected.

To be able to judge the elasticity of asphalt cement modified with different amounts of rubber, the values of G'/η^* were determined at one frequency (46.41 rad/s) at a constant temperature and were then plotted as a function of rubber in asphalt cement, as shown in Fig. 6. There is a small change in elasticity when the amount of rubber is increased from 2.5% to 7.5%, but the change in elasticity is very large as the amount of rubber is increased from 7.5% to 10%. The reasons for this dramatic change are not yet clear. It could be due to the distribution and size of the rubber particles; however, more work is needed to study the effect of rubber-particle size on the rheological properties of asphalt cement modified with rubber.

Creep Rupture

Unmodified asphalt cement has a very poor creep resistance and fails almost instantly at even a load as low as 30 g (stress = 28.3 Pa) as can be observed from Fig. 7, which is a plot of strain as a function of time for unmodified asphalt cement under different constant loads. However, this is a major problem, which restricts its application under different conditions. This is the major difference between asphalt cement and other engineering materials, which resist against creep for several weeks to years. Drastic changes in the creep properties of asphalt cement are brought about by the incorporation of rubber. Figs. 8 and 9 show that the addition of rubber to asphalt cement improves its creep resistance. There is an increase in the creep resistance of asphalt cement as the amount of rubber is increased. The change in creep resistance is very large as the amount of rubber is increased from 7.5% to 10%, which is similar to the change in the elasticity of asphalt cement modified with rubber.

It is reported that metals and polymers exhibit three stages of creep: an initial slow increasing rate of creep, a transition region (constant rate), and a final fast region of increasing creep rate. Depending on the amount of rubber in asphalt cement and the magnitude of the applied load, different stages of creep can be observed (Figs. 7–9). Pure asphalt cement has only one stage of creep, where the strain rate increases with time until failure. Asphalt cement modified with rubber (more clearly when the amount of rubber is greater than 2.5%) exhibits two stages of creep: an initial slow-rate region and a final fast-rate region. The stage where the creep rate is extremely high is the result of localized area reduction, known as "necking." This is accompanied by a flow of the asphalt-cement samples. Fig. 9 indicates that, when the samples are subjected to high stress levels, the first stage of creep is virtually nonexistent.

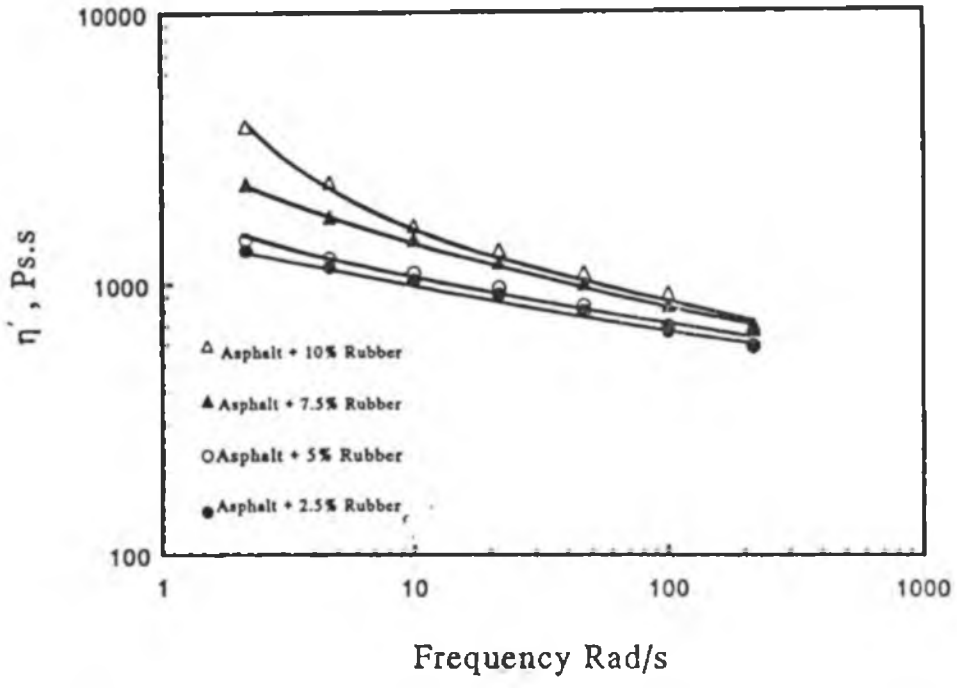


FIG. 3. Dynamic Viscosity as Function of Frequency for Asphalt Cement Modified with Rubber at 55°C

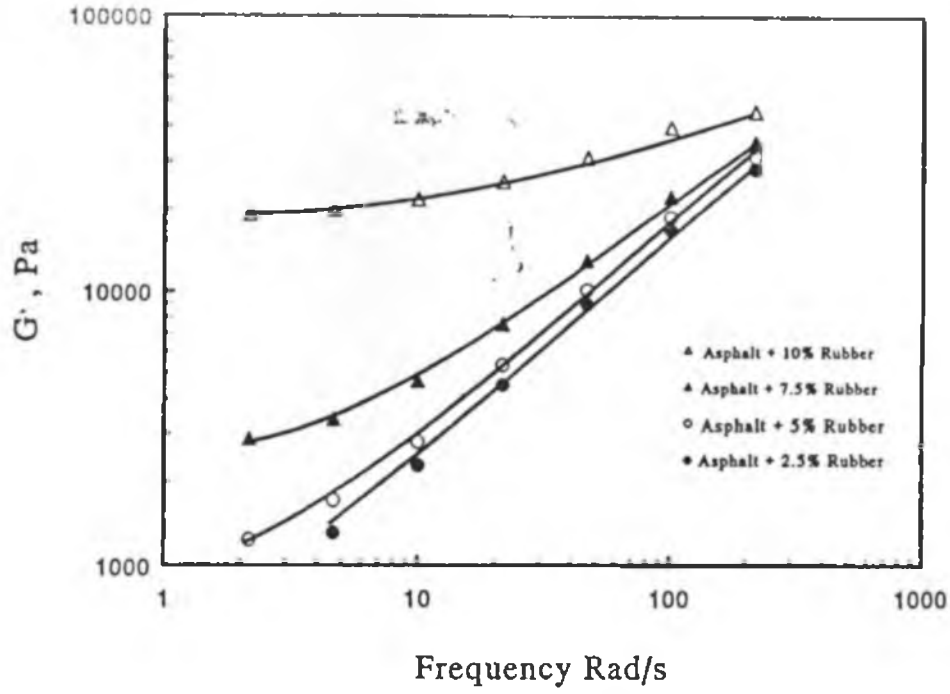


FIG. 4. Storage Modulus as Function of Frequency for Asphalt Cement Modified with Rubber at 55°C

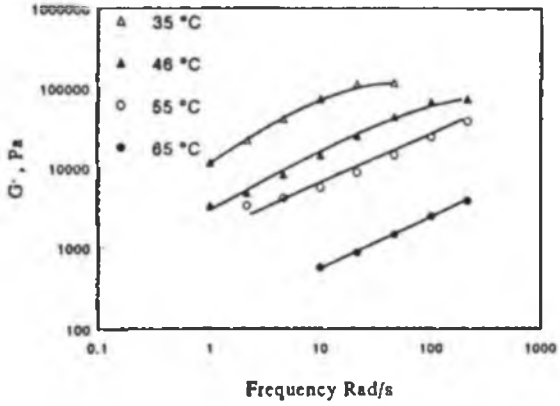


FIG. 5. Effect of Temperature on Storage Modulus of Asphalt Cement Modified with Rubber at 55°C

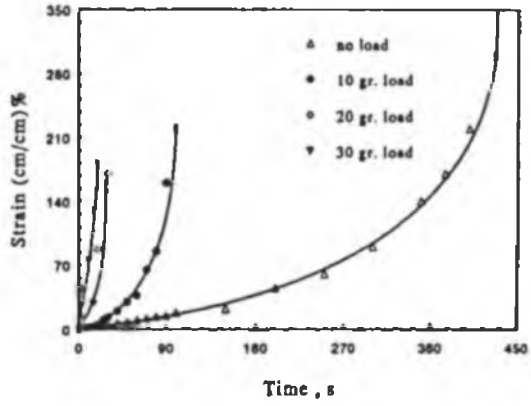


FIG. 7. Creep-Rupture Curves of Unmodified Asphalt Cement Subjected to Different Constant Loads

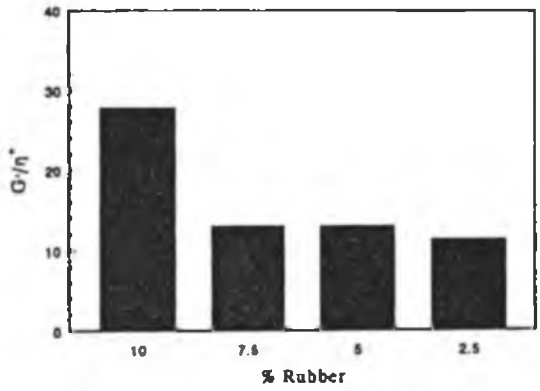


FIG. 6. Elastic Characteristic of Asphalt Cement Modified with Rubber at Frequency = 46.41 rad/s and T = 55°C

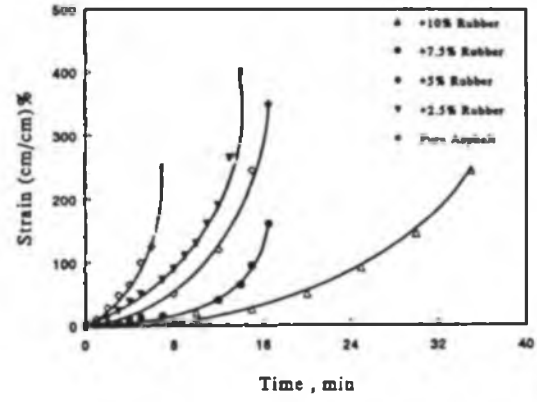


FIG. 8. Creep-Rupture Curves of Asphalt Cement Modified with Rubber at No-Load Condition

A comparison between the viscometric functions and creep indicates that the sample which had the maximum viscosity (and elasticity) showed the highest creep resistance. Similarly, unmodified asphalt cement, which had the lowest viscosity, exhibited the lowest creep resistance.

Effect of Stress

Figs. 10 and 11 represent the isochronous stress-strain plots for unmodified and asphalt cement modified with 10% rubber. These plots describe the stress-strain behavior at differ-

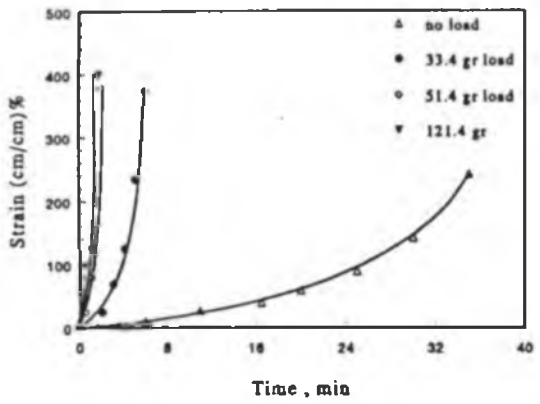


FIG. 9. Creep-Rupture Curves of Asphalt Cement Modified with 10% Rubber Subjected to Different Constant Loads

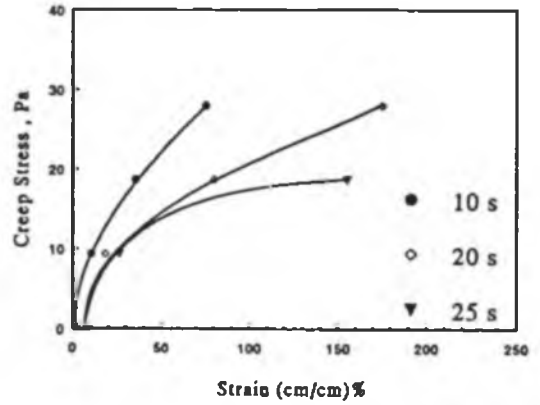


FIG. 10. Isochronous Stress-Strain Curves of Unmodified Asphalt Cement Subjected to Different Constant Loads

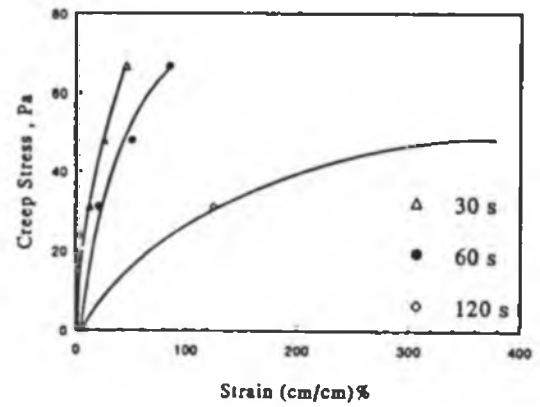


FIG. 11. Isochronous Stress-Strain Curves of Asphalt Cement Modified with 10% Rubber Subjected to Different Constant Loads

ent constant times. Using the values of stress, strain, and time, plots of tensile creep modulus as a function of time at constant stresses were obtained. The effect of time on the modulus of unmodified asphalt cement and asphalt cement modified with 10% rubber is shown in Figs. 12 and 13. At any constant stress, the modulus is a decreasing function of time and the magnitude of the modulus is dependent on the magnitude of the applied stress. It is also observed that at any level of time, the modulus decreases with an increasing stress.

CONCLUSIONS

Unmodified asphalt cement and rubber-asphalt blends exhibited dilatant, Newtonian, and pseudoplastic behavior. At

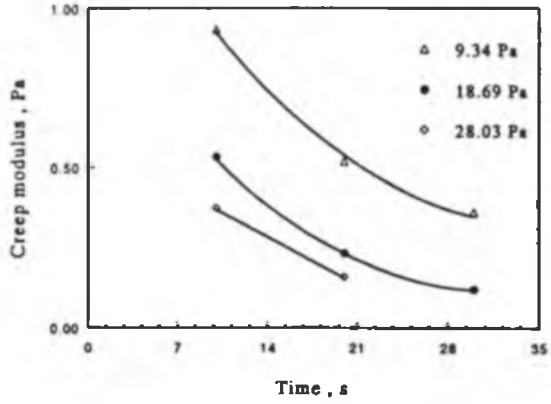


FIG. 12. Creep Modulus as Function of Time for Unmodified Asphalt Cement Subjected to Different Constant Stresses

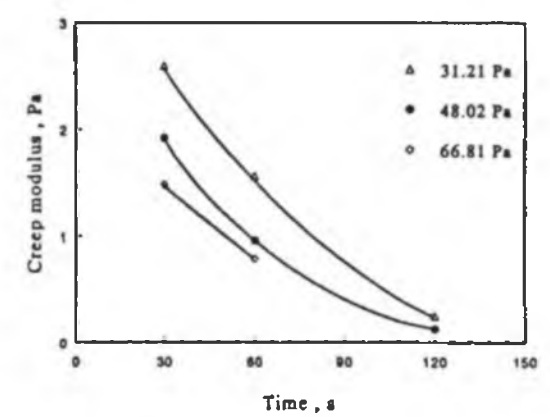


FIG. 13. Creep Modulus as Function of Time for Asphalt Cement Modified with 10% Rubber Subjected to Different Constant Stresses

low shear rates, unmodified and rubber-modified asphalt-cement samples exhibited shear-thickening behavior, while at high shear rates, shear-thinning behavior was observed. However, between these two types of behavior, there is a small range of shear rate, where all samples showed a Newtonian behavior. The viscosity of asphalt cement increases with the addition of rubber, and rubber-modified asphalt-cement samples show a more uniform and higher resistance against loading as the amount of rubber is increased. The degrees of shear-thickening and shear-thinning behavior decrease by increasing the amount of rubber in asphalt cement.

The linear viscoelastic functions (dynamic viscosity and storage modulus) of asphalt cement modified with different amounts of rubber were investigated in small amplitude oscillatory shear flow. Both dynamic viscosity and storage modulus will be increased by increasing the amount of rubber in asphalt cement. Dynamic viscosity is a decreasing function of frequency, while storage modulus is an increasing function of frequency. The results indicate that the elastic behavior of asphalt cement modified with 10% rubber is approximately two times larger than that of asphalt cement modified with 7.5% rubber, but there is only a small difference in the elasticity of asphalt cement modified with 5% and 7.5% rubber.

There is a great improvement in the creep resistance and the fracture time of asphalt cement modified with rubber. Both the fracture time and creep resistance of asphalt-cement samples increase as the amount of rubber is increased.

ACKNOWLEDGMENTS

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APPENDIX II. NOTATION

The following symbols are used in this paper:

D = diameter of the capillary (m);
G' = storage modulus (Pa);
G'' = real part of the complex modulus (Pa);
L = length of the capillary (m);
N = intersection of plots of ΔP versus (L/D) with (L/D) axis;
n' = $d\ \mathrm{Log}_e\tau_w/d\ \mathrm{Log}_e Q$, correction for non-Newtonian behavior;
Q = volumetric flow rate (m^3/s);
R = radius of capillary in (1) and radius of the plate elsewhere (m);
T = torque;
T^o = torque amplitude;
t = time (s);
α = phase shift;
α_o = cone angle (rad);
$\dot{\gamma}_w$ = shear rate at the wall of the capillary (s^{-1});
ΔP = pressure drop along the capillary (Pa);
η = shear viscosity (Pa·s);
η_o = zero shear rate viscosity (Pa·s);
η' = dynamic viscosity (Pa·s);
η'' = imaginary part of the complex viscosity (Pa·s);
θ = angular displacement;
θ^o = angular amplitude;
τ_w = shear stress at the wall of the capillary (Pa); and
ω = frequency (rad/s).

RHEOLOGY AND MICROSTRUCTURE OF POLYMER/ASPHALT BLENDS*

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INTRODUCTION

There are essentially four generic classes of polymers which have been shown to lead to improved performance of bituminous binders, these being[1-3]:

- Thermoplastics,
- Rubbers,
- Thermosets, and
- Thermoplastic Block Copolymers.

Thermoplastic block copolymers characteristically have a styrenic endblock and a rubbery midblock, such as butadiene (SBS), isoprene (SIS) and their respective hydrogenated forms (SEBS, SEPS). The structure and properties of these thermoplastic block copolymers have been reviewed[4].

One of the major causes of pavement failure is rutting (permanent deformation) as shown in Figure 1. In many circumstances, changing mix design or aggregate types, or other approaches have failed to solve rutting problems in the field. Therefore, polymeric and other additives have been incorporated into asphalt binders to mitigate rutting in HMAC[3]. This is especially true in regions experiencing elevated temperatures and/or high traffic loadings.

Recently, attempts have been made to characterize the fundamental viscoelastic properties of both neat and modified binders. A major goal of these efforts has been to correlate such properties with improvements in classical creep measurements of mixes and, finally, field performance concerning resistance to rutting[1,5-7]. It is important to further characterize the viscoelastic behavior of these binder systems in greater detail so as to better understand their significance in real performance. This is one of the major objectives of this paper. We will, therefore, attempt to elucidate some of the inherent problems and potential pitfalls in actually making measurements and properly interpreting the results.

We will also address the impact of the judicial selection of asphalt type (*i.e.*, crude slate and method of manufacture) and asphalt grade (*e.g.*, AC-5 through AC-40). The influence of these variables on the rheology, compatibility, morphology, and overall performance of modified asphalt cements will also be discussed.

Even though this paper is primarily devoted to the fundamental rheological properties of polymer-modified binders, complementary work concerning rutting of HMAC has been done with such binders by Valkering, *et al.*[8]. The last reference includes dynamic creep and its correlation with wheel track rutting experiments using unmodified bitumen as well as bitumen modified with thermoplastic block copolymers.

* Based on a paper presented at a meeting of the Rubber Division, American Chemical Society, Las Vegas, Nevada, May 29 to June 1, 1990. G.

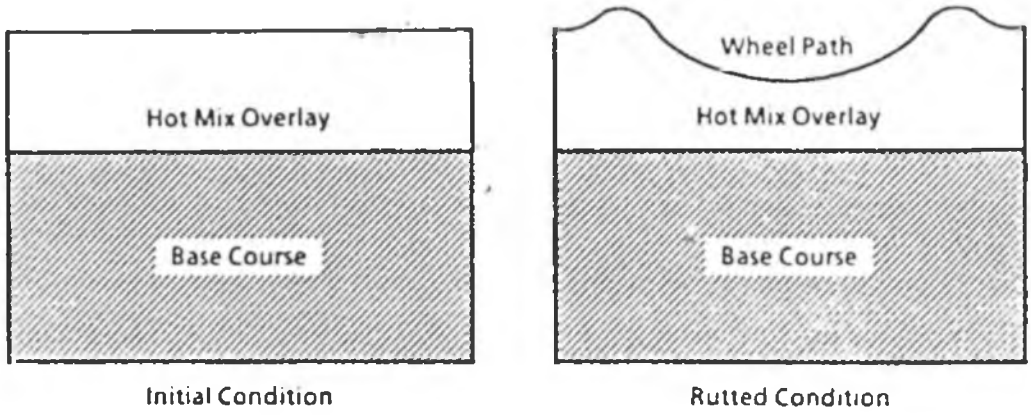


FIG. 1.—Schematic of pavement rutting.

NOMENCLATURE

ENGLISH SYMBOLS

$a_0, \cdots$	polynomial coefficients	
a_T	shift factor	
c	concentration	kg/m^3 or %w
c^*	critical overlap concentration	kg/m^3 or %w
C_1, C_2	constants of the WLF equation	
E'	tensile storage modulus	Pa
E''	tensile loss modulus	Pa
g	front factor	
$G(t)$	shear relaxation modulus	Pa
G^*	complex dynamic shear modulus	Pa
G'	storage modulus	Pa
G''	loss modulus	Pa
$G'_\rho(t, T_{ref})$	density corrected modulus	Pa
G'_m/G'_u	ratio G' (60°C, modified)/G' (60°C, unmodified); ω = 1 rad/s	
G'_T	ratio G' (25°C)/G' (60°C); ω = 1 rad/s	
$H(\ln \lambda)$	logarithmic relaxation time spectrum	Pa
i	$(-1)^{1/2}$	
$J(t)$	shear creep compliance	Pa^{-1}
M	molecular weight	kg/mol
SBR	styrene–butadiene rubber random copolymer	
SBS	styrene–butadiene–styrene block copolymer	
SEBS	styrene–ethylene–butylene–styrene block copolymer	
SEPS	styrene–ethylene–propylene–styrene block copolymer	
SIS	styrene–isoprene–styrene block copolymer	
R	universal gas constant	J/(mol·K)
r	platen radius	m
t	time	s
tan δ	loss tangent, G''/G'	
T	absolute temperature	K
T_G	glass-transition temperature	K
%w	percent weight	

GREEK SYMBOLS

β	cone angle	° or rad
γ	strain	

$\dot{\gamma}$	shear rate	s^{-1}
δ	phase angle between stress and strain	° or rad
ΔE	activation energy	J/mol
η	viscosity	Pa·s
λ	relaxation time	s
μ	Poisson ratio	
ρ	density	kg/m^3
σ	shear stress	Pa
ω	frequency	rad/s

SUBSCRIPTS

$_a$ = asphalt
$_g$ = glass
$_p$ = polymer

EXPERIMENTAL

SAMPLE PREPARATION

The experimental approach, in all cases, was designed to minimize polymer and/or asphalt degradation. We wanted to eliminate any significant artifacts introduced by such degradation upon mixing or further handling of the samples. Neat asphalt alone, for example, was subjected to the same procedures as the harshest mix conditions for the polymer blends. Neither gel permeation chromatography (GPC), elemental analysis, NMR, nor change in physical properties indicated any significant degradation.

The initial work was carried out with an oil extended SBS, Polymer A, (Kraton® D4460X Rubber). This compound consists of essentially, Polymer B, (Kraton D1101 Rubber) blended with an equal amount of a blend of naphthenic and aromatic oils. Both Polymer A and B are linear triblock polymers with a styrene content of 31%*w*.

Following the work with Polymer A, all subsequent work was done with Polymer B in a powder form using low-shear mixing equipment for sample preparation. The SBR Latex, Polymer C, (Ultrapave 70®, supplied by Goodyear) was treated similarly.

Blends of Polymer A were prepared using a model L4R Silverson® high-shear mixer. A large quantity of masterbatch using the highest polymer concentration (15%*w* neat Polymer B or 30%*w* Polymer A) was prepared first and blended for two hours at 180°C. Subsequent lower concentrations were prepared by diluting this masterbatch with neat asphalt under

TABLE I

ASPHALT COMPOSITION

AC Identification		Saturates %	Aromatics %	Polars %	Asphaltenes, %[a] (*n*-Pentane)	Asphaltenes, % (*n*-Heptane)
A	Martinez AR-1000	15.5	35.2	39.9	9.4	4.1
B	Boscan AC-6[b]	14.1	26.4	39.1	20.4	15.7
C	Deer Park AC-5	16.9	39.7	31.4	11.9	5.4
D	Deer Park AC-10	15.4	39.3	32.7	12.6	5.3
E	Deer Park AC-20	13.9	38.8	34.0	13.2	5.4
F	Deer Park AC-30	13.1	38.5	34.8	13.6	5.3
G	Deer Park AC-40	12.4	38.4	35.2	13.9	5.3
H	Wood River AC-10	15.8	35.3	26.7	22.2	14.5

[a] The first four rows add up to 100%.
[b] Boscan AC-6 is a blend of approximately 85% Boscan-derived asphalt and 15% of a heavy gas oil.

low shear conditions using a series 30 variable speed Lightnin® low-shear mixer for 1.5 h again at 180°C. The stirring speed was adjusted to provide good consistent agitation without undue entrapment of air (about 600–2500 rpm). Blends using Polymer B and C were prepared at 180°C, again using the low-shear mixer (about 600 rpm). A 3-blade 5 cm diameter "boat prop" mixer insured adequate mixing. Obviously the degree of mixing is not only important, but is also influenced by a number of variables including the type and grade of the base asphalt. The time to complete a blend, therefore, varied with each base AC type. The end-point was determined visually and then continued for 15 min more. A more compatible system such as the Martinez AR1000, Asphalt A, for example, required about half an hour of mixing *vs.* approximately 4 h for the Boscan asphalt, Asphalt B. These represented the two extremes. The compositions of the asphalt used are shown in Table I.

When blending was complete, samples were poured for testing according to ASTM procedures for traditional paving binder testing. Sample plaques for rheological testing were poured onto release paper and stored at ambient temperature. Samples for the electron microscopy work were stored in a refrigerator at approximately 7°C prior to staining and microtoming.

MICROSCOPY OF POLYMER/ASPHALT BLENDS

Scanning transmission electron microscopy (STEM).—Asphalt samples present a unique challenge for microscopic analysis because of their pliable and sticky nature. Thin sections

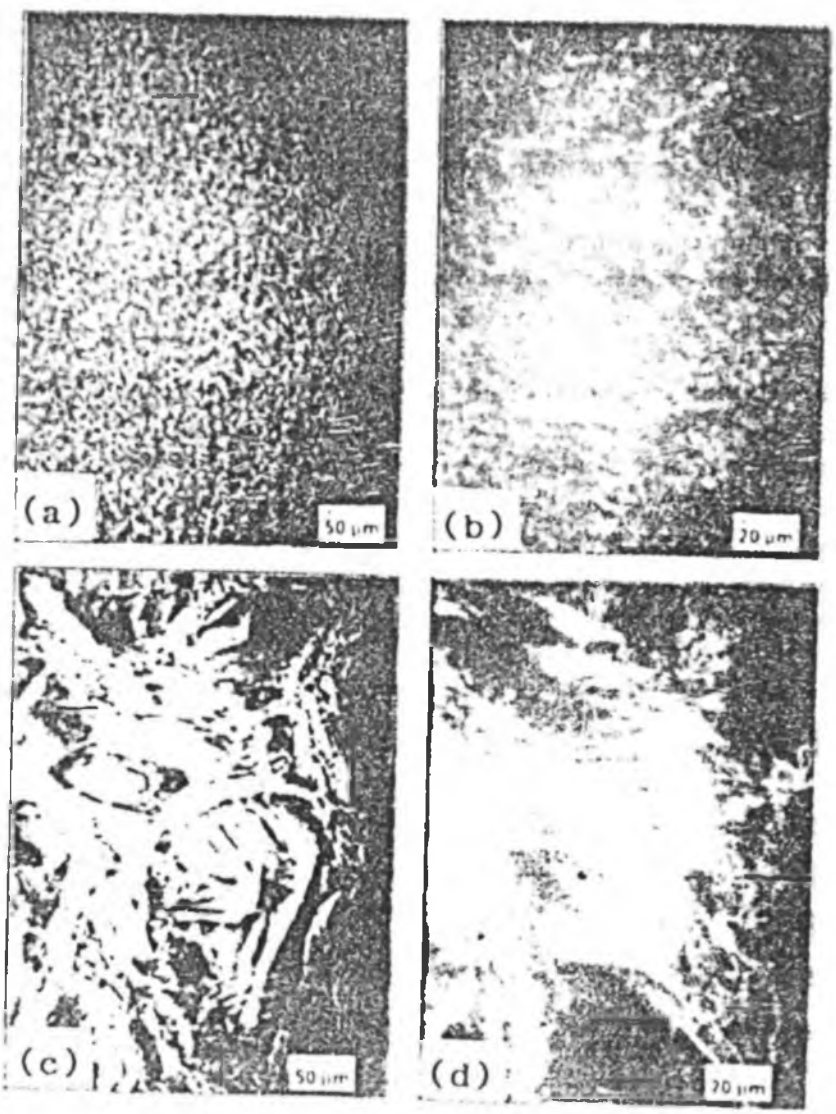


FIG. 2.—Fluorescence photomicrographs: (a), 8%*ac* in Asphalt B, 120 ×; (b), 8%*ac* in Asphalt B, 300 ×; (c), 16%*ac* in Asphalt B, 120 ×; (d) 16%*ac* in Asphalt B, 300 ×.

(less than 200 nm) are required in the STEM analysis. Polymer-asphalt mixtures were prepared for STEM analysis in the following way. The sample was spread on release paper with a sample thickness of approximately 3 mm. Because of its pliable nature, handling of the sample required the use of cold tools. Tweezers and the cutting blade utilized in the preparation were cooled in liquid nitrogen prior to use. A 1 cm sided triangle of material was cut from the sample and mounted in a cryomicrotome holder. The triangle was then faced as in standard microtoming procedures utilizing cooled tools. The faced sample was then allowed to recover at room temperature for a period of one hour.

The bulk faced sample was immersed in 2% osmium tetroxide (OsO_4) solution to specifically stain the unsaturated rubber component of the polymer. Additionally, by staining the sample, the internal structure became fixed, facilitating subsequent preparation procedures. The sample temperature was set at −5°C and the diamond knife at −30°C. Sections approximately 150 nm thick were cut and then analyzed. The neat asphalts exhibit very little adsorption.

Fluorescence microscopy.—Fluorescence measurements were carried out on a Zeiss Inverted Metalograph* microscope. With the fluorescence microscopy technique, the asphalt-rich phase appears dark, while the polymer-rich phase appears light (*cf.*, Figure 2). When asphalt is broken down into its broad components however, we see that the naphthenic and polar aromatics appear light, while the asphaltenes and saturates appear dark (*cf.*, Figure

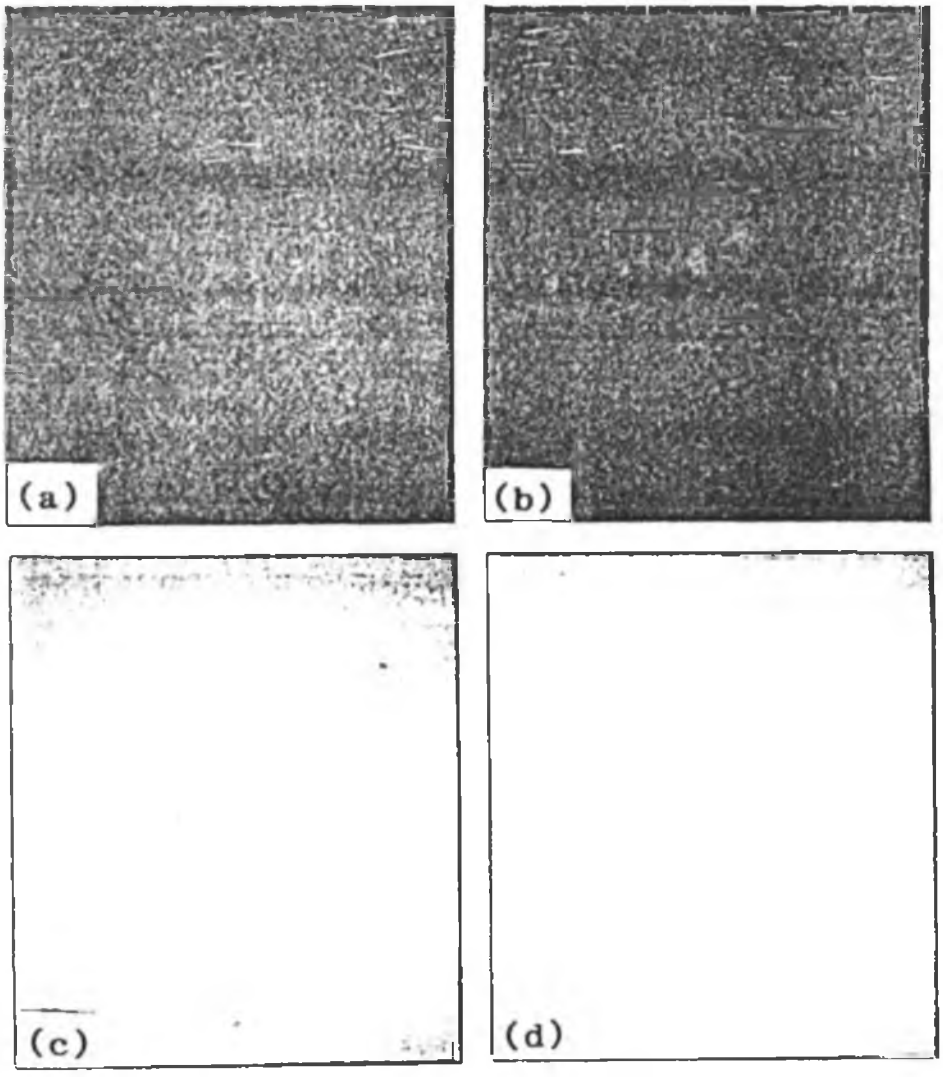


FIG. 3.—Fluorescence photomicrographs; (a), asphaltenes, 2 min exposure time, magnification 300 ×; (b), saturates, 2 min exposure time, magnification 300 ×; (c) polar aromatics, 2 s exposure time, magnification 300 ×; (d), naphthenes, 1/30 s exposure time, magnification 300 ×.

3). Note that the rubber, which appears as the bright phase under fluorescence and also optical microscopy, shows up as the dark phase in STEM.

ASPHALT CEMENT CHARACTERIZATION

Table I gives the composition of the base asphalts used in this study as derived by clay gel analysis (ASTM D 2004). The Deer Park asphalts, Asphalt C through G, grades AC-5 to AC-40, are blends of a solvent deasphalted stream and a road flux which were analyzed separately and the compositions of each subsequently calculated.

DYNAMIC MECHANICAL TESTING

Small-amplitude oscillatory shear experiments are probably the most frequently used rheological method to characterize polymer modified asphalts[9]. All dynamic mechanical measurements presented in this work have been carried out on a Rheometrics® RMS800 using a plate–plate geometry. The gap height was generally in a range between 1.5 to 2.2 mm. The platen diameters were varied depending on the stiffness of the sample (*i.e.*, AC grade) and the operating temperature. For an AC-5 asphalt the following ranges were used:

$$T > 60°C \qquad r = 25.0 \text{ mm},$$

$$25° < T < 60°C \qquad r = 12.5 \text{ mm},$$

$$5° < T < 25°C \qquad r = 6.25 \text{ mm}.$$

In many cases, we observed that, even though the torque values were well within the normal limits of the instrument and no apparent anomalies (*e.g.*, bumps in the curve) were present, larger platens led to smaller values of G' than small platens. We have some evidence that this is due to slip. It is, therefore, in many cases, worthwhile repeating the measurements with a smaller diameter geometry to assure that slip does not occur. We also experimented with grooved plates, which should reduce slip at low temperatures. The data obtained with these platens were commensurate with those obtained with smooth platens. However, we believe that the groove height should be sufficiently small compared to the gap (*i.e.*, $h_{gap}/h_{groove} > 100$) and surface corrections must be applied. Special care must be taken to ensure that the platens are parallel.

A crucial problem is compliance of the rheometer (the transducer is not infinitely stiff). At low temperatures ($T \leq 25°C$) the instrument gives correct data only over a very limited

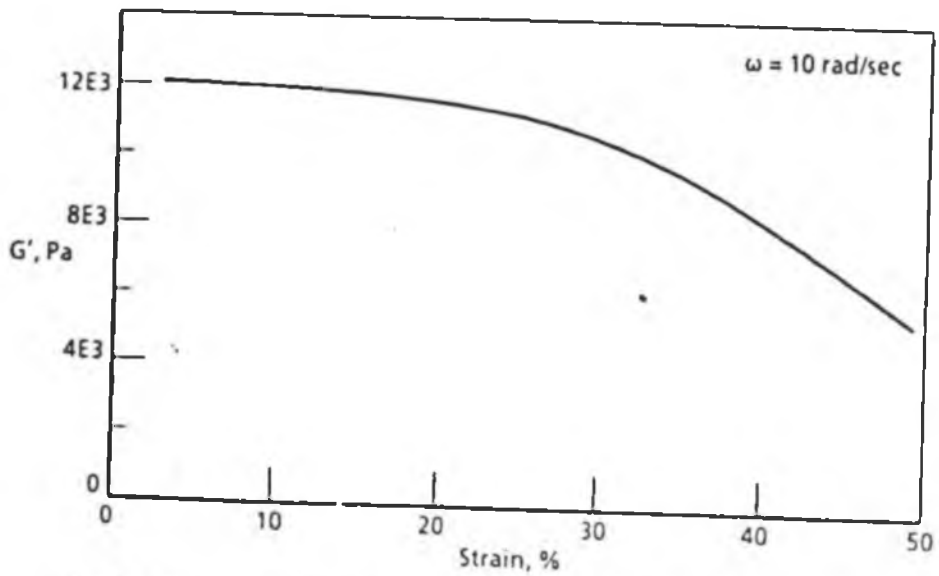


FIG. 4.—Strain dependency of the storage modulus of Asphalt F at 40°C.

TABLE II

TYPICAL TEST PROCEDURE

15 min	60°C
frequency sweep at 60°C	
15 min	40°C
frequency sweep at 40°C	
15 min	32.5°C
frequency sweep at 32.5°C	
15 min	25°C
frequency sweep at 25°C	
15 min	60°C
rerun of the frequency sweep at 60°C	

range. This problem limits the accessible temperature range. Also, a crucial requirement is that the frequency sweeps are carried out within the linear viscoelastic range, *i.e.*, that the material functions (*e.g.*, G', η^*) are independent of the applied strain levels. Generally, strain sweeps are applied to determine if this is the case (*cf.*, Figure 4). However, in the case of asphalts and polymer-modified asphalts, we found that this technique may fail. Therefore, we ascertained that we were operating in the linear viscoelastic range by conducting frequency sweeps at two strain levels at which we believed $G'(\omega) \neq f(\gamma)$. If the data are equivalent at both strain levels, one may assume to be in the linear viscoelastic range over the entire range of frequencies. If this was not the case, the strain was reduced until the frequency sweeps of the two smallest strain levels were commensurate.

In order to obtain satisfactory results, it is essential to establish exact procedures on how to carry out the measurements. This is especially important, as many of these systems may not be in thermodynamic equilibrium (*e.g.*, a homogeneous polymer/asphalt "solution" may exist at the mixing temperature T_{mix}, whereas the equilibrium state at ambient temperature may be a two-phase system). In the following, we will give a brief overview of how the samples were handled.

The samples were cast on nonadhesive paper, put into plastic bags, and stored at 25° ± 3°C. Generally the samples were measured within a period of 5 to 7 days after blending

TABLE III

COMPARISON OF POLYMER B (SBS) AND POLYMER C (SBR) MODIFIED ASPHALT BLENDS

Blend identification	Asphalt C	Asphalt C with 4%*w* Polymer C	Asphalt C with 4%*w* Polymer B
Properties			
Penetration, dmm			
100 g, 5 s @ 25°C	150	105	116
200 g, 60 s @ 4°C	35	37	36
Ring & ball softening point, °C	39	49	47
Ductility, cm			
5 cm/min @ 4°C	150+	150+	102
Elastic recovery, %			
1 h @ 4°C	15	62	72
Absolute viscosity			
Pa·s @ 60°C	53.4	235.2	430.9
Asphalt Institute Tube #	50	200	200
Kinematic viscosity			
cm^2/s @ 135°C	1.93	23.75	5.36
Zeitfuchs Crossarm			
Viscometer Tube #	5	8	6

TABLE IV

EFFECT OF ASPHALT COMPOSITION

Blend identification	Asphalt C	Asphalt C with 4%w Polymer B	Asphalt A	Asphalt A with 4%w Polymer B	Asphalt B	Asphalt B with 4%w Polymer B
Properties						
Penetration, dmm						
100 g, 5 s @ 25°C	150	116	117	89	153	79
200 g, 60 s @ 4°C	35	36	25	25	56	40
Ring & ball softening point, °C	39	47	39	66	40	63
Ductility, cm						
5 cm/min @ 4°C	150+	102	62	90	31	54
Elastic recovery, %						
1 h @ 4°C	15	72	13	65	20	80
Absolute viscosity						
Pa·s @ 60°C	53.4	430.9	67.3	4091	73.4	549.1
Asphalt Institute Tube #	50	200	100	400R	100	200
Kinematic Viscosity						
cm^2/s @ 135°C	1.03	5.36	1.39	4.82	2.67	12.19
Zeitfuchs Crossarm						
Viscometer Tube #	5	6	5	7	5	6

in order to avoid any kind of aging effects. In the case of the Asphalts A and C (and their blends), we found no changes of the physical properties over a time period of 28 days. It cannot, however, be granted that this is also the case in less compatible systems. The samples were treated as shown for one typical case in Table II. In all cases, the measurements were carried out beginning at the highest temperature and subsequently reducing the operation temperature. After the final measurement, the sample was brought to the initial temperature and the measurement repeated. Only if these data were equivalent to the initially obtained data, then the data of the measuring cycle were used. This is very important, as shear and temperature history can influence the morphology and rheological behavior of the system. The testing mode just described ensures that such effects are minimized.

COMPRESSION-TENSION TESTING

Due to the compliance problem with the RMS800, we carried out low-temperature measurements on the Rheometrics Solids Analyzer® (RSA) in cooperation with Professor Chartoff from the University of Ohio, Dayton. For this instrument, the neat bitumen and modified binders were molded into rectangular bars at a temperature between 80 and 100°C and then let cool down to ambient temperature for 24 h. The measurements were taken at −30°C.

The dynamic moduli E' and E'' were determined using a three-point bending geometry. The advantages of this technique are:

- Compliance problems are not encountered (moduli up to 10 GPa can be measured).
- The strain levels were extremely small so that linear viscoelasticity was ensured (strain ~0.05%).

TRADITIONAL PAVING BINDER TESTS

Both neat and polymer-modified AC's were subjected to traditional physical tests which are commonly used in the asphalt paving industry. Most of these methods are described in ASTM and include such methods as follows:

TABLE V

THE EFFECT OF BASE ASPHALT GRADE

Blend identification	Asphalt C AC-5		Asphalt D AC-10		Asphalt E AC-20		Asphalt F AC-30		Asphalt G AC-40	
	0%	4%ae Polymer B	0%	4%ae Polymer B	0%	4%ae Polymer B	0%	4%ae Polymer B	0%	4%ae Polymer B
Properties										
Penetration, dmm										
100 gm, 5 s @ 25°C	150	107	97	72	55	43	39	33	33	28
200 gm, 60 s @ 4°C	35	32	26	23	14	15	8	10	9	9
Ring & ball softening point, °C	39	52	42	55	45	58	49	61	51	59
Ductility, cm										
5 cm/min @ 4°C	150+	86	6	53	0	0	0	0	0	0
Elastic recovery, %										
1 h @ 4°C	15	75	Fail	73	Fail	Fail	Fail	Fail	Fail	Fail
Absolute viscosity										
Pa·s @ 60°C	53.3	584.6	103.8	405.6	255.7	702.6	364.0	957.7	496.4	1160
Asphalt Institute Tube #	100	200	100	200	100	200	200	200	200	200
Kinematic viscosity										
cm^2/s @ 135°C	1.93	6.22	2.47	7.66	3.62	10.0	4.29	11.1	4.45	13.1
Zeitfuchs Crossarm										
Viscometer Tube #	5	6	5	7	7	7	7	7	6	7

TABLE VI

EFFECT OF INCREMENTAL ADDITION OF POLYMER B (SBS) *VERSUS* POLYMER C (SBR) TO ASPHALT C

Blend identification	0%	Polymer B						Polymer C					
		1.4%*w*	2.0%*w*	3.0%*w*	4.0%*w*	5.0%*w*	6.0%*w*	1.4%*w*	2.0%*w*	3.0%*w*	4.0%*w*	5.0%*w*	6.0%*w*
Properties													
Penetration, dmm													
100 gm, 5 s @ 25°C	150	133	128	118	116	103	96	140	133	122	105	114	119
200 gm, 60 s @ 4°C	35	34	34	35	36	35	35	36	36	37	37	40	41
Ring & ball softening point, °C	39	40	42	46	47	69	85	40	40	46	49	52	52
Ductility, cm													
5 cm/min @ 4°C	150+	138	114	103	102	102	107	150+	150+	150+	150+	150+	150+
Elastic recovery, %													
1 h @ 4°C	15	50	58	70	72	78	80	40	45	55	62	62	65
Absolute viscosity													
Pa·s @ 60°C	53.4	114.2	191.8	298.3	430.9	20 700	Would not flow	90	102	163.1	235.1	330.7	351.4
Asphalt Institute Tube #	50	100	100	200	200	400R		100	100	100	200	200	200
Kinematic Viscosity													
cm^2/s @ 135°C	1.93	2.76	3.31	4.64	5.35	8.59	22.5	4.32	9.97	12.9	23.7	43.7	41.6
Zeitfuchs Crossarm Viscometer Tube #	5	5	6	6	6	6	7	5	6	7	8	8	8

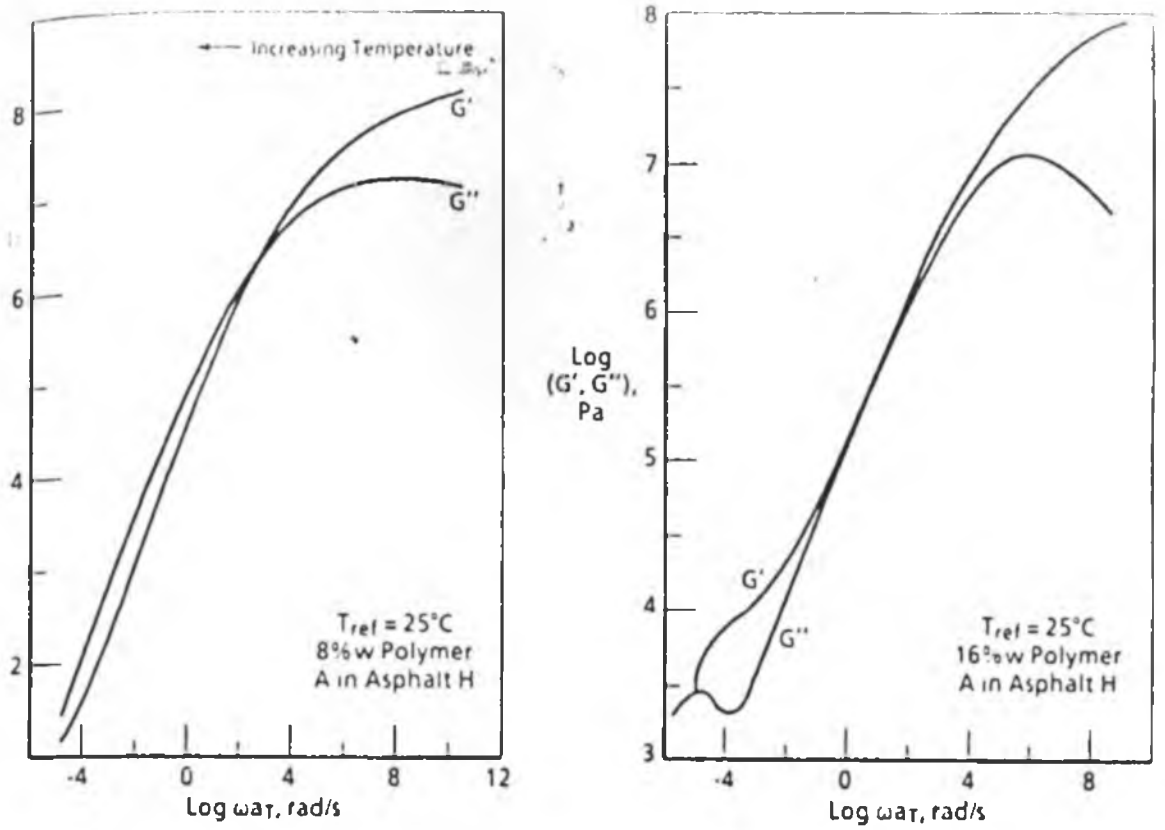


FIG. 5.—Dynamic data.

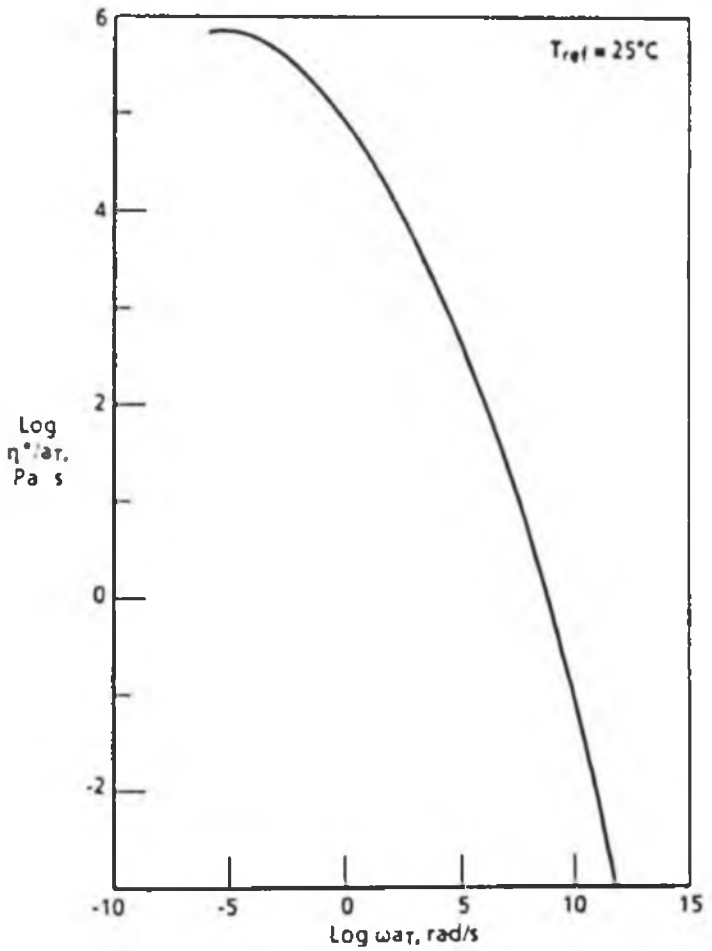


FIG. 6.—Dynamic data of 5%w Polymer A in Asphalt H.

Penetration at various temperatures	ASTM D 5
Ring and ball softening point	ASTM D 36
Absolute viscosity @ 60°C	ASTM D 2171
Kinematic viscosity @ 135°C	ASTM D 2170
Ductility @ 4°C	ASTM D 113

Elastic recovery, toughness, and tenacity are not ASTM methods, but are described in References 10 and 11, respectively. The test described in Reference 10 is an extension of the routine ductility test (ASTM D 113-85 or AASHTO-T51) and the Kentucky specification. When the specimen is extended 10 cm, the distressed area is severed in the middle by a pair of shears. After one hour at the test temperature, 4°C, the severed distressed ends are returned to contact, and the ductilometer is read again. These results are included for reference and intended to be descriptive only, as no rigorous analysis of them is included. These data are shown in Tables III–VI.

RESULTS AND DISCUSSION

RHEOLOGY OF POLYMER-MODIFIED ASPHALTS

The polymer is added to give the binder improved end-use properties such as reduced creep at high temperatures, less brittleness at low temperatures, and better impact properties at intermediate temperatures. Figure 5 shows examples of the response of viscoelastic polymer-modified bitumen in oscillatory shear flow. The actually obtained curves are a function of polymer type, asphalt, temperature, and other factors.

According to Ferry[12], the storage modulus *vs.* frequency plot can be subdivided into four zones:

- a terminal or flow zone,
- a plateau zone (only present in the case of a network),

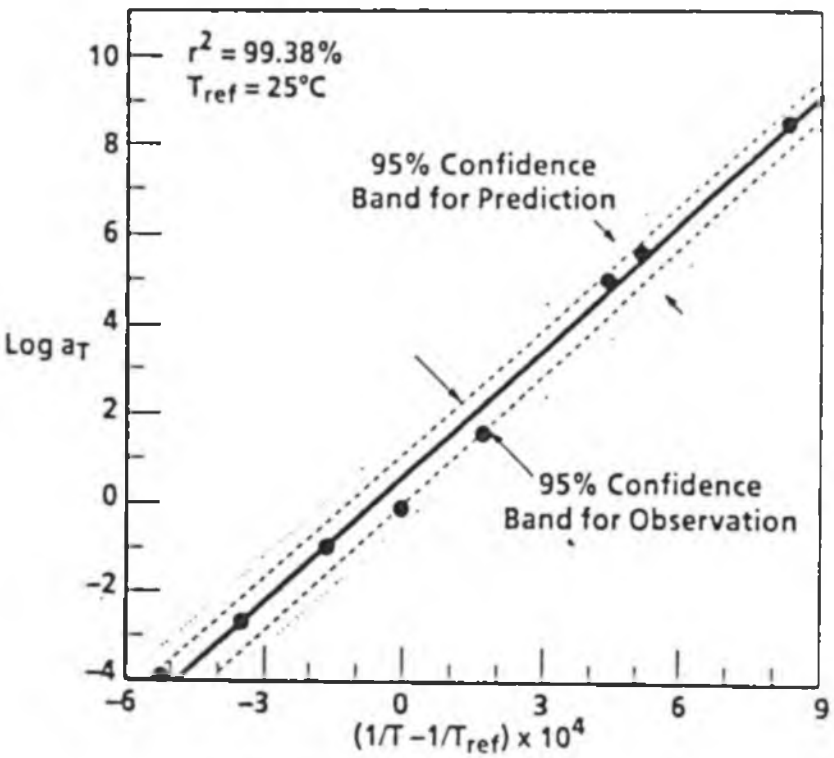


FIG. 7.—85/*x* Polymer A in Asphalt H.

- a transition zone, and
- a glassy zone.

At each concentration level, G' and G'' were measured in the linear viscoelastic range. For all the blends studied, time–temperature superposition was found to be valid over the entire temperature range. This is interesting, as this principle does not apply for neat block copolymers.

The time–temperature superposition principle can be expressed as:

$$G(t, T_{ref}) \approx G(t/a_T, T), \tag{1}$$

where

$$A_T = a_T(T, T_{ref}) \tag{2}$$

is called the shift factor and depends, for a given system, only on the temperature. Thus, G', G'' *vs.* ω curves, obtained at different T levels, can be shifted horizontally along the t-axis in such a way that they overlap and form one master curve at some arbitrarily chosen reference temperature, T_{ref}.

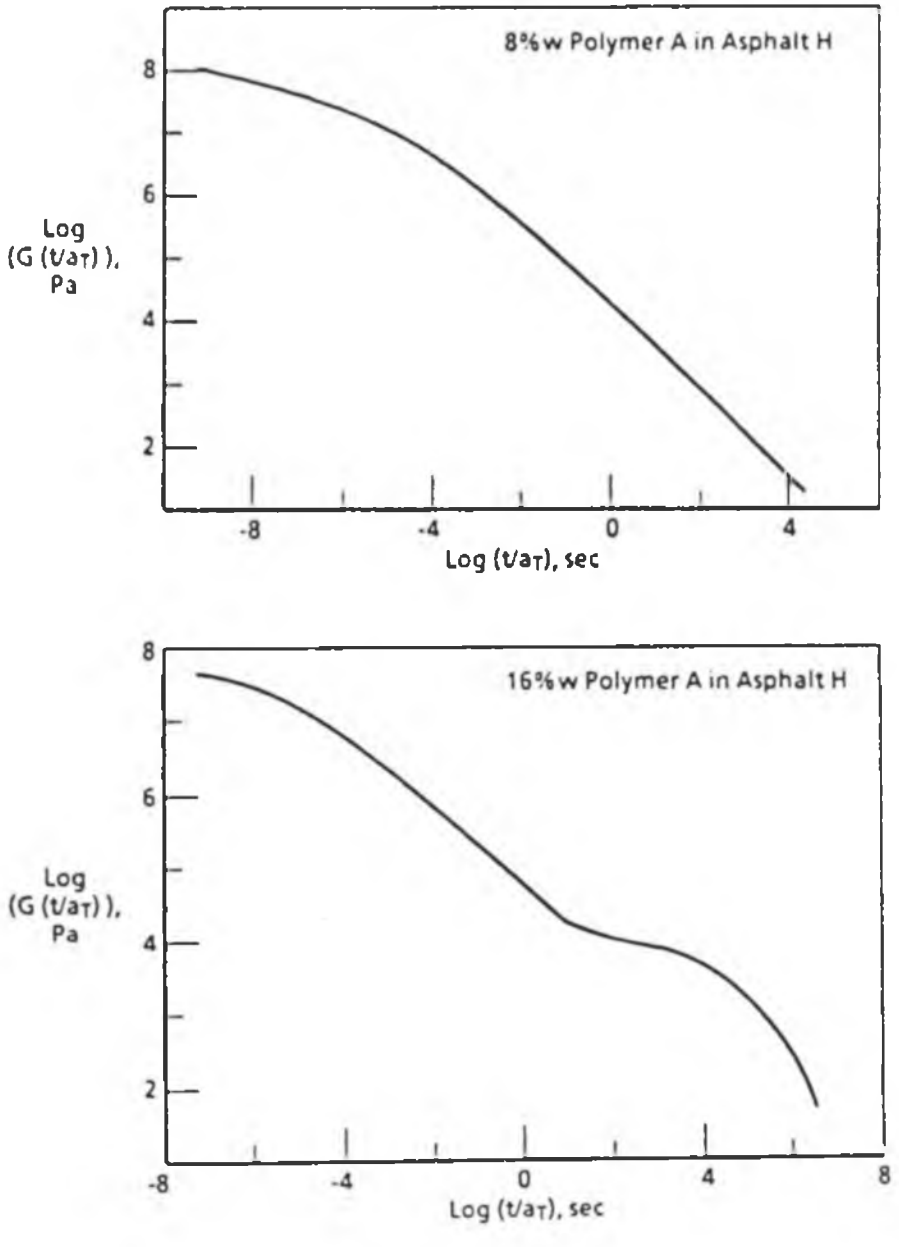


FIG. 8.—Linear shear relaxation modulus fit.

The master curve shown in Figure 5 was obtained by paying close attention to the position of the crossover frequency, where $G'(\omega) = G''(\omega)$. In practice, some minor vertical shifting may also be necessary to account for changing densities at different Ts. However, for the systems investigated here, no corrections were necessary. This standardization technique can also be used for the complex viscosity, η^*, as shown in Figure 6.

In all cases studied, the shift factors were found to fit an Arrhenius relationship given by:

$$\log a_T = \left\{ \frac{\Delta E_{ref}}{2.303R} \left(\frac{1}{T} - \frac{1}{T_{ref}} \right) \right\}. \tag{3}$$

The resulting fit for the 5%w Polymer A in Asphalt H blend is shown in Figure 7. For all the blends covered in the study, Equation (3) fits the data within $99.38\% \leq r^2 \leq 99.80\%$. As polymer concentration was increased beyond 5%w Polymer A (*i.e.*, 2.5% Polymer B), it was observed that a rubbery plateau gradually formed in the master curves, indicating some sort of network evolution. This can be seen by comparing the master curves for the 8%w Polymer

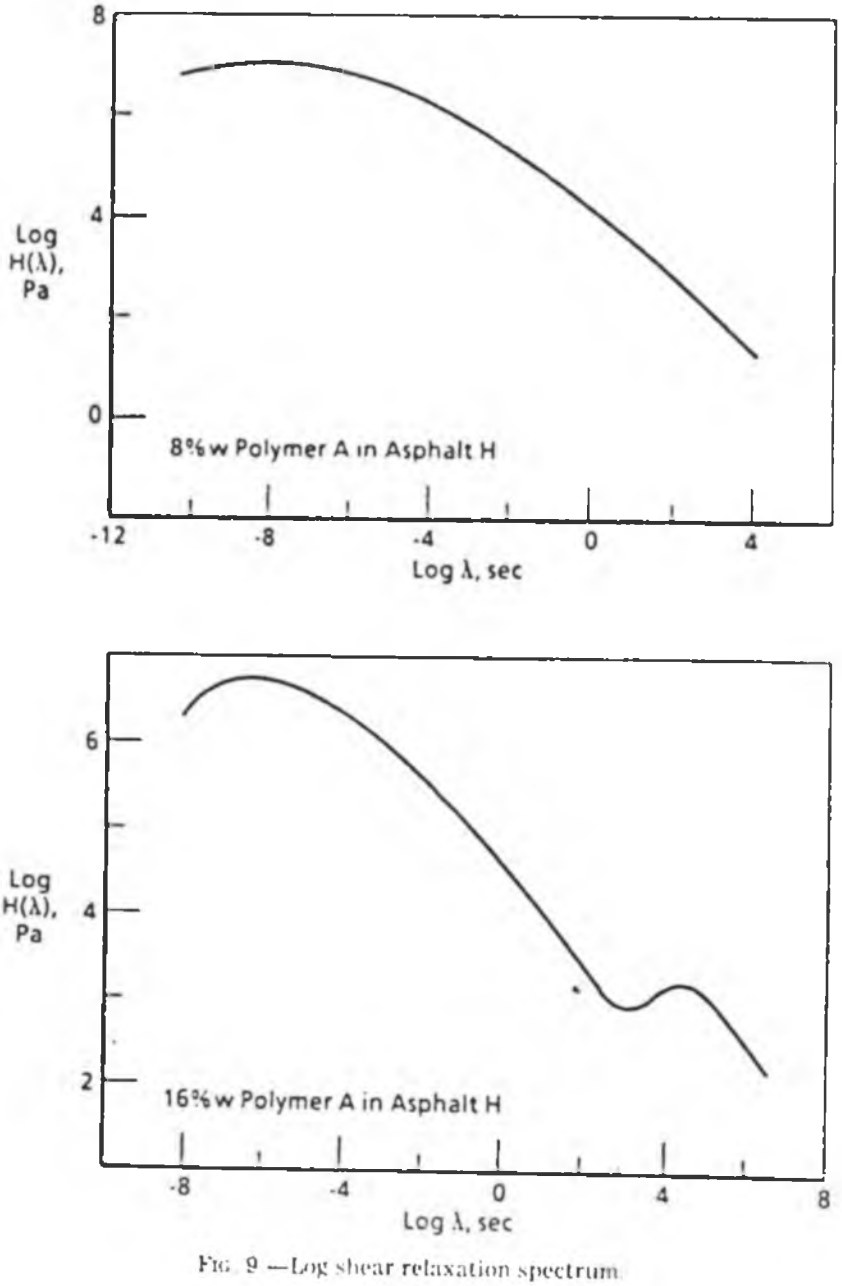


FIG. 9 —Log shear relaxation spectrum

A and the 16%w Polymer A curves, as shown in Figure 8. When the neat asphalt (Asphalt H, AC-10) master curve is compared with the curve for the sample containing 16%w Polymer A, the lack of a network structure is evident.

The dynamic moduli G', G'' were then used to obtain the linear viscoelastic shear relaxation modulus, $G(t)$, *via* the approximation method of Ninomiya and Ferry[13] given by:

$$G(t) = [G'(\omega) - 0.40G''(0.40\omega) + 0.014G''(10\omega)]_{\omega=1/t}. \quad (4)$$

An example is shown in Figure 9.

Figure 10 also shows the fits to the $G(t)$ master curves in the form:

$$G(t) = \sum_i G_i e^{-t/\lambda_i}. \quad (5)$$

Having obtained the relaxation modulus, we then calculated the approximate relaxation spectra, via[12]:

$$H(\lambda) = \frac{2}{\pi}\left[G'(\omega) - \frac{a}{(a-1)^2}[G''(a\omega) + G''(\omega/a) - 2G''(\omega)]\right]_{1/\omega=\lambda}, \quad (6)$$

with $\log a = 0.2$. Figure 10 shows the retardation spectrum for 8%w and 16%w of Polymer A in Asphalt H. Note that a distinct maximum appears in the relaxation spectrum of the 16%w blend, whereas the corresponding spectrum for 8%w changes monotonically with λ. The peak in H is, again, indicative of the presence of a network-like structure. Also note that with the 16%w blend, the peak of $H(\lambda)$ occurs at $\log \lambda \sim 5$.

Preliminary results on a small number of asphalts and asphalt blends indicate that the Cox-Merz[14] rule applies (*cf.* Figure 10), *i.e.*, that $\eta = \eta^*$ for $\dot{\gamma} = \omega$. However, it should be noted that steady-shear experiments on modified asphalts are not easily carried out. At shear rates as low as 0.3 s^{-1}, flow anomalies can occur and, thus, the obtained viscosity numbers are not necessarily meaningful.

In the literature[6], repeated attempts have been undertaken to correlate the loss tangent with the results obtained from traditional mixture tests. We found that it is generally difficult to obtain accurate values for tan δ, especially at low polymer concentrations and elevated temperatures. This is shown in Figures 11a to 11c. For the neat Asphalt C, we have plotted the loss tangent *vs.* the reduced frequency. Obviously, in the case of unmodified asphalts, the results are very unsatisfactory. With increasing polymer concentration (we have plotted

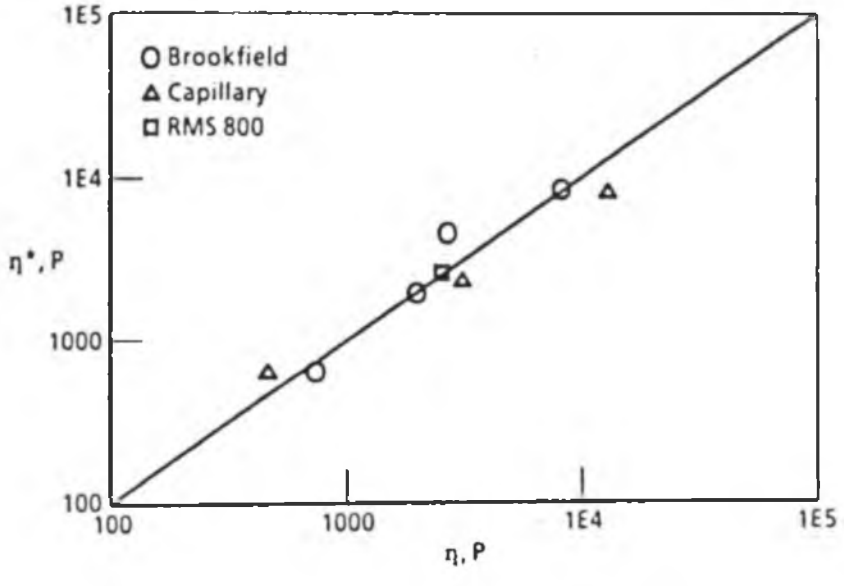


FIG. 10.—Comparison of η^* and η for various asphalt/SBS blends.

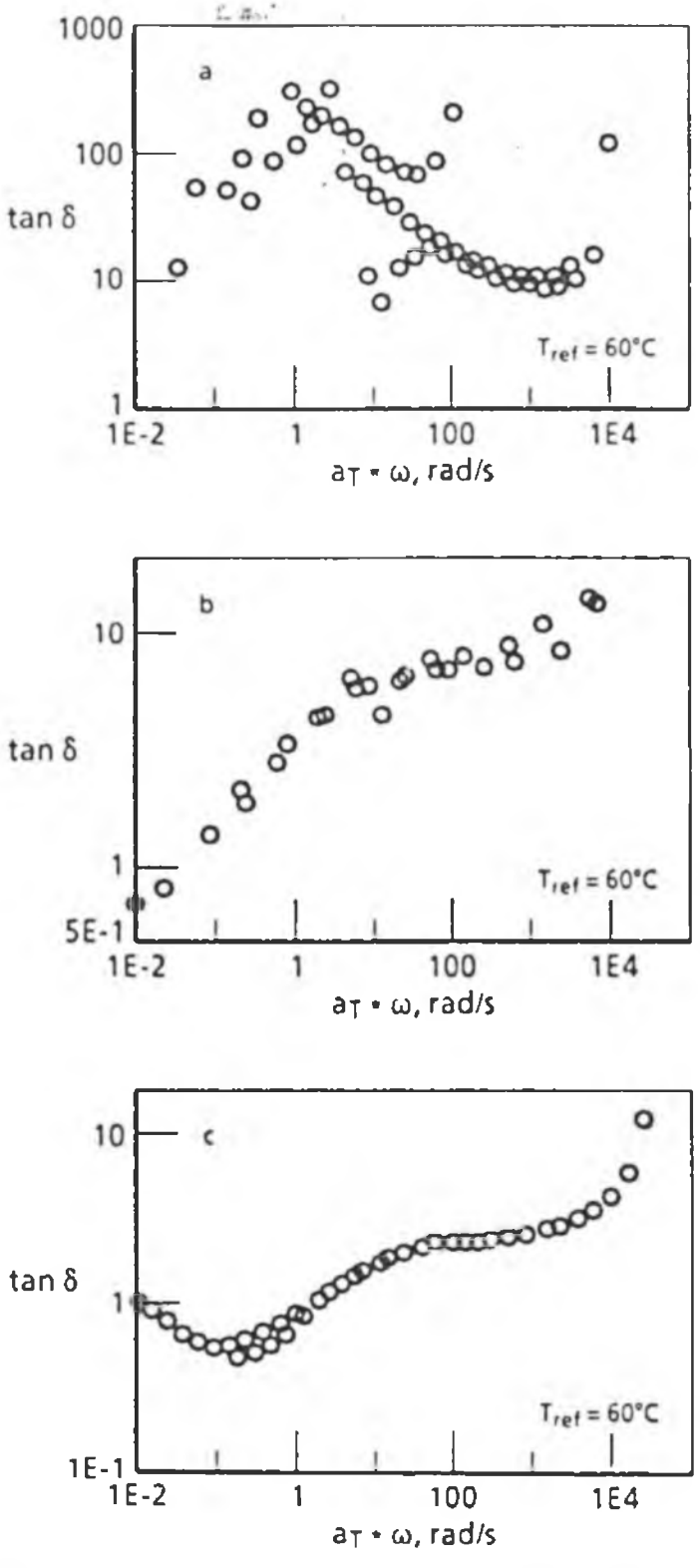


FIG. 11.—Tan δ *vs.* the reduced frequency; a, Asphalt C; b, 2%*w* Polymer B in Asphalt A; c, 6%*w* Polymer B in Asphalt C.

two typical cases), the results become steadily better. However, we do advise being cautious when using tan δ as a predictive tool.

INFLUENCE OF THE POLYMER ON THE BINDER PROPERTIES

For optimal performance at elevated temperatures, it is essential that a network be present. In this case, a plateau range is formed, and the elastic response of the system can become



FIG. 12.—STEM photomicrograph of Polymer B (SBS) in Asphalt C; magnification: 40,000 ×.

virtually temperature independent over a wide temperature range (or the decrease of the complex modulus, G^*, and the storage modulus, G', becomes negligibly small compared to the neat asphalt). However, whether a polymer/asphalt system will form a network is determined by various factors:

(i) the polymer concentration,
(ii) the chemical nature of the polymer (*e.g.*, block copolymer, SBR latex, . . .),
(iii) the physical properties of the polymer (*e.g.*, M, degree of branching, . . .), and
(iv) the nature of the interactions between the polymer and the asphalt.

In this section we will center our interest on points (i) through (iii). Point (iv) will be addressed in the following section.

In the case of a linear random coil polymer, it has been demonstrated that there is a critical concentration, c^*, the so-called overlap concentration, at which the coils overlap and form a polymeric network[15]. This concentration depends on a variety of parameters. However, for a given polymer, the molecular weight and the nature of the polymer/solvent (solvent = asphalt) interactions are the determining parameters[15,16]. The formation of such a network-like structure leads necessarily to a dramatic increase of the viscosity and even more so of the elasticity of the system[17]. Hence, one would ultimately want to ensure that the solution exhibits a network-like structure (*i.e.*, $c > c^*$).

TABLE VII

ESTIMATED CRITICAL OVERLAP CONCENTRATION

Asphalt	Polymer	c^*, %m
A	B	~2
B	B	>4
C	B	3
C	C	~4

In the case of block copolymers and SBR lattices, the situation becomes somewhat more complicated. A network-like structure is an inherent characteristic of these polymers, i.e., even for $c \rightarrow 0$, a network is present within the micelles (or latex particles). This is the case provided the micellar structure of the block copolymers prevails and the solution is non-homogenous.

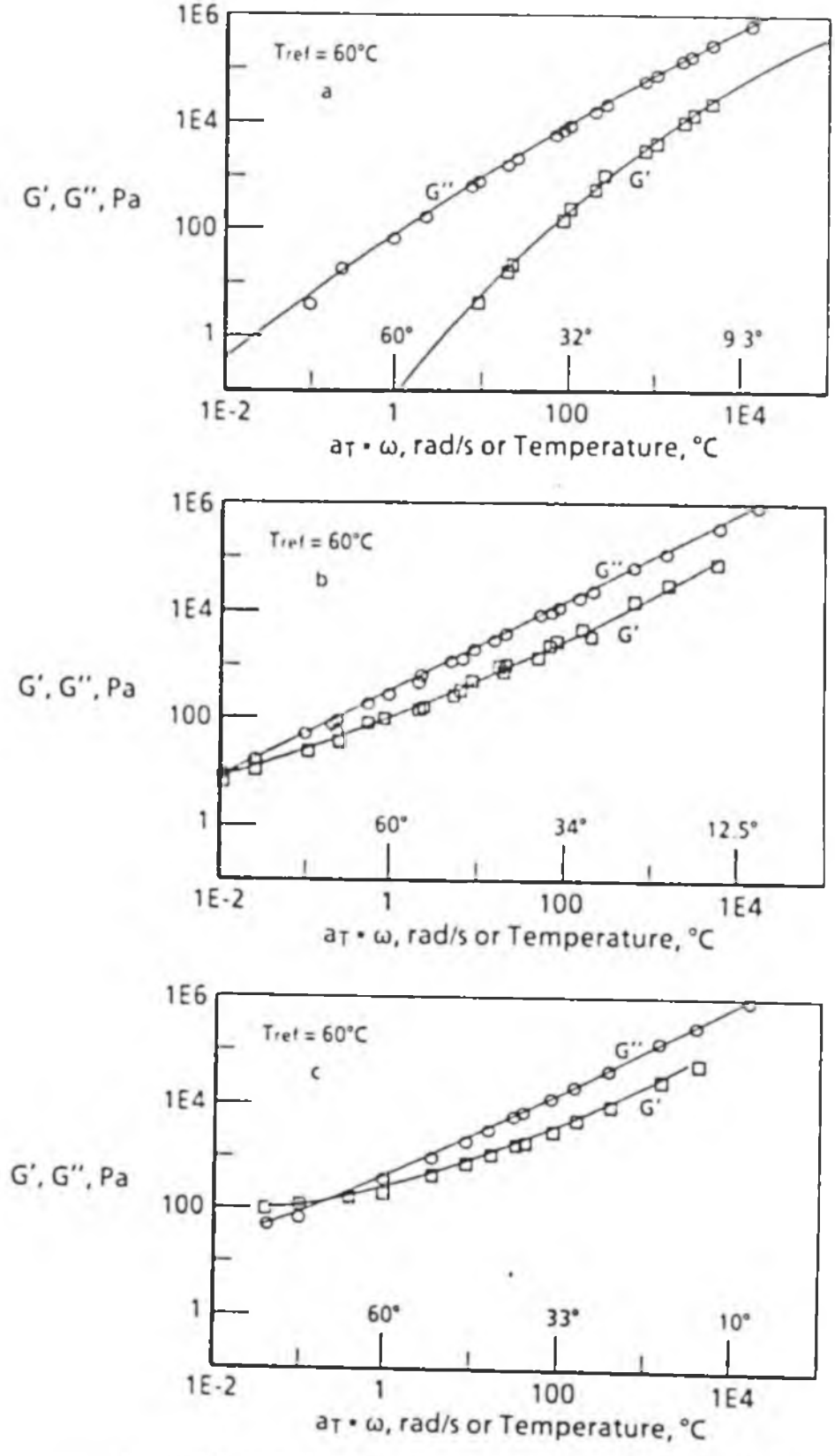


FIG. 13.—Time-temperature superposition: a, Asphalt C; b, 4% Polymer C in Asphalt C; c, 4% Polymer B in Asphalt C.

Microscopy studies carried out in our laboratories show that in all asphalts we have studied, the micellar structure is stable, and no homogeneous solutions are obtained, *i.e.*, the block copolymers are phase separated. This is shown in Figure 12. However, the largest boost of the rheological response is found when the micelles or lattices form a continuous network throughout the binder[18]. In Table VII, c^* is shown for various polymer/asphalt systems; c^* is the concentration where a network is formed and a plateau modulus appears. A more comprehensive discussion of the influence of the structure of the block copolymers was presented several years ago[19].

In the case of Polymer A in Asphalt H, the photomicrographs (fluorescence) indicate that around 8%*w* neat polymer, changes of the morphology occur (*cf.*, Figure 2). This is supported by the dynamic mechanical data (*cf.*, Figure 5). For a concentration larger than 8%*w* polymer, a pronounced plateau modulus can be detected. Note, however, that for complex morphologies as block copolymers or even lattices, the molecular weight of the segment between two entanglements cannot be simply calculated from the plateau modulus.

The formation of a network can also be shown, as previously mentioned, in the relaxation time spectrum H (log λ) (or retardation time spectrum)[20]. Some thirty years ago, Ferry, Landel, and Williams showed that a shift in the relaxation times is caused by intermolecular entangelements[21] ($\lambda_{network} = h \cdot \lambda_{Rouse}$). As shown in Figure 9, the relaxation times are indeed shifted.

Besides concentration effects, we also studied how different molecular structures influence the viscoelasticity and morphology of polymer/asphalt blends. We carried out dynamic mechanical measurements on blends of SBR latex (Polymer C) and SBS block copolymer (Polymer B) in Asphalt C.

In Figure 13, the master curves are shown for these blends as well as for the neat asphalt. At a polymer concentration of 4%*w* in Asphalt C, the Polymer B (SBS) forms a network, whereas the Polymer C (SBR) does not lead to a continuous network. Therefore, in the case of the latex, the viscous component G'' is always larger than the elastic component G'.

In Table VIII, the performance of the modified bitumens is demonstrated on the basis of two characteristic ratios, $G'_T[G'(25°C)/G'(60°C)]$ and $G'_m/G'_u[G'(60°C, \text{modified})/G'(60°C, \text{unmodified})]$. These moduli are measured at a frequency of 1 rad/s, which may approximate truck-traffic conditions. The first ratio is a measure of the temperature susceptibility of the elasticity of the system, whereas the second ratio gives us a feeling for how much the elasticity has been boosted by the addition of the polymer. Consequently, one would ultimately want the resulting blend to exhibit small values of G'_T and large values of G'_m/G'_u. At a polymer level of 4%*w*, Polymer B (SBS) shows significantly reduced temperature susceptibility relative to blends containing 4%*w* of Polymer C (SBR) in the same asphalt. Both, however, exhibit significant improvement *versus* the neat base asphalt. The addition of Polymer B in Asphalt

TABLE VIII

INFLUENCE OF ASPHALT CHOICE AND POLYMER ON RESULTING ELASTICITY

Asphalt	c, %*w*	Polymer	G', Pa (T = 60°C, ω = 1)	G', Pa (T = 25°C, ω = 1)	G'_T	G'_m/G'_u
A	0		~0.01	1 142	~114 200	—
B	0		~1	15 870	~15 870	—
C	0		~0.035	1 466	~41 890	—
A	4	B	192	14 850	78	19150
B	4	B	247	38 590	156	247
C	4	B	260	14 850	57	7428
C	4	C	94	14 690	156	1695

C was found to increase the elasticity at 60°C (ω = 1 rad/s) by a factor of approximately 4.4 relative to the Polymer-C-modified Asphalt C, while simultaneously reducing the temperature susceptibility by a factor of approximately 2.8. This can be attributed to the network-forming capability of the block copolymer. SBR (C) would require higher polymer concentrations and/or higher molecular weights which can lead to problems in mixing.

INFLUENCE OF ASPHALT ON MODIFIED BINDER PROPERTIES

In order to obtain a blend with optimal properties, it is essential to assure that the appropriate asphalt is chosen, *i.e.*, the asphalt and polymer must be (at least to some degree) compatible. We believe that the choice of incompatible systems has, in some cases, led to poor results for polymer-modified bitumens in the literature. Improved compatibility leads to the following enhancements:

- reduced mixing time at reduced mixing speeds,
- improved bulk-storage stability, and
- micelles are swollen to a higher degree and, hence, form a continuous network-like structure at lower concentrations.

As discussed in the previous section, a network will lead to a boost of the binder properties, *i.e.*, the elasticity of the system is significantly enhanced and, thus, the system recovers to a much higher degree after a given loading (less susceptible to permanent deformation). This increase of the elasticity as measured in a dynamic mechanical measurement is shown in Figure 14. Obviously, the sample containing 4%*w* Polymer B (SBS) in the Asphalt B is not very well dispersed, and no network is formed (*cf.* Figure 15). The frequency sweep indicates no plateau. In the case of the more compatible Asphalt A, a pronounced plateau of G' is observed. This finding is supported by the photomicrograph (Fig. 15), which indicates the formation of a polymeric network. A comparison of the elasticity and temperature susceptibility of asphalts with different degrees of compatibility are given in Table VIII. Increased compatibility leads to reduced temperature susceptibility and improved thickening efficiency

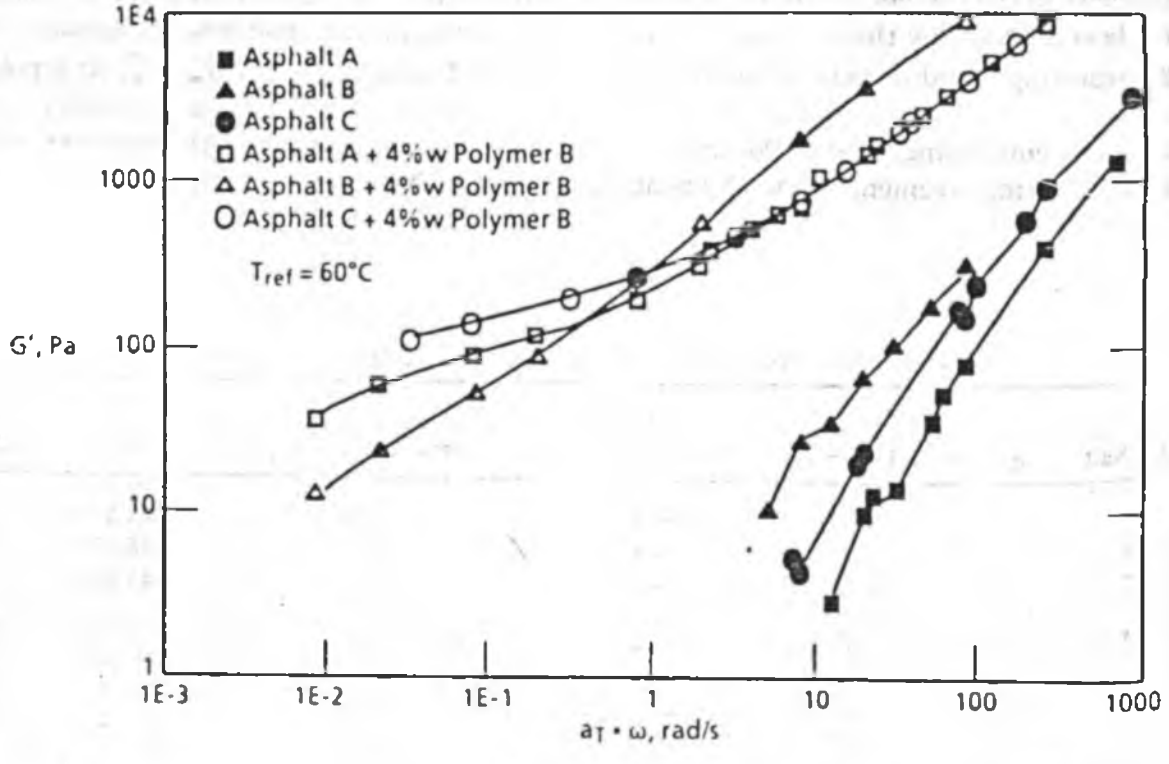


FIG. 14—Storage modulus as a function of the reduced frequency for various different binders.



Asphalt A

Asphalt B

Asphalt C

FIG. 15.—[illegible] of Polymer B (SBS) in different asphalts.

TABLE IX

INFLUENCE OF AC-GRADE AND POLYMER ON ELASTICITY

Asphalt	AC Grade	c, %w	Polymer	G', Pa (T = 60°C, ω = 1)	G', Pa (T = 25°C, ω = 1)	G'_T	G'_m/G'_n
C	5	0		~0.035	1 466	~41 890	—
D	10	0		~0.5	9 768	~19 536	—
E	20	0		~1.21	28 280	~23 370	—
F	30	0		~1.89	36 240	~19 175	—
G	40	0		7.9	69 650	8 816	—
C	5	4	B	260	14 850	57	7428
D	10	4	B	207	39 340	190	414
E	20	4	B	206	88 580	430	170
F	30	4	B	357	173 800	486	188
G	40	4	B	125.6	138 000	1 099	15.9

at elevated temperatures. This again demonstrates the importance of the asphalt choice on the resultant properties.

We also looked at different AC-grades and how they influence the low and high temperature properties. Thus, we obtained the following results:

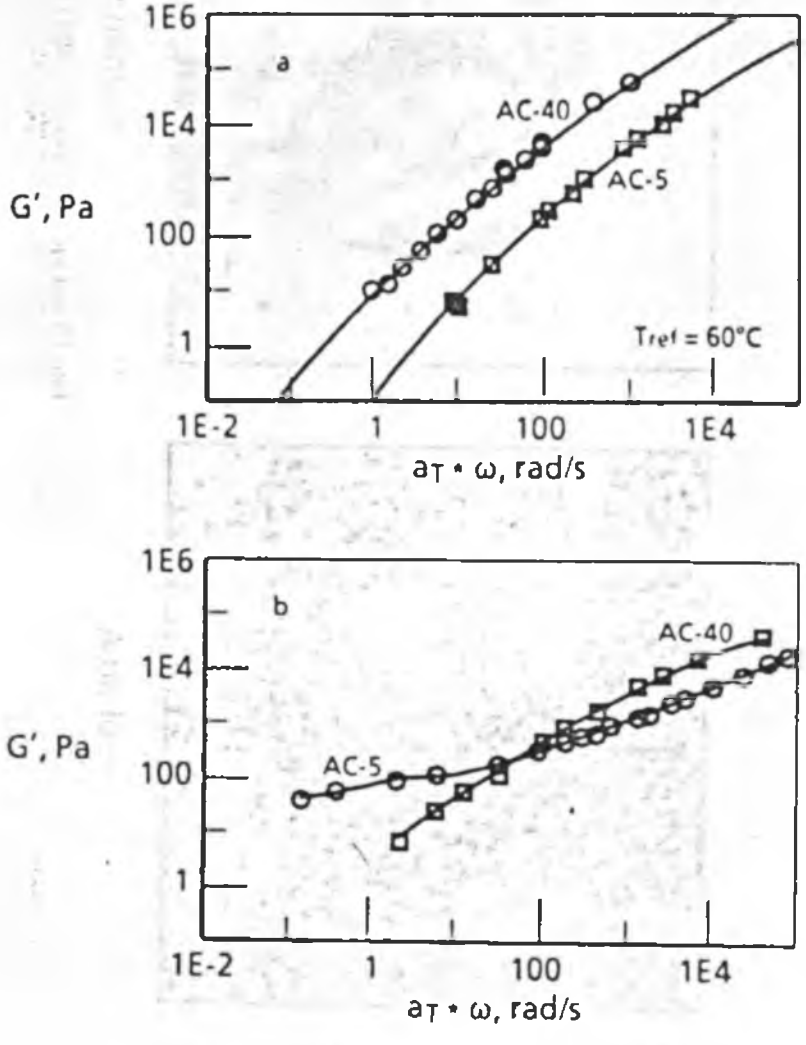


FIG. 16.—Time-temperature superposition: a, Asphalt C (AC-5) and Asphalt G (AC-40); b, 4% Polymer B in Asphalt C and Asphalt G.

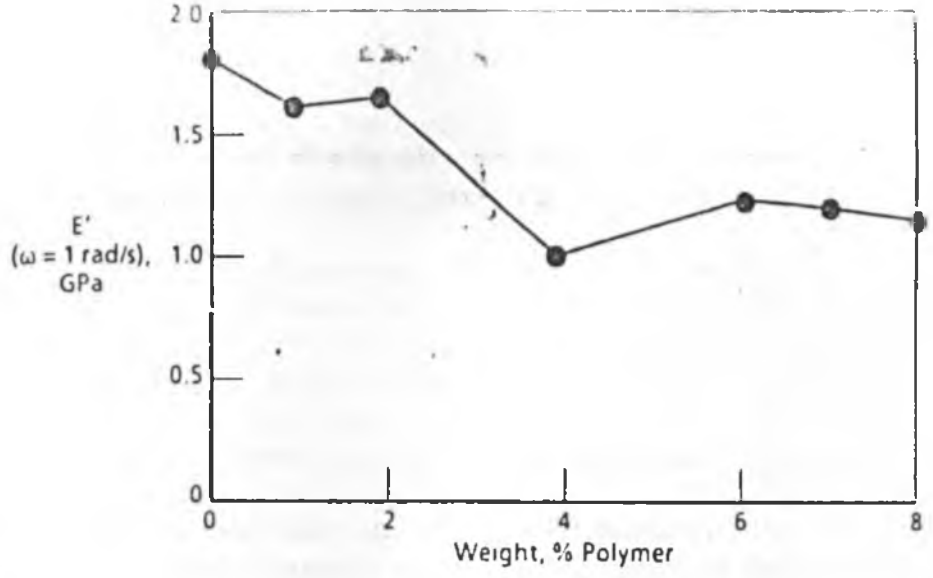


FIG. 17.—Concentration dependency of the stiffness of blends of Asphalt A with Polymer B at −30°C.

• With increasing AC-grade, the compatibility decreased. Mixing time and the critical overlap concentration increased.

• The temperature susceptibility increased with increasing AC-grade (*cf.* Table IX).

• Also the effectiveness of the added polymer dropped when going from a soft to a hard binder. An AC-5 asphalt exhibits approximately 7400 times higher elasticity after 4%*w* Polymer B (SBS) addition, whereas the addition of 4%*w* Polymer B (SBS) to the AC-40 leads only to a 16 fold increase relative to the unmodified AC-40. This is shown in Figure 16.

These results imply that the optimal route for obtaining reduced temperature susceptibility is to take a low AC-grade asphalt and give it the necessary body at high temperatures by polymer addition. Its already good low-temperature properties will be further enhanced by the polymeric additive, *i.e.*, the bitumen will exhibit a higher storage modulus at high temperatures and be less brittle at low temperatures (*cf.* Figure 17).

CONCLUSIONS

This work demonstrates the effectiveness of polymers in improving, especially, the high temperature properties of asphalt. The appropriate choice of asphalt, asphalt-grade, polymer type, polymer concentration, and the method of mixing determine if a network-like structure is formed. This morphology significantly improves the creep performance of the binder at elevated temperatures, *i.e.*, the binder has the ability to store deformation energy with subsequent recoil. This is contrary to Newtonian fluids which transform the energy into viscous flow (no recoil). Within the context of dynamic mechanical measurements, the presence of a polymeric network is manifested through the appearance of a plateau modulus. In the case of binders containing block copolymers, we have repeatedly observed that such property improvement in the high-temperature range is generally accompanied by a reduction of the glassy modulus at the low-temperature range as well. It should be noted that by modifying low-viscosity asphalts (*i.e.*, low AC-grades) with polymers, binders can be obtained which exhibit significantly lower moduli at low temperatures and higher moduli at elevated temperatures. This suggests that although using a high AC-grade asphalt may yield satisfactory results at a particular temperature (high temperature), one may instead optimize binders over the entire temperature range (high and low) by starting with a low AC-grade and adding polymer. These results indicate that careful rheological measurements can be a powerful tool in the characterization and design of viscoelastic blends.

We find, in general, that:

- Time–temperature superposition is valid over a range between −30 to 80°C. Superposition can hold over a range of 16 or more decades in time.
- The temperature dependency of the shift factor a_T obeys, in all cases, an Arrhenius-like relationship.
- For a limited number of capillary and steady shear data, it was shown that the Cox-Merz rule is valid. This implies that steady-shear viscosities can be inferred from dynamic data and, thus, allows the construction of flow curves (η *vs.* $\dot{\gamma}$).
- For the blends of Polymer A (SBS oil extended) in Asphalt D, it was observed that the slope of $d \log G'/d \log (\omega \cdot a_T)$, in the transition zone had a value of 0.46. This compares well with the slope of 0.5 as predicted by the Rouse theory[22].
- It is worth stressing that these polymer blends can exhibit nonlinear viscoelastic behavior [*i.e.*, $G(\omega) = f(\gamma)$] even at low strain levels. It is, therefore, important to ensure that this effect is accounted for in dynamic mechanical measurements.
- Next, it has been demonstrated that in many cases, tan δ is susceptible to errors originating from both the torque and phase measurements.
- Microscopy has been found to be a useful tool which complements rheological measurements. The judicious use of microscopy allows a deeper understanding of the underlying morphologies.

ACKNOWLEDGMENTS

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Road Performance Studies And An Investigation Of Some Problems Associated With Rubberised Bitumen Road Construction

By

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ROAD PERFORMANCE STUDIES AND AN INVESTIGATION OF SOME PROBLEMS ASSOCIATED WITH RUBBERISED BITUMEN ROAD CONSTRUCTION*

BY

A. WEERARATNE† AND M. NADARAJAH

SYNOPSIS

The work on this project so far carried out indicates that:

(i) *the addition of 5 — 10% kerosene oil by volume of bitumen reduces the viscosity and improves the workability characteristics of an otherwise cumbersome binder;*

(ii) *"masterbatches" are not only convenient, but are essential to save time in blending of natural rubber latex and bitumen and in the ensuring of better quality control;*

(iii) *a mixture of sodium hydroxide and ammonia is a better stabilizer than either sodium hydroxide or ammonia;*

(iv) *better bonding was achieved with rubberised bitumen than with neat bitumen with the aggregates tested;*

(v) *bleeding taking place on the rubberised bitumen sections was less than in the control sections without rubber.*

INTRODUCTION

Rubber in various forms has been used in road construction work for a period of over hundred years and records of experience available indicate that rubber does modify the bitumen to give roads with better performance.

However the use of rubber as an additive to bitumen has left the engineer with the problem of handling a more viscous bitumen that makes its use very difficult and cumbersome in the field at normal working temperatures. Despite the advantages to be gained by the addition of rubber to bitumen this single factor alone may have discouraged the more widespread use of rubberised bitumen in road construction.

This research programme was therefore undertaken jointly by the Department of Highways and the Rubber Research Institute in order to investigate problems encountered in road construction using natural field latex, the cheapest and the most readily available form of rubber in Ceylon, and also to further observe the performance of stretches of rubberised bitumen road laid under controlled conditions. This led to the commencement of laboratory and field investigations with the following objectives:—

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† Research Institute, Department of Highways, Ceylon.

(i) development of techniques for overcoming field problems of blending rubber with bitumen and improving the workability characteristics of the product;

(ii) investigation of the use of different stabilizers for preserving natural rubber latex;

(iii) laying of experimental stretches of road for observing field performance;

(iv) correlation of measurable physical properties of rubberised bitumen with field performance.

REVIEW OF PAST RESEARCH

In 1951 a co-operative research programme had been started between the Road Research Laboratory and the Natural Rubber Producers' Research Association and laboratory investigations and full scale road trials were carried out for 15 years (Thompson, 1967). This programme has shown that the addition of rubber to bitumen decreased its brittleness, reduced the temperature susceptibility and increased the softening point with the result that the following advantages were gained with surfacing materials:—

(i) resistance to cracking,

(ii) resistance to fatting up,

(iii) resistance to deformation,

(iv) resistance to stripping.

The data collected by Machlaclan & Morrel (1964) agree with those of Thompson (1967) in this context.

It is generally accepted that natural rubber latex with a high molecular weight is a better additive to bitumen than synthetic rubber in present day use.

In non-natural rubber producing countries concentrated latex in the form of evaporated latex (70% rubber) or centrifuged latex (60% rubber) is used. In the natural rubber producing countries however field latex is more suitable and promising results of experiments with low ammonia field latex preserved with 0·3% pentachlorophenate and with high ammonia field latex have been reported (Fernando & Nadarajah, 1969).

Smith (1960) in his research work found that unvulcanized rubber in latex form was more effective on bitumen than other forms of rubber, although the powder form has the advantage of convenience of addition.

The field latex used in the past on road projects in Ceylon had been stabilized with ammonia. Latex thus preserved gives out a pungent smell and makes blending of rubberised bitumen unpleasant. Natural field latex has also been stabilised with sodium hydroxide which has been observed as a better stabilizer as it is non-volatile and gives a stable latex that is odourless. Also, sodium hydroxide renders the proteins in latex soluble thereby permitting closer contact between the rubber and bitumen to produce a better blend (Baker, 1941).

Fernando & Nadarajah (1969) have indicated the possibility that the interaction between natural rubber and bitumen is not only physical but also chemical. This is because the polyisoprene molecule in *Hevea* latex contains carbonyl and/or carboxylic groups. These groups under dry conditions either condense or combine with each other, inter- or intra-molecularly or combine with each other in a similar manner through polyfunctional amines or other like molecules naturally present in latex. This reaction is catalysed by strongly alkaline substances such as sodium hydroxide (Sekhar, 1964). Since bitumen also has highly polar atoms such as nitrogen, sulphur and oxygen, and would be expected to contain aldehyde and aldehyde condensing groups, it is reasonable to expect some chemical interaction with the rubber in the dry state, and more so in the presence of sodium hydroxide and under the influence of heat.

Although heat is required in the blending of bitumen and rubber, prolonged heating at high temperatures causes a breakdown of the rubber in bitumen and renders it less effective (Thompson, 1964). This breakdown is more severe at temperatures above 350°F so that the temperature and the duration of heating have to be closely controlled in order to obtain the maximum effect of the rubber added.

The effective rubber content has been determined by the measurement of the specific viscosity of the benzene solution of the acetone insoluble fraction of the rubber bitumen and finding the amount of undegraded rubber which will produce the same viscosity in benzene as the sample (Szatkowski, 1963). In this work, effective rubber content has been identified as the useful fraction of rubber that remains in combination with the bitumen.

LABORATORY INVESTIGATIONS

Physical properties

Investigations were carried out in the laboratory in order to determine properties of bitumen with and without rubber that could subsequently be correlated with field performance.

The bitumen used for this purpose were 60/70, 80/100 and 180/200 penetration grades, each rubberised with natural field latex stabilized with ammonia, with hydroxide and with a mixture of ammonia and sodium hydroxide respectively.

The properties determined in the laboratory were:-

(i) Penetration — Method A.S.T.M. D. 5 - 52;

(ii) Softening point — Method A.S.T.M. D. 36 - 26;

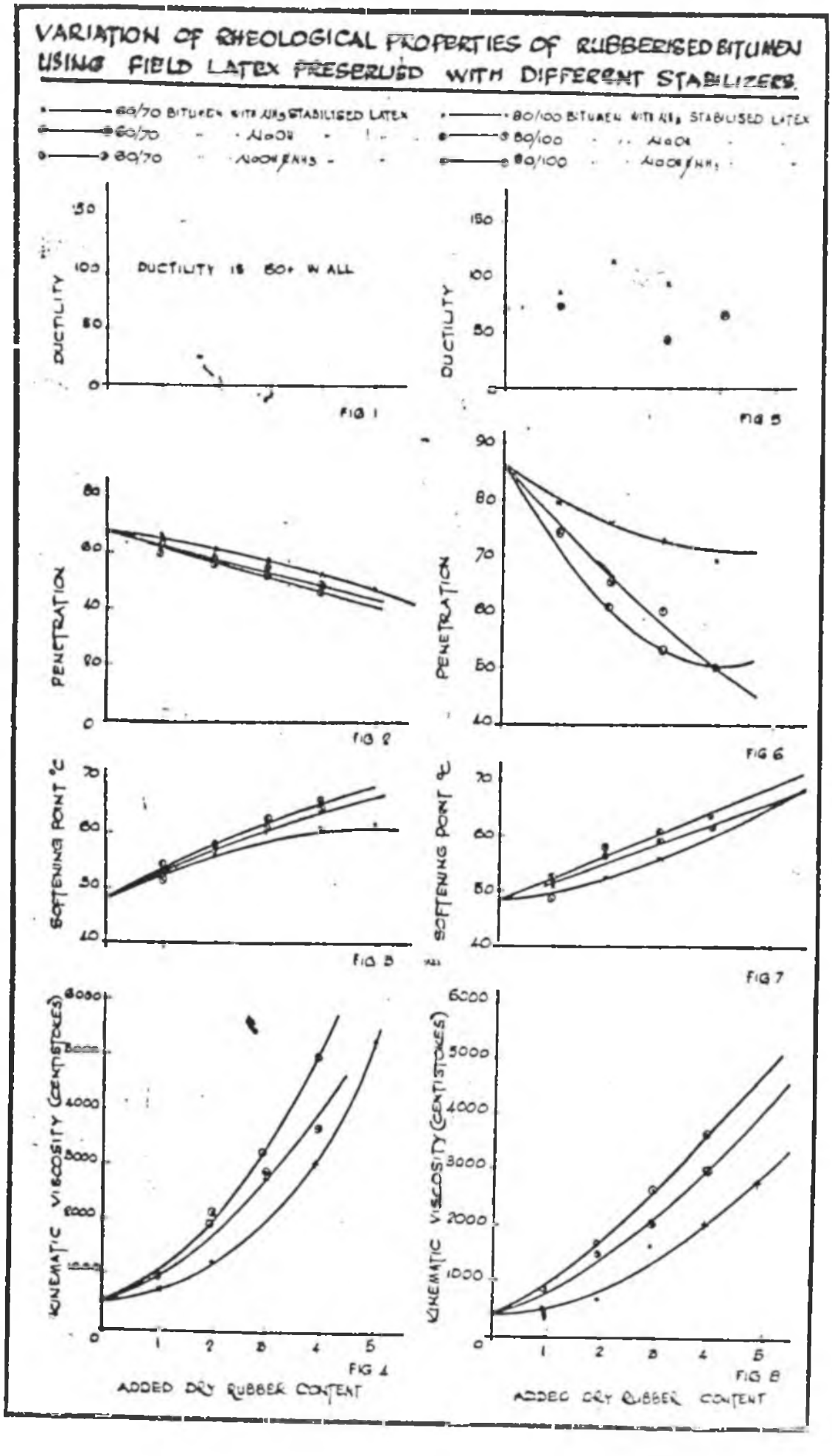
(iii) Ductility — Method A.S.T.M. D. 113 - 44;

(iv) Kinematic viscosity — Method A.S.T.M. D. 2 - 63 T;

(v) Effective rubber content (7);

(vi) Anti-stripping characteristics (visual observations)

and the test results (i) - (v) obtained are presented by the graphs in Figs. 1 to 8.


VARIATION OF RHEOLOGICAL PROPERTIES OF RUBBERISED BITUMEN USING FIELD LATEX PRESERVED WITH DIFFERENT STABILIZERS.
80/70 BITUMEN WITH NH3 STABILISED LATEX
80/70 - NaOH -
80/70 - NaOH/NH3 -
80/100 BITUMEN WITH NH3 STABILISED LATEX
80/100 - NaOH -
80/100 - NaOH/NH3 -
DUCTILITY
DUCTILITY IS 80+ IN ALL
FIG 1
FIG 5
PENETRATION
FIG 6
FIG 8
SOFTENING POINT °C
FIG 7
FIG 3
KINEMATIC VISCOSITY (CENTISTOKES)
ADDED DRY RUBBER CONTENT
FIG 4
FIG 8

It is observed from the test results that field latex stabilized with a mixture of ammonia and sodium hydroxide has given the highest softening point, the lowest penetration and the highest kinematic viscosity. From the observations made on the stripping test although no stripping had occurred in any of the samples tested, it was evident that the test samples containing rubberised bitumen had achieved better bonding. These observations indicate the possibility that more rubber has effectively combined with bitumen in this case than in the other two cases. The next best stabilizer appears to be sodium hydroxide followed by ammonia.

These observations could be explained as follows. The incorporation of the latex with bitumen involves heating at temperatures around 300°F. At these temperatures ammonia evaporates in a very short time and the latex coagulates and a non-uniform mixture of rubberised bitumen is obtained.

Sodium hydroxide on the other hand being non-volatile permits more time for the latex particles to get dispersed in the bitumen on stirring thus explaining that sodium hydroxide is a better stabilizer than ammonia.

In field latex, aldehydic groups in the natural rubber molecule can condense with time with the aldehydic condensing groups in the natural rubber molecules in the presence of sodium hydroxide. This can be minimised by first adding some ammonia which reacts with the aldehydic groups rendering these temporarily inactive and then adding sodium hydroxide. In the preparation of rubberised bitumen at a temperature of 300°F, the ammonia is driven off, leaving the aldehydic group free to interact with bitumen. This reaction is accelerated by the presence of sodium hydroxide in the absence of moisture. Hence a mixture of sodium hydroxide and ammonia as the stabilizer is superior to either sodium hydroxide or ammonia.

Effect of prolonged heating on rubberised bitumen

Once the rubberised bitumen is prepared in the field, it may be necessary to keep the binder in the bitumen kettle at a temperature of 300° - 350°F up to a maximum of about 8 hr before use, during which time, degradation of the rubber can take place. In order to investigate the degree of degradation that occurs on heating, rubberised bitumen samples prepared at different added dry rubber contents were subjected to heat at 300°F and 350°F for periods of 2, 4, 6 and 8 hr respectively, and their effective rubber contents were determined. The results available up to date are illustrated by the graphs in Figs. 9 and 10.

THE VARIATION OF EFFECTIVE RUBBER CONTENT WITH TIME

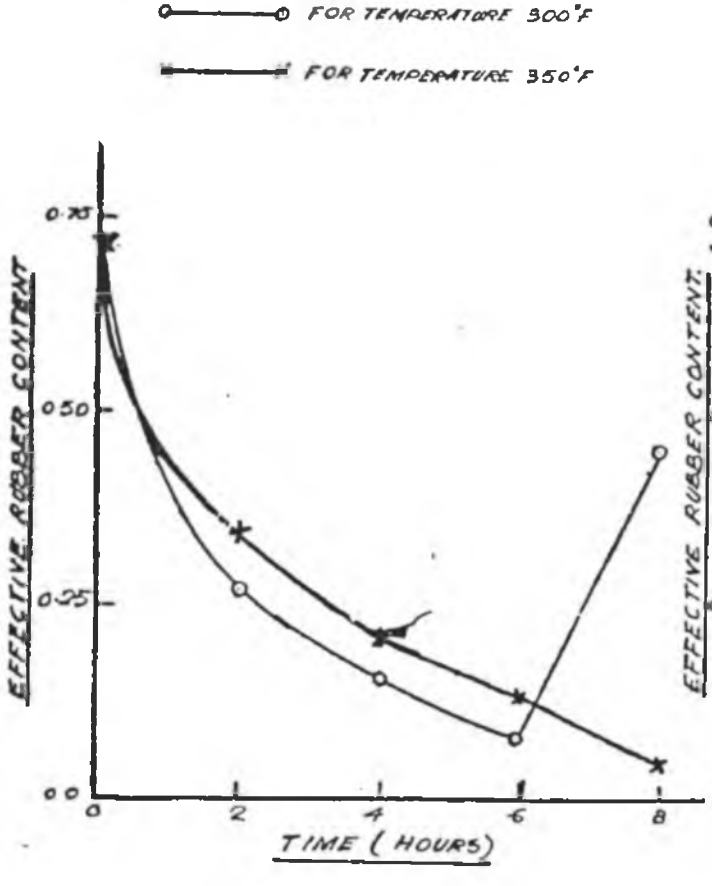


Fig. 9

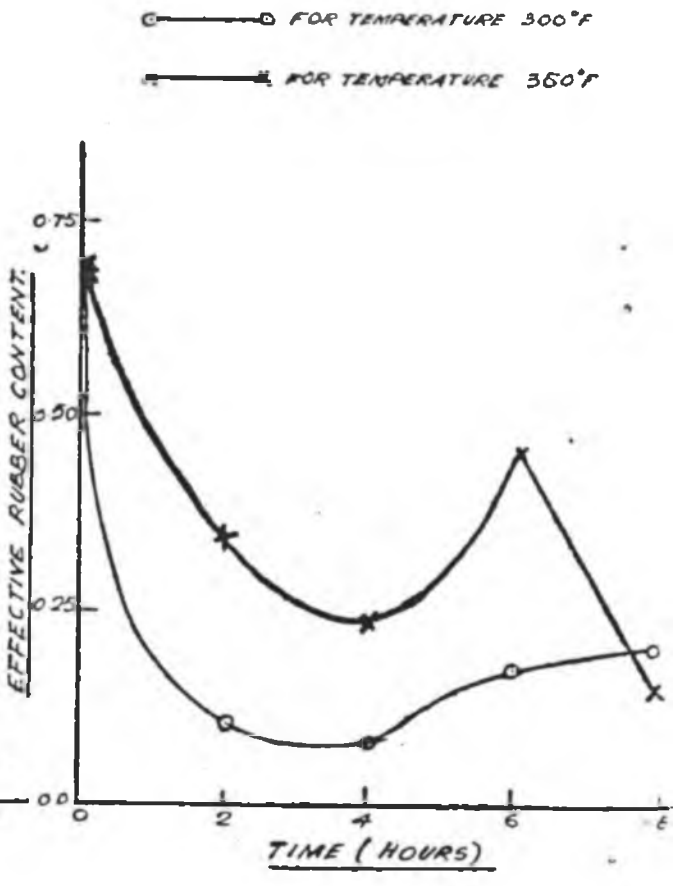


Fig 10

These graphs indicate that effective rubber content had changed on heating showing both a rise and a fall in its value. An explanation is not attempted at this stage as further work at other added dry rubber contents is yet in progress.

Masterbatches

The blending of field latex and bitumen at the work site is a time-consuming procedure that has to be carried out with the utmost care on account of the foaming that is taking place due to the presence of water in the latex. This phase of the work has been greatly facilitated in obtaining the desired rubber content by the addition of the requisite quantity of a preblended masterbatch containing a high concentration of rubber.

Investigations were carried out on the preparation of masterbatches at the Rubber Research Institute using natural field latex in order to incorporate the highest concentration of rubber in bitumen. The latex used was stabilized with 1·25% ammonium hydroxide in one case and 0·7% sodium hydroxide in the other. Masterbatches were prepared at 12%, 14% and 16% dry rubber contents and these were wrapped in polyethylene or polypropylene that would dissolve ultimately in the bitumen kettle. It was found that the preparation of rubberised bitumen with sodium hydroxide-stabilized latex was easier than working with ammonia-stabilized latex possibly on account of the better dispersion of rubber afforded by sodium hydroxide as discussed earlier (Nadarajah & Mendis, 1970).

Experience gained during field operations discussed later on in this paper, indicates that higher concentrations of dry rubber content could be incorporated, if about 5 - 10% kerosene oil by volume of bitumen is added into the bitumen prior to the addition of rubber. This aspect of masterbatch preparation is presently under investigation.

FIELD EXPERIMENTS

Whatever results are indicated in the laboratory the final test of the success or otherwise of the use of rubberised bitumen depends entirely on its performance in the field. This is because factors such as traffic volumes, wheel loads and climatic conditions experienced in the field cannot be fully simulated in the laboratory. Full scale road experiments are therefore being carried out under this programme to observe the effect of rubberised bitumen on—

(*a*) asphalt penetration macadam;

(*b*) seal coat surface treatment;

(*c*) subsequent coat bituminous treatment;

(*d*) asphalt concrete.

(*a*) *Asphalt penetration macadam*

Hotel road — Mount Lavinia — B class — medium traffic

The first field stretch of road under this project was laid on Hotel Road, Mount Lavinia where the road edges along the entire mile and sections over the full width were repaired by re-metalling. This work was carried out by manual labour using plant generally used in this type of road surfacing.

Approximately 70 gal of 80/100 penetration bitumen were heated in a 120 gal bitumen kettle to a temperature of approximately 300°F. Field latex was added into the kettle a little at a time and after about 20 sec the bitumen was vigorously stirred manually. There was a high degree of foaming due to the water present in the latex so that just the right amount of latex had to be added to prevent spilling of the binder. No anti-foaming agents were used. This method is a slight modification of that given by the Natural Rubber Producers' Research Association (1964).

When this work was in progress for a few days, it was found that foaming could be reduced if the stirring of the bitumen was started immediately after the latex was added and not 20 sec later as was done earlier. This practice was therefore adopted in all later work.

A control section without rubber was also laid on the same road.

Experimental details:

Dry rubber content	=	1% by weight of bitumen
Temperature of spraying	=	350°F (approximately)
Maximum duration of bitumen at this temperature		4 - 6 hours
Length of road surfaced	=	1 mile
Weight of roller	=	8 - 10 tons
Date of construction	=	March 1970

Remarks : Considerable difficulty was experienced in mixing and spraying the rubberised bitumen due to its high viscosity. The work had to be frequently interrupted to clean the spraying cans and the spout of the bitumen kettle.

Performance: After edge metalling on a road, it is not uncommon to find an over-bituminised section of road along the joint of the old and the new surfaces with considerable bleeding of the bitumen taking place along this joint. This effect was noticeable in the unrubberised section of road but was hardly noticeable in the rubberised section of road.

12th mile Nagoda-Kalawellawa-Bellapitiya road — B class — medium traffic

To overcome the difficulties of mixing and spraying experienced on Hotel Road, Mount Lavinia, in all subsequent experiments, a small percentage of kerosene oil by volume of bitumen was added in order to reduce the viscosity of bitumen, where the latter had reached a temperature of about 250°F. The latex was then added and mixed with the bitumen as mentioned earlier.

In some sections of this road masterbatches of rubberised bitumen were experimented with in the presence of kerosene oil.

A control section of road of length 1/4 mile was also laid.

Experimental details :

Dry rubber content	=	1·5% by weight of bitumen
Kerosene oil added	=	5% by volume of bitumen
Temperature of spraying	=	350°F (approximately)
Maximum duration of bitumen at this temperature		4 – 6 hours
Length of road	=	¼ mile
Weight of roller	=	8-10 tons
Date of construction	=	July 1970

Remarks : The addition of 5% kerosene oil into the bitumen reduced its viscosity to a great extent, made the blending easier and enabled the spraying of the binder to be continued without interruption.

The use of masterbatches greatly facilitated the stirring of the binder in the absence of foaming and the presence of bitumen made this task still simpler.

Performance : The rubberised bitumen section and the control section are both performing satisfactorily. It appears too early to draw a comparison.

(*b*) *Seal coat surface treatment*

Single seal coat surface treatment using rubberised bitumen was carried on the two roads described below. The heated binder was sprayed on the road surface using manual labour and spraying cans. Stone chips conveniently piled in close proximity on the road side were spread on the road surface by manual labour. These chips were rolled with a steel-wheeled roller.

Experimental details :

2nd mile Dehiwela-Maharagama road — B class — medium traffic

Dry rubber content	=	2% by weight of bitumen
Kerosene oil	=	5% by volume of bitumen
Temperature of spraying	=	350°F
Maximum duration of bitumen at this temperature		2-4 hours
Length of road surfaced	=	½ mile
Weight of roller	=	2½ tons
Date of construction	=	March 1970

Remarks : A half mile of seal coat was laid on a road close by, to study the effect of 5 and 10% kerosene oil on the bitumen to obtain improved workability as the control section in this case.

Performance : The metal whip-off observed with the passage of traffic was less in the rubberised bitumen section of road than in the control section. Also some

bleeding was observed in the control section of road whereas no bleeding was observed in the rubberised bitumen section of road.

Hotel road — Mount Lavinia — B class — medium traffic

Dry rubber content	=	2% by weight of bitumen
Kerosene oil	=	10% by volume of bitumen
Temperature of spraying	=	350°F (approximately)

Maximum duration of bitumen at this temperature 2-4 hours

Length of road	=	½ mile
Weight of roller	=	2½ tons and 8 tons
Date of construction	=	September 1970

Remarks : There was no control stretch of single seal coat laid on this road.

Performance : This section of road is behaving satisfactorily and no bleeding has been observed so far.

Double seal coat : Double seal coat surface treatment was carried out on a section of Hotel Road, Mount Lavinia.

Experimental details :

Hotel road — Mount Lavinia — B class — medium traffic

Dry rubber content	=	2% by weight of bitumen
Kerosene oil added	=	10% by volume of bitumen
Temperature of spraying	=	350°F (approximately)

Maximum duration of bitumen at this temperature 2-4 hours

Length of road	=	½ mile
Weight of roller	=	8-20 tons
Date of construction	=	July 1970

Remarks : There was a short stretch of a control section laid on this road.

Performance : Satisfactory performance has been observed on this road and no signs of bleeding have been visible up to date.

(*c*) *Subsequent coat bituminous treatment*

A thin coat of bitumen is generally applied on a polished road surface to restore the lost binder. This same treatment was tried out on the following road. The rubberised bitumen was sprayed by manual labour using spraying cans fitted with baffles.

Experimental details :

13th mile Panadura - Nambapana road — A class — heavy traffic

Dry rubber content	=	1% by weight of bitumen
Kerosene oil	=	10% by volume of bitumen
Temperature of spraying	=	350°F
Maximum duration of bitumen at this temperature		3-4 hours
Length of road surfaced	=	¾ mile
Weight of roller	=	8-10 tons
Date of construction	=	July 1970

Remarks : A control section of a quarter mile of road was laid along the same mile of road.

Performance : Satisfactory performance has been observed on both the rubberised bitumen and the control sections of road. It appears too early to draw a comparison.

(*d*) *Asphalt concrete*

Asphalt concrete with rubberised bitumen was prepared in a continuous mixing plant and the mix was transported two miles and spread on the road surface with a paver. The rolling was carried out with a tandem roller.

Experimental details :

60th mile Colombo-Galle-Hambantota-Wellawaya road — A class—heavy traffic

Dry rubber content	=	2% by weight of bitumen
Kerosene oil	=	5% by volume of bitumen
Temperature of spraying	=	350°F (approximately)
Maximum duration of bitumen at this temperature		1-2 hours
Length of road surfaced	=	½ mile
Date of construction	=	June 1970

Remarks : An attempt was made in this case to mix asphalt concrete with rubberised bitumen containing no kerosene oil. After 10 min of working, the bitumen pump got choked and work had to be suspended for cleaning operations. Five percent kerosene oil was thereafter added and the work was carried on uninterrupted throughout the entire half mile.

A control section of road was also laid along this mile.

Performance : Satisfactory performance has been observed in both sections of road. It appears too early to draw a comparison.

SUMMARY

In the course of this work it was found that delays and difficulties usually associated with rubberised bitumen work could be mostly overcome by the introduction of a little kerosene oil into the bitumen (5 - 10%). The kerosene oil not only facilitated the blending and spraying of the binder but also cut down on the idling time of labour and plant resulting from the delays caused in cleaning the plant. The use of masterbatches further speeded up the blending of rubber and made this work more congenial.

The laboratory investigations carried out indicated that the addition of rubber to bitumen improved its properties.

Natural field latex was preserved with three stabilizers of which a mixture of 0·3% ammonia and 0·7% sodium hydroxide was found to be the best followed by 0·7% sodium hydroxide and 1·1% ammonia respectively.

The experimental stretches of road so far laid indicate that better bonding properties had been imparted to the aggregates coated with rubberised bitumen and also reduced the bleeding.

The cost was seen to increase by about 10% for labour intensive work such as seal coat surfacing and to a lesser extent for asphalt concrete paving. However, initial cost of a road should not be taken as the criterion as the maintenance during its lifetime too has to be considered, so that if better durability is obtained this will more than offset the initial cost.

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especially has been losing out, being passed for the first time by West Germany as leading supplier. Of total imports only 3 per cent were bias ply, the steel-belt radial share being as high as two-thirds. As production is showing a similar pattern, Sweden no doubt is now completely radialised.

Swedish imports of truck tyres were on about the same level in 1977 as 1976, again with a certain decrease for the UK, which is still the dominant supplier.

These figures do not give the total picture as the multinational companies often switch the supplies from one country to the other.

Spain falls off, Finland improves

Off-the-road tyre imports were also on the 1976 level, but with a drastic drop for Spain and with Finland and France moving upwards. Japan is still the leading supplier from abroad.

In motorcycle tyres Taiwan strengthened its market position, reaching the same quantities as UK, but to less than half the value. This shows in a nutshell how hopeless the competitive situation is becoming for standardised products.

Bicycle tyres were doubled in 1977 compared with 1976. The market was flooded by low-price tyres from Taiwan. With prices 30 per cent lower than the average imports, Taiwan has become the dominant foreign supplier, also hard-hitting Swedish production.

June conference in Norway

On June 8-9 the Norwegian Institute of Rubber Technologists is expecting 300 Scandinavian participants at a conference in Oslo. The conference is run as a joint venture with the fellow organisations in Denmark and Sweden.

Reinforcing materials, both textile and steel, and energy and scrap are topics which will be examined during the conference. However, most of the interest is focused upon the panel discussion between representatives of leading Swedish rubber industries with the challenging title: "Future prospects for the Nordic rubber industry".

Danish industry highlighted

The Danish Institute of Rubber Technologists arranged a local conference in Nyborg on April 13-14. The theme of the conference was "Quality control and standardisation". Mr Berthelsen of Roulend, one of the leading European belting manufacturers, discussed quality control problems with Sören Haglund, representing the leading Scandinavian industrial rubber consumer, Volvo.

Gunnar Friberg, rubber specialist in Volvo's corporate staff, was among the speakers reviewing Danish rubber industry and its competitiveness as an international supplier.

Rubber could give the 100 year old road surface

DAVID DEMPSTER—TORONTO

The results of the research at the University of Toronto—under the sponsorship of the Metro Toronto Roads and Traffic department—on the addition of granulated rubber to asphalt, have been very much on the positive side. So much so that research has continued over the last six months and could carry on for a while yet to further refine the process.

All tests have confirmed that the addition of the ground tyre scrap rubber produces measurable improvements in road performance.

A simple, economical method of adding rubber to the asphalt has been devised as a result of the study. Also, the blend improves road durability and, should it become a standard procedure, could make use of the some 30,000 scrap tyres that are sent to Metro dumps every month.

Other plus values gained are: increased pavement flexibility (fewer potholes); greater skid resistance and improved adhesion of the topping to the base. Low temperature performance is improved because of this latter feature because water seepage between the pavement-base layers is minimised, cutting back on freeze-thaw spalling.

Cost against advantages

On an average, the cost of using ground scrap rubber in the mix is about 25 per cent more than unfilled asphalt but conservative estimates see an increase in road-life of at least 50 per cent, and one of the co-developers of the system, Professor Ray Woodhams, sees a road-life increase of 100 per cent. Metro sees other savings. The mix would lower maintenance costs because less service would be needed and, consequently, traffic interruption due to road repairs would be less frequent.

When spring arrives, tenders are expected to be called for the surfacing of 3,500 feet of Dixon Road west of Highway 27, near Toronto International Airport. Late last year a strip was laid in downtown Toronto along University Ave.

A length of north Yonge Street was to have been entirely paved last year with the rubberised asphalt but this was not accomplished but parts of the road were repaired with the modified asphalt.

Data have established that the optimum mix ratio is 14 kg of granulated rubber per tonne of asphaltic concrete using a 7 per cent asphalt content.

The mix was first pre-heated for two test strips out of four that were applied in the fall on a street in the eastern part of Toronto and it was noted that there

was a decided improvement in the pavement performance. For these test strips without heating regular paving equipment was used. Should pre-heating be employed on a regular basis then special equipment would have to be used and this would add to the expense. It is felt that the benefits of rubber when added directly into the pug mill without any pre-heating is sufficient to negate the need for the added cost.

Firms providing the ground rubber for the tests have been Goodyear Canada and National Rubber, both capable of supplying the required 30-mesh grind. Cryogenically ground rubber has also been evaluated and such material has been found to improve somewhat the cost effectiveness of the rubber-asphalt strips.

The cryogenic process involves the introduction of reclaimed tyre rubber which had first been prepared mechanically to remove all steel cord and pre-ground into chunks prior to feeding the scrap into a pressurised liquid nitrogen chamber.

After immersion in the liquid nitrogen the fast-frozen chunks are shattered in a hammer mill to an average particle size of 50-mesh. This size products a slightly more effective rubber-asphalt mix. Compared to mechanically grinding the rubber tyres to this mesh, the cryogenic process is less energy intensive and therefore, less costly.

What is holding up the full-scale use of this material on Metro roads is the approval by the Transportation committee. The committee's recommendation will then be passed on (if it approves) to Metro Executive. It then goes to Metro Council for final clearance —the whole procedure taking anywhere from one month to six months.

Professor Woodhams and his colleague, Professor M. Pigott are now tieing up the few loose ends still outstanding under their contract with Metro. Woodhams' estimate of doubling of road life is based on the properties of the reclaimed rubber. It is felt that certain chain reactions in the rubber which are caused by atmospheric changes, could help improve the road performance. For example, the antioxidants which are added when the tyres were first made would likely prove beneficial.

Under a continuing programme at the university, Pigott will be developing a rubberised asphalt sealer to be used for maintenance on any asphalt road surface. Various formulae and compounds are to be tested.

When the fall meeting of the American Chemical Society is held in Miami, Florida, Professor Woodhams will be giving a paper at a session devoted to ionomers. His paper will be on the ionomer he has developed by adding a chemical additive to asphalt which retains its strength when wet. Under such conditions conventional asphalt has been known to lose about 80 per cent of its strength.

According to Woodhams, road-life might be extended to 100 years if a rubber/asphalt ionomer mixture is employed.

Nissan Chemicals to make myrcene

STUART GRIFFIN

A chemical synthesis method has been developed by Nissan Chemical Industries to produce myrcene, a compound of isoprene, that is conventionally turned out from pulp waste liquid. It is used as a raw material for a variety of specialty chemicals, including perfumes, vitamins A and E, heart drugs and cosmetics. The worldwide myrcene market has been featured by short supplies in the past several years, causing its prices to go up to the present Y350-400 kg. Its consumption totals at least 10,000 tonnes, worldwide, and users here totally depend upon imports.

In the Nissan Chemical method, a specialist catalyst is employed to convert isoprene molecules into myrcene. It is difficult to control isoprene reaction with the achievement limited only to the production of isoprene isomers. The Japanese company has successfully synthesised myrcene with the same structure as one extracted from natural sources for the first time in the world.

It will commercialise the process, according to present schedule, by 1979, and has already filed patent applications with five major countries' governments, including those in the USA, West Germany and France. Sample quantities, as have been produced by a pilot plant, are being distributed to potential buyers and responses have prompted Nissan Chemical to consider plant construction by 1979 for an annual output of a few thousand tons.

The firm intends to conclude export deals with major users by the time the commercial plant is on-stream at its big Chiba works, near Tokyo, management terming this "as serving as a foothold toward expansion of fine chemicals enterprise based upon isoprene and the C4 stream."

Ube and Dow in chemical deal

Ube Industries has concluded a three-year polybutadiene export contract with Dow Chemical which will manufacture high-impact PS from the Ube-supplied material. The two companies started joint studies on polybutadiene for such purposes four years ago, and this has resulted in this current contract. Dow is to buy at least 10,000 tonnes of the polybutadiene between now and the end of 1979. The later deliveries will be carried out, according to the renewable long-term agreement.

Ube is supplying polybutadiene with at least 90 per cent 1,4-polybutadiene content for high-impact PS production. It differs from conventional polybutadiene, as is employed for man-made rubber manufacture. Dow Chemical, America's largest PR maker, named Ube as its source for the chemical in the light of the

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RUBBER FOR ROAD-MAKING AND BUILDING MATERIALS

SHAW, K

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Rubber for road-making and building materials

K. Shaw

Bituminous materials combined with natural or synthetic rubber for use in surface coating of highways and roads has been the subject of many research and development programmes throughout Europe and North America for many years. Research workers in the Soviet Union have been taking a closer look at bitumastics for surface coatings, sealants and mastics.

IT is now almost a century since the first attempts were made to improve the properties of road bitumens by the addition of natural rubber. English and Dutch road materials chemists made intensive studies of the problem in the 1920s, and between the year 1930 and 1940 several countries put down stretches of test roads using bitumen-mineral mixtures and incorporating natural rubber. Various test reports drawn up after periods of up to 20 years showed that such roads had withstood the working conditions of the experiments.

Natural rubber had, of course, been employed in the form of massive blocks as road coatings before these experiments but, owing to the high cost and the slippery running surface in the wet, these failed to find extensive use. The best method of taking advantage of the valuable road-making properties of rubber is to incorporate it in the bitumen or tar binder, so the chemistry and physics of bitumen in its various forms and states are obviously important in any attempt to use rubber for this purpose. Many bitumen researches, while not directly concerned with rubber additives, are therefore of interest, for they provide information on the properties and behaviour of the main carrier or reactant material in the rubber-bitumen-mineral system.

At the present time research into the use of rubber in road making is being done in France, Britain, Germany, Holland, the USA and the Soviet Union. In 1963 alone American road engineers laid more than 5,000 miles of rubberised road surfaces. In the Soviet Union, building materials are being made with rubber additives to confer special properties, and Soviet chemists are particularly interested in the special combinations of properties resulting from rubber (both natural and synthetic) and bitumen blends at various temperatures and in different process conditions. The information from these investigations is of use, therefore, not only in the development of road-making techniques, but also to producers of materials such as roof coverings, sealants, mastics and coatings.

It is known that coatings based on bitumens and chloroprene synthetic rubbers are resistant to oxidation, the action of light, abrasion and tearing, and that they are very elastic. Added to this, is the advantage that chloroprene rubbers are the cheapest of all synthetic rubbers.

The Ukraine Plastics Research Institute (UkrNII-Plastmass), for example, which is investigating the properties of polymer-bitumen systems, has developed a waterproof roofing material of bitumen-neoprene composition not containing water, which means that it can be applied to reinforced concrete panels at negative temperatures.[1] The process is described in more detail below.

Following the incorporation of rubber, bitumen undergoes radical changes in its properties and this depends to a large extent on the degree of dispersion of the rubber. The rubber must be dissolved in the binder to be effective. Upon dissolution it increases the viscosity, strength and heat resistance of the system, and these properties are all improved as the rubber content rises. The amounts of rubber used in road binders vary from 0.6% for surface treatment to 8% for mastic asphalts.

TABLE 1
PROPERTIES OF BITUMEN-RUBBER BLENDS WITH ALTERATION IN THE RUBBER CONTENT

	% *Natural rubber on weight of bitumen*		
	0	2	4
Depth of penetration at 25 C	100	86	66
Softening point, °C	43	50	58

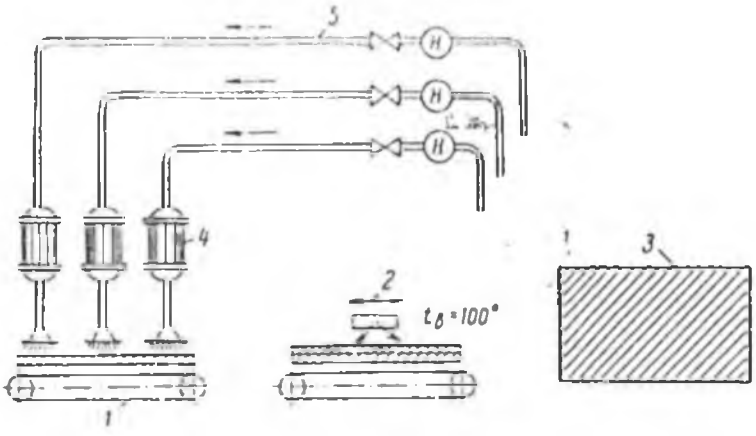


Fig. 1. Scheme for applying latex waterproofing coatings to roof panels in factory conditions. Key: (1) application site for latex solution; (2) site for drying the coating; (3) tilting device; (4) vessel for latex mixture; (5) pvc tubing for carrying the latex

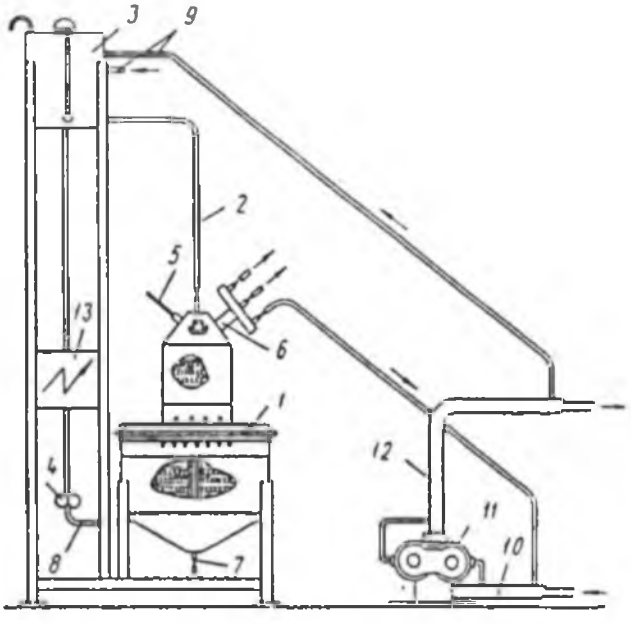


Fig. 2. Electric oil heater [illegible] unit; (2) gas removal [illegible] mercury thermometer; (6 [illegible] (9) pipeline; (10) bitumen [illegible] (13) control panel

Key: (1) electric heating [illegible]ing tank; (4) pump; (5) [illegible]alve; (8) distributor pipe; [illegible] bitumen pump; (12) pipe;

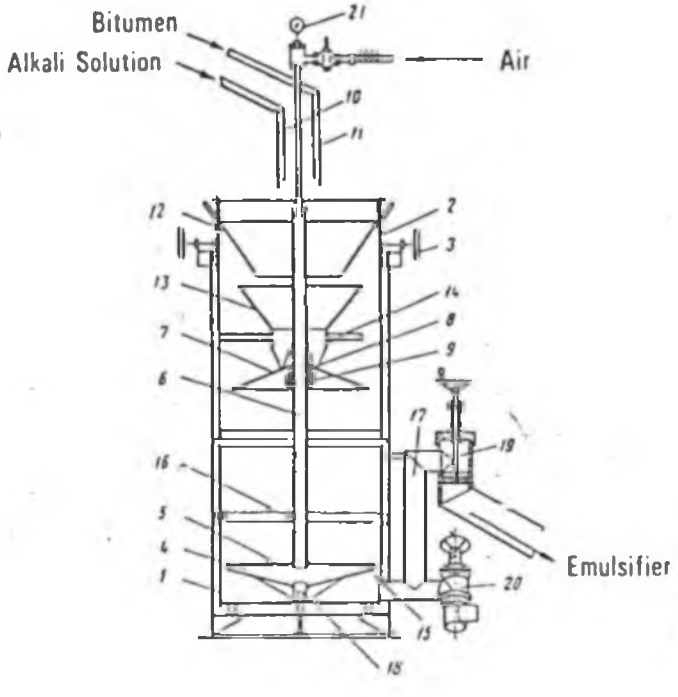


Fig. 3. Equipment for chemical emulsifying bitumen. Key: (1) heat-jacketed vessel; (2) cylinder; (3) spring catches; (4) air distributer; (5) apertures; (6) tube; (7) guard plate; (8) slipping clutch; (9) screws; (10) pipes; (11) pipes; (12) funnel; (13) conical funnel; (14) rods; (15) circular gap; (16) conical mixer; (17) tubes; (18) support pivot; (19) valve; (20) valve; (21) manometer

In addition to cost factors, the difficulties of working with high r ber compositions imposes a limit on the total rubber content.

The depth of penetration of a test instrument and the softening temperature of rubber-bitumen blends are useful indicators for practical purposes, since on these factors depend the workability and life of the coatings. Table 1 gives some data for these tests using a standard bitumen.

If the viscosity and heat resistance of bitumen are increased through the addition of rubber, we find that there is a corresponding increase in the strength of the road coating. The most important property of the road coating containing such bitumen is the big rise in the elasticity which determines its deformation resistance and gives the surface a high impact resistance. It also helps the surface to absorb vibration and shocks when heavy traffic passes over it.

The degree of change

Chemists have established that the degree of change produced in bitumen by rubber addition depends on the molecular weight of the rubber. The greatest change is obtained with rubber having a molecular weight of not less then 600,000-900,000. Since MW is affected by temperature the heat process cycle for rubber used in road making and building materials is critical. For instance, when binder is being prepared, rubber is subjected to temperatures of from 140 to 200°C as well as mechanical action, which leads to its decomposition and a fall in the MW from 500,000-1,000,000 to a few thousands. As the MW falls there is a serious reduction in the rubber's power to influence the properties of bitumen.

It is therefore important to know not only the total content of the rubber in the bitumen but also the state, for the assessment of which a special term is used, called 'effective rubber'. When rubber-bitumen blends are being prepared it is essential to keep to the specified temperature cycle so that the content of 'effective rubber is not reduced by more than a half.[2]

When rubber is used to improve the properties of bitumen it is preferable to use natural rubber, according to many investigators, but it is of course possible to use synthetic rubbers which are cheaper than natural, and furthermore, can be obtained with predetermined properties. Chloroprene, isoprene and butadiene-styrol rubbers have been found to be suitable for road building. US rubber producers are making a range of synthetic rubbers including rubber BSR sold under the trade name Pliopave which are added to the bitument in amounts of 1.5-5%.

The maximum changes

The maximum changes in the properties of the bitumen (and therefore the greatest benefit) are noted with an addition of latex, and the minimum alterations in the properties with the introduction of vulcanised powdered rubbers (especially those obtained from waste and reclaimed rubbers). The use of rubber in the form of sheets, owing to the complications of preparing it and the existence in it of impurities such as sulphur, is very limited. Natural powdered rubber has obtained the widest use, and several commercial varieties are now available. These are non-vulcanised, or slightly vulcanised rubbers in the form of powders containing 60-96% rubber, various amounts of fillers and some sulphur. Since it is more difficult to disperse the vulcanised powders in bitumens than the non-vulcanised, the working properties of the latter are better, but since the vulcanised are cheaper they are often preferred.

The technique of adding rubber powders to bitumen depends on the type of powders and the type of bitumen (viscous or thinned) that are used. The producers of non-vulcanised rubber powders for road making, for instance, advise that it should be spread in a thin layer over the surface of the bitumen, heated to 120-160°C for viscous bitumen, or at 120-135°C for thin, liquid bitumen. The batch is mixed with a propellor stirrer and the next batch is added when the first is thoroughly blended in with the bitumen.

If the viscous bitumens are being used, the method is similar, but the bitumen's temperature before adding the rubber should be 140-180°C. The mixing time is anything from 30min. to 8hr.

Since the temperature cycle employed and the blending times are incompatible with the deflocculating agents incorporated in the bitumens, it is not possible to mix liquid bitumen directly with the vulcanised rubber powders. It is then necessary first to prepare the mixture of vulcanised powder with the viscous bitumen and then dilute the result to the desired consistency with thinners.

According to Soviet reports[2] the best results are obtained by adding rubber in the form of latex which has a high molecular weight and is more easily mixed and dispersed in the bitumen (especially when bitumen emulsions are being prepared). The existence of water in the latex may lead to undesirable spitting and foaming of the bitumen during blending.

Addition of latex

Latex is added to viscous bitumens in the following manner. An antifoaming agent is added to the bitumen (heated to 150°C), followed by a measured amount of latex in small portions (or a fine jet may be slowly distributed over the surface of the bitumen) and the whole is blended. Under these conditions the latex should not remain on the surface of the bitumen for more than 20sec., so that coagulation is avoided.

When all the latex has been homogenised with the bitumen, the blend is cooled to 130°C and mixed for another 20min. According to information from the Bayer Company in Western Germany, latex should be added to the bitumen heated to 200-240°C which eliminates foam formation, spitting and lumping in the blend.

When thinned bitumens are used the following technique is suggested. The thinner is mixed with the bitumen heated to the liquid state; then the latex is gradually poured in, and the whole mixed at 60°C until the blend is well dispersed. The mix is then heated until all the water evaporates (140-160°C). The concentration of rubber in such blends may be as high as 16%.

A great deal has been published on the use of bitumen emulsions as binders in road making and Soviet specialists have made some useful contributions to this field. Some of their researches have included experiments involving rubber additives, especially for the development of mastics and sealants which are widely needed in the Russian large-panel home building programme for sealing the various members of the reinforced concrete constructions.

In addition, bitumen emulsions are being proposed for the preparation of asphalt-concrete mixtures, and it is reported that these would reduce the cost of making 1 ton

of asphalt-concrete by 0.25 roubles and would extend the road laying season for such mixtures.

Another aspect of Soviet road and building materials research is the use of surface-active agents and activated

TABLE 2

Sealants	*Bulk density kg./m.*³	*Relative elongation before rupture, %*	*Operating temperature °C*
Polyisobutylene mastic UMS-50, clear	1,100-1,500	200-300	from +70 to -60
Thiocol mastics based on polysulphide liquid rubber	1,100-1,200	150-250	from +80 to -60
Inserts based on reclaimed neoprene, porous with dense, elastic water-impermeable film (clear and dark tones)	400	150-300	from +80 to -40
Inserts from devulcanised black rubber. Used in combination with Izol mastics	250-400	20	from +80 to -50

mineral powders for laying asphalt-concrete coatings; here according to Russian experts, the use of such materials would save 0.95 roubles per km. of road.

Rubber could play an increasingly important part in building sealants and mastics, since traditional materials such as cement mortars and tarred packing materials deteriorate very rapidly — 25% of joints rendered with such materials lose their sealing powers after two years.

Research work done by the VNIINSM Institute to find reliable joint sealants has lead to recommendations being made for the use of sealants based on polymers. The new sealants last 5-10 times longer than conventional materials. They consist of mastics and inserts based on synthetic rubbers and resins with appropriate fillers. Table 2 lists some of the properties of such materials.[3]

Bitumen-rubber emulsions are made by emulsifying prepared rubber-bitumen blends or by direct blending of latex and rubber emulsions at ordinary temperatures. The second method is much simpler and therefore more commonly used in road making. Anion-active bitumen emulsions are of special interest and for these it is customary to use 60-70% latex stabilised with ammonia. For cationic bitumen emulsions the latex is pre-acidified. The storage life of rubber-bitumen emulsions depends on the temperature. At room temperature they can be stored indefinitely; at 120°C for a week and at 200°C they can be stored only for one hour.

The processes of bitumen emulsification are quite complex and various methods are used on an industrial scale. This article is not the place for a review of the

TABLE 3

Type of material and purpose	*Amount of rubber on binder weight, %* *Powder*	*Latex*
Bitumen:		
for surface dressing	1·5-2·5	1-1·5
for asphalt-concrete	2-6	1·5-4
for impregnation	2-4	1·5-3
Asphalt mastics	10-18	—

chemical and physical methods that are used, but it is obvious that since the properties and natures of bitumens prepared by the different methods are quite different, then they will behave differently with rubber additives in the preparation of bitumen-rubber blends, and a knowledge of bitumen emulsion techniques is important for rubber technologists concerned with spreading the use of rubber in the building industry.

Rubber is also added to tars to improve bonding capacity and other properties. Research done in this area suggests that an addition of rubber to tars reduces their temperature sensitivity and gives coatings as good as those containing petroleum bituments. Those considered most suitable for this purpose are chlorene rubbers, natural rubber with grafted methylmethacrylate groups, and butadiene nitrile rubber. The additions of rubber should be around 2% of the weight of the tar.

According to information collected by Russian technologists from the world's literature, the recommended additions to bitumen in relation to the type of materials and their purpose are listed in Table 3.

The pouring temperature of rubber-bitumen binder is 10°C higher than for ordinary bitumen.

Extended programmes of road research have now proved that rubber has an important part to play in road building and can substantially increase the life of roads. The research data obtained from such programmes is also finding use in other building materials investigations. In spite of the higher cost of road coatings containing rubber additions, which for surface dressing may be 25% higher, the additional costs are recovered owing to longer road life.

No repairs after 17 years

For example, Dutch road engineers found that a rubberised road surface did not need repairs even after 17 years' service, while the adjacent sections laid at the same time for comparison, without rubber additives, had to be mended three times during 17 years. Over a period of 20 years, according to the Dutch calculations, the savings would be 38s./m.² In another case the original cost of the surface treatment was 18% higher but the service life was doubled. In the State of New Jersey work has been done on road dressing with bitumen emulsions containing latex additives, and after five years' use, out of 122 sites only seven needed a protective layer. The cost of the material for repairing the roads in the last three years (out of the five) was 294s./km.

It is estimated that adding rubber to road surfacing materials puts up the average cost by 15-20% and more than doubles the road life up to the first repairs. In their literature searches and investigations of foreign research trends, the Russian specialists observe that the main trend is in studying the action of heat on rubber-bitumen mixtures, and the development of such methods of blending as will permit reductions in the oxidation damage of the rubber in bitumen, increasing the content of effective rubber, reducing the content of total rubber additives and hence the cost of the mixture.

Mention was made above of the use of rubber in roofing materials. In this field Soviet researchers are using rubberised compositions based on vulcanised synthetic latexes.[4] The imperfections of existing roofing materials in regard to atmospheric resistance and also the new requirements (elasticity and frost resistance) being placed on roofing materials in connection with the wide use of them in precast reinforced concrete building units, have led to mounting interest in new materials based on polymers, including rubbers.

Roofing materials based on synthetic rubbers possess outstanding elastic properties typical of rubber itself. Thermoplastic polymers, for example, polyisobutylene,

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Rubber for road-making and building materials

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are used in roof making only with a base material such as glassfibre fabric or in the form of rigid components (non-plasticised pvc).

To obtain an elastic film from synthetic latexes possessing the properties of vulcanised rubber it is necessary to vulcanise the polymer film. This can be done by vulcanising the film in the dry form by adding ingredients of the vulcanising group to the latex mixture followed by heating of the film together with the panel at 100-150°C for 30-60min.

A second method consists of preliminary vulcanisation of the latex. It yields an elastic rubber-like coating on roof panels without the need for subsequent film vulcanisation.

Elastic roofing materials have been obtained from prevulcanised latexes by the Soviet Asbestos-Cement Research Institute. Studies showed that vulcanisation of the latex, besides giving the films elastic properties, reduces the water absorption of the coatings and makes them more resistant to biological action (fungus and rot resistant).

The properties of the product suggest that the life is not less than 20 years, water absorption in 30 days not more than 6%, frost resistance 100 cycles, embrittlement temperature -30°C, working temperature from -50° to 100°C, breaking strength not less than 40kg./cm.^{2} and relative elongation not less than 450%. The thickness of the material is 1mm. and the colours can be brown and silver-blue. The coating resists fungi and bacteria. Owing to complete exclusion from the material of bitumen and the non-combustibility of the base (neoprene, known in Russia as Nairite L-7) the roofing material is perfectly safe and offers advantages over other types of roofing.

Fig. 1 shows the arrangement used in Russia for applying the latex waterproofing coatings to roofing panels in factory conditions.

The Nairite material is also being used for making waterproofing coatings on the basis of bitumen-rubber compositions, as mentioned above.[1] These are prepared by dissolving the Nairite composition and the bitumen, followed by blending of the solutions. Nairite A is first subjected to mechanical plasticisation on roll mills for 10min. and then a softening agent in the form of stearine in amounts of 2.5% by weight for 100 parts of Nairite is added. Plasticisation boosts the rate of solution, reduces the viscosity of the solutions and keeps the material stable during storage.

After the final plasticisation two additives are introduced: the vulcanisation additive consisting of zinc oxide 1.25 parts by weight and sulphur 0.8 part by weight; and the stabilising additive (Neozone D 0.25 part in combination with 0.1 part of thiuram). Then the roll milling is continued for a further 1-10min. The mixture is removed from the mill, remixed and loaded into a glue mixer and then the solvent is added, consisting of toluene (400 parts by weight of solvent per 100 parts of Nairite). The finished materials, after being mixed for 5-6hr. consists of a light-brown mass with a viscosity of 180-300sec.

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Rubber In Asphalt Pavements. A Method for Utilising All of Our Rubber Waste.

Huff, Bobby J.

Paper NO: 35. 111th ACS meeting. Illinois 1977.

RUBBER IN ASPHALT PAVEMENTS

A METHOD FOR UTILIZING ALL OF OUR RUBBER WASTE

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INTRODUCTION

The obvious flexibility and resilience of rubber led experimenters many years ago to try to incorporate it into asphalt pavements where the absence of these properties often caused failure of the road surface resulting in a need for constant maintenance and repeated reconstruction.

In addition, the rubber chemists knew that many of the compounding ingredients for rubber were closely related to asphalt indicating a special compatibility between the two materials.

The development and acceptance of these products has been slow because of the difficulty in compounding and applying them with construction equipment and the long periods required for field testing. These periods can be as long as ten years and any necessary modifications of the product require a repetition of the testing cycle.

Added to this difficulty was the apathy of highway engineers toward trying new products unless the cost to performance ratio was extremely good when compared to ordinary asphalt pavement.

We feel that rubber-asphalt technology has now overcome

these obstacles and is succeeding in the market place to the extent that it will convert a serious solid waste problem into a conservation of billions of pounds of valuable resources.

EXPERIMENTAL

As early as the 1920's, experiments were performed in which small quantities of powdered rubber were added to asphalt concrete mixes. At first, natural rubber was used and as the synthetics were developed, these too were tried, followed by ground vulcanized rubber and reclaim in attempts to save on costs.

In some instances, latex was added to the mix, but at the temperatures involved, the water flashed off leaving minute particles similar to those used when the powdered rubber was added.

In practically all cases, the rubber added a resilience to the pavement and postponed cracking but this extension of pavement life was usually insufficient to justify the added cost of the rubber.

The failure of these experiments was due primarily to attempts to modify the aggregate or filler portion of the mix rather than the binder. The majority of failures in asphalt pavements are a result of a lack of flexibility in the asphalt binder. Where the rubber was added to the hot mix, the low temperatures and the short contact time were insufficient to produce any significant solution of the rubber or subsequent modification of the asphalt.

This was soon realized and small quantities of latex were dissolved in the asphalt which greatly increased its toughness and ductility. The addition of the latex achieved a degree of acceptance and it is still used routinely by highway engineers in some areas but again the cost vs. performance problem has prevented more general usage.

The lack of the desired long term performance has been due to a number of factors. The quantity of rubber added was small because of cost and the fact that the addition of large quantities of latex increased the viscosity of the asphalt beyond a workable range. The latex also lacked the ingredients of compounded rubber and oxidized when exposed to the weather resulting in the eventual loss of its rubbery properties. Since this rubber was almost totally dissolved in the asphalt, the mix contained no sizeable rubber particles to contribute resiliency.

Later, powdered devulcanized or reclaim rubber was added to the asphalt. Being a solid, it was somewhat more difficult to disperse in asphalt but its more limited solubility permitted a large amount to be added without increasing the viscosity beyond a workable range.

Since it was prepared from rubber compounded to resist weathering, the exposure to severe atmospheric conditions did not affect its properties.

The limited solubility did not produce the high ductility of the latex modified asphalts but it retained a degree of resiliency and the resulting compound was a compromise with some

improvement in both properties.

The pavement life extension has been sufficient enough to promote its continued use in certain highway applications.

Numerous random attempts have been made to add scrap rubber indiscriminately to asphalt. This has generally resulted in a viscous mass which is too thick to apply without difficulty. One answer to this problem was developed by Charles H. McDonald[1]. In his process, powdered tread buffings are reacted with asphalt at high temperatures to produce limited dispersion of the rubber followed by the addition of kerosene to lower the viscosity sufficiently for application. Upon evaporation of the kerosene, a highly resilient layer is formed which can absorb much of the pavement shattering loads and which also has sufficient cohesiveness to absorb limited horizontal strains without cracking.

The major problems with this system are first that it requires special construction equipment to prepare and apply the blend and second at the time of application the blend often lacks sufficient tack to readily bond itself to the existing pavement or protective cover material. In spite of these problems, the system has had a measure of success and has gained some acceptance.

From this background and our own experience with reclaim, our research was oriented toward combining the merits of each of these systems to produce a material that would be of value in any pavement application.

The product of this research is a combination of a selected ground vulcanized scrap rubber and powdered devulcanized rubber

providing controlled properties. When this product is added to hot asphalt at a rate of 20-23% and reacted for a short period at temperatures of 200-220°C, a rubberized asphalt is produced which can be applied with conventional asphalt equipment to produce a tough, elastic membrane which has excellent bond to the existing surface.

This membrane can be coated with rock to produce the chip seal road found in many areas of our country. The chip seal can be further paved with a thin layer of asphalt concrete to produce an interlayer which will absorb the strains produced by movement in the old pavement and prevent recurrence of cracking.

A special application of this membrane is to waterproof bridge decks which are often severely damaged by the effects of salt and ice. By applying a layer of the rubberized asphalt and covering with a wearing course of asphalt concrete the surface can be sealed and this deterioration eliminated.

Another potential use of this product is to seal the expansive clay soils which absorb moisture and produce heaving of the pavement. This application is new and currently being developed.

This product is also used to seal joints and cracks in pavement. Although the volume used is relatively small when compared to construction usage, the rubberized asphalt has proven highly effective in retaining the desired flexibility to protect the joints and prevent the recurrence of cracking. This performance has resulted in the acceptance of this technique by several states.

In addition to the membrane type applications, rubberized

asphalt is also being used as the binder in asphalt concrete. Laboratory studies have shown that the use of reclaim rubberized asphalt for this purpose produces substantial increases in the strength, flexibility, and resilience of the mix when compared to conventional mixes[2&3]. These results have been substantiated in field tests.

A few tests have been placed in which the McDonald material was used as a binder for asphalt concrete. The performance has been good but the viscosity of the material makes it difficult to use for this application.

Studies are also in progress to determine the feasibility of using the reclaim-vulcanized rubber blend in asphalt for this application.

FIELD RESULTS

Since highway engineers are rarely convinced by laboratory tests, the field test is the usual proof of the effectiveness of a material. The performance of the current methods of rubberizing asphalt in the field is being demonstrated by their growing acceptance for routine use by highway departments.

Sections of streets in Phoenix, Arizona which were treated with the material developed by McDonald have lasted ten years without any cracking. With normal pavement, serious deterioration would have occurred within two years.

After noting the performance in Phoenix, the Arizona Department of Transportation began to test this product. The success of their studies produced a decree that a rubberized asphalt

interlayer would be included in all resurfacing projects where less than three inches of new pavement were to be placed.

Over the last four years, we have placed numerous test sections nationwide wherein reclaim rubber was added to asphalt and used in such applications as chip sealing, interlayers, asphalt concrete, crack sealing, and bridge deck waterproofing.

We have received reports of substantial pavement improvement in practically all of these tests and several states have accepted some of these systems for routine use. As this performance continues, we feel that the states will eventually accept the rubber for all these purposes.

More recently, the reclaim-vulcanized rubber blend has been introduced for rubberizing asphalt. After three years in the field, its ability to stop cracking in highways is even more dramatic than the aforementioned products and we are very optimistic regarding its full acceptance.

RECREATIONAL SURFACES

Separate from the highway development, it was realized that powdered rubber could be added to asphalt mixes and used in playgrounds, athletic running tracks, and tennis courts to produce a resiliency that would reduce injuries and provide a more comfortable playing surface.

Since this type surface is not subjected to the stress and abrasive effects of highway traffic, large quantities of rubber could be added without worrying about high tensile strengths or special methods for reacting the rubber and asphalt.

These products have been highly successful and there are currently at least eight companies marketing surfaces of this type. Since each track requires 30 to 40,000 pounds (14 to 23 thousand kilograms) or rubber, this application is calling for as much as 10 million pounds (4.5 million kilograms) from our scrap pile annually.

As our schools call for better facilities, more of this product will be used and again we can improve our quality of life by utilizing our wasted resource.

ECONOMICS

As previously indicated the major roadblock to using rubber in highways has been whether the improvements produced would justify the additional cost of the rubber.

In a paper prepared for the Environmental Protection Agency, H. C. Goddard noted that if pavement life could be extended long enough to prevent one major reconstruction, the savings is construction costs would make the rubber in a tire worth $48.60[4]. Obviously this is far above the cost of the rubber.

We feel that the field results have proven that the rubber can prevent not one but several reconstruction projects making the rubber worth even more.

In addition to the savings in reconstruction costs, there is evidence that the use of the rubber interlayer can reduce the quantitiy of new pavement needed and consequently save this cost.

At a time when highway funds are difficult to obtain, these cost advantages of using rubber are becoming very attractive to

highway engineers.

CONSERVATION

In a project proposed for this summer, eleven miles of roadway will require 360,000 pounds (164,000 kilograms) of rubber or 18,000 scrap tires to produce the interlayer. Since this interlayer will also be substituted for 1½ inches (3.8 centimeters) of asphalt concrete, 170,000 gallons of asphalt will be saved.

As of December 31, 1973 there were 3,806,883 miles (6,125,275 kilometers) of roads and streets in the United States. If the above concept were applied to only 6.4% of these roads, the entire 8 billion pounds (3.6 billion kilograms) of scrap tires would be required to furnish the needed rubber and 3.8 million gallons (14 million liters) of asphalt would be conserved. By preventing frequent reconstructions, this asphalt along with other raw materials would be repeatedly saved.

CONCLUSIONS

We feel that the value of scrap rubber in highways and recreational surfaces has been established making it a valuable commodity rather than a serious solid waste problem. As this usage continues to grow, it is forseeable that the entire scrap pile could be required to supply this market and that it might even be necessary to create new material of similar composition for this purpose.

If these developments continue, we also have the potential

for conserving billions of pounds of rubber and asphalt which are essentially the petroleum which is so critical to the maintenance of our industry and life styles.

All that remains to be done is to make highway engineers more aware of the value of the rubber and to develop more efficient methods of collecting and processing the scrap.

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Rubber in low cost roads

The author, who is Borough Engineer, Director Public Works, South Plainfield, New Jersey, U.S.A., describes a method of making low cost roads which is of special interest to overseas territories undergoing rapid development.

AREAS undergoing rapid development are often confronted with the problem of building adequate roads or streets. Usually the small amount of traffic does not justify construction of the expensive high types of pavements, particularly during the early years of development. The lack of funds also may require that some low-cost type of construction be used.

Typical case history

The Borough of South Plainfield, New Jersey, was confronted with such a problem in 1955. This residential community had developed rapidly because of its nearness to large industrial and high-population areas. As the population grew, the Borough Engineer received more and more complaints on the condition of the roads. This was particularly true during the spring thaws and the rainy season when the existing earth roads were unstable.

Attempts were made to improve the stability by placing stone on the road surface. This was not only expensive but, when the stone was placed on unstable roads in the spring, it soon settled to the bottom, the mud came to the top, and little improvement in stability was achieved.

In the spring of 1955 a programme of reconstruction of the streets and roads was started. Since the funds available for this programme were limited, it was extremely important that a low-cost type of construction be used. It was decided that a light surface treatment type of construction would be adequate to carry the traffic and it would be low in cost.

At the time the reconstruction programme was started, the majority of the existing roads and streets in South Plainfield were only one car in width and had no crown. The first step in the reconstruction was to widen the roads to 30 ft., and establish uniform grade by cutting off the high spots and filling the low spots. When the grade was satisfactory the roads were shaped with a blade grader so as to have an 8-in. crown and adequate side drainage ditches. Culverts or other drainage features were also installed where they were needed to carry off the surface water.

The soil in South Plainfield varies from a shale to a sandy loam. Some areas have clay. An analysis of the sandy loam showed it to contain 84 per cent. particles larger than 0.25 mm. and 16 per cent. between 0.05 and 0.25 mm. Tests also showed the soil to have a high rate of percolation of water. Thus the sandy loam soils were considered to be suitable for use in base courses. Where the shale or clay materials existed, it was necessary to add selected material to improve the stability of the base. Therefore, these areas were covered with 2 to 3 in. of crushed stone and compacted with an 8-12-ton



Fig. 1. *Before construction—typical condition of a road*



Fig. 2. *Stone-spreading and rolling of stone for surface treatment*

roller. The maximum size of the stone was ¾ in. and it contained a sufficient amount of finer material to give a dense and stable base when compacted. After rolling, traffic was allowed to use the roads.

Just before the bituminous surface was applied, a blade grader was used to fill any minor depressions and smooth the surface without cutting through the hard packed layer made by traffic and by rolling. After this final shaping, a low-viscosity medium-curing cutback bitumen was applied to the surface with a binder distributor.

Importance of moisture

The cutback was applied to these roads in the early part of May in order to take advantage of the moisture in the base. The presence of some moisture improved the uniformity of coverage and resulted in a maximum penetration of the cutback into the base material. In those areas where the natural soil was used as a base the cutback penetrated to a depth of 1 to 1½ in. Approximately the same depth of penetration was also obtained for the base supplemented with the crushed stone. The good penetration of the cutback resulted in a stable, waterproof



Fig. 3. *Application of stone on rapid-setting emulsion*

base on which the surface treatment could be applied.

In order to control the depth of penetration of the cutback, grade MC-1 was used on sandy surfaces and grade MC-0 on the more dense surfaces. In some cases a blend of MC-0 and MC-1 was applied. The rate of application was 0.3 to 0.4 gal. per sq. yd.

The surfaces treated with the cutback were allowed to cure for at least seven days and in some cases were left for as long as six weeks before the emulsified bitumen surface treatment was applied. During this curing time traffic was allowed to use the roads. Any holes caused by the action of traffic were patched with hot asphaltic concrete (rolled asphalt) or with ⅜ in. and ¾ in. crushed stone and emulsified bitumen applied by a hand spray.



Fig. 4. *Application of rubberized emulsified bitumen for surface treatment*

Emulsified bitumen chosen

Because emulsified bitumen was known to have certain beneficial qualities for surface treatment not found in cutback bitumens, this was selected for the programme. Previous work had indicated that the addition of small amounts of natural rubber latex to the emulsified bitumen would improve the adhesive properties and result in better retention of the stone. Therefore, an emulsified bitumen with a natural rubber additive was specified for the binder for the surface dressings. The emulsified bitumen chosen for this work was a low-viscosity rapid-setting type commonly designated in the United States as RS-1. The specifications required that 0.25 to 1.0 per cent. by weight of natural rubber latex be added to the emulsion.

The surface treatment was constructed by applying the rubberized emulsified bitumen by a tank distributor at the rate of 0.3 gal. per sq. yd.,

and covering immediately with ½ in. crushed stone applied at the rate of 20 to 22 lb. per sq. yd. As soon as the road was covered with stone, a drag made of chain-link fence was used to smooth the surface and fill in any irregularities. The road was rolled with an 8-10-ton roller and immediately opened to traffic.

Since the emulsified bitumen used was of the rapid-setting type, there was only a short interval of time available between the application of the emulsion and the completion of the dragging operation. It is important not to allow the distributor to apply the emulsion further than 150 to 200 ft. ahead of the application of the stone cover. When the emulsion is first applied it is brown in colour and after 15 or 20 minutes it turns black. The stone must be applied and the surface dragged within that time. The emulsion is an excellent material, but must be handled properly to be effective and obtain the desired results. The superintendent or foreman in charge of construction should see that all operations are closely controlled.

The roads that were surfaced with rubberized emulsified bitumen in 1955 have been in use for nearly two years; during this time they were exposed to several freezing and thawing cycles and are still in excellent condition. To date there has been very little loss of cover stone.

A double treatment

One street, which is a connecting link between two county roads, was given a double treatment at the time of construction in 1955. Each treatment consisted of an application of 0.3 gal. of rubberized emulsified bitumen and 22 lb. of cover stone per sq. yd. During the winter of 1956-57 this street was subjected to extremely heavy traffic during the construction of a new school in that area. Trucks delivering ready-mix concrete and reinforced concrete pipe, power shovels, bulldozers, and heavy earth-moving equipment all used this street during the winter. Within this period the ground was frozen to a depth of 14 in. There followed a four-day rain which thawed the ground. Even though this road was constructed with no stone base material, the road surface has remained intact and free from holes.

It appears that normal maintenance, such as patching and a light re-treatment of emulsified bitumen and stone every three or four years, will make these roads last indefinitely; or the present roads stabilized and surfaced by this method can be used as a base for the construction of higher type surfaces.

The total cost of the cutback used in the penetration treatment and the rubberized bitumen emulsion and stone for the surface treatment was very low. For the areas built on the existing sandy soil, the cost of all the materials was 14.3 cents per sq. yd.; where a double surface treatment was used, the cost was 21.6 cents per sq. yd. In the areas where 3 in. of stone was first placed on the road, the cost of all materials was 39.3 cents per sq. yd.

Since the start of this programme in 1955,

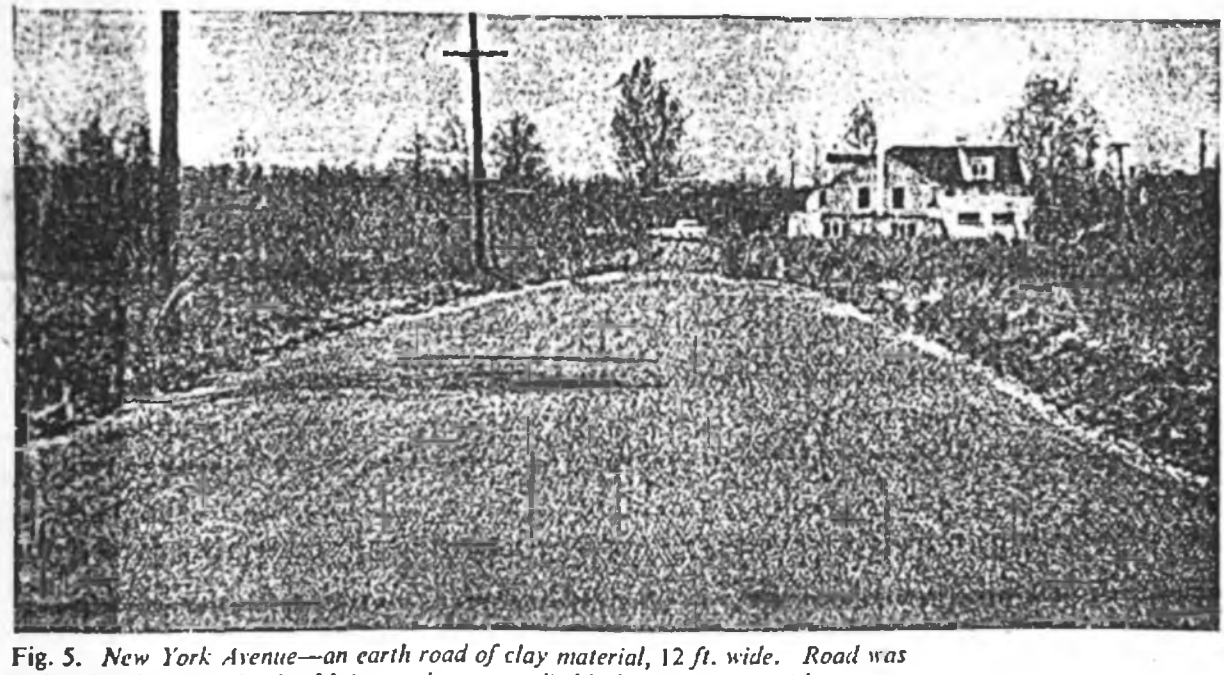


Fig. 5. *New York Avenue—an earth road of clay material, 12 ft. wide. Road was widened and 3 in. in depth of ¾ in. road stone applied before treatment with rubberized emulsified asphalt*

approximately 9.7 miles of road in South Plainfield have been surface treated with rubberized emulsified bitumen. During 1957 it is anticipated that an additional 3.5 to 4 miles will be constructed by the same method.

These roads in South Plainfield have been inspected by many contractors, municipal and county officials and others, and the same method of construction is being used or considered by other communities. The performance of the surface-treated roads using emulsified bitumen containing a natural rubber additive has proven to be excellent and the roads so constructed are low in cost.

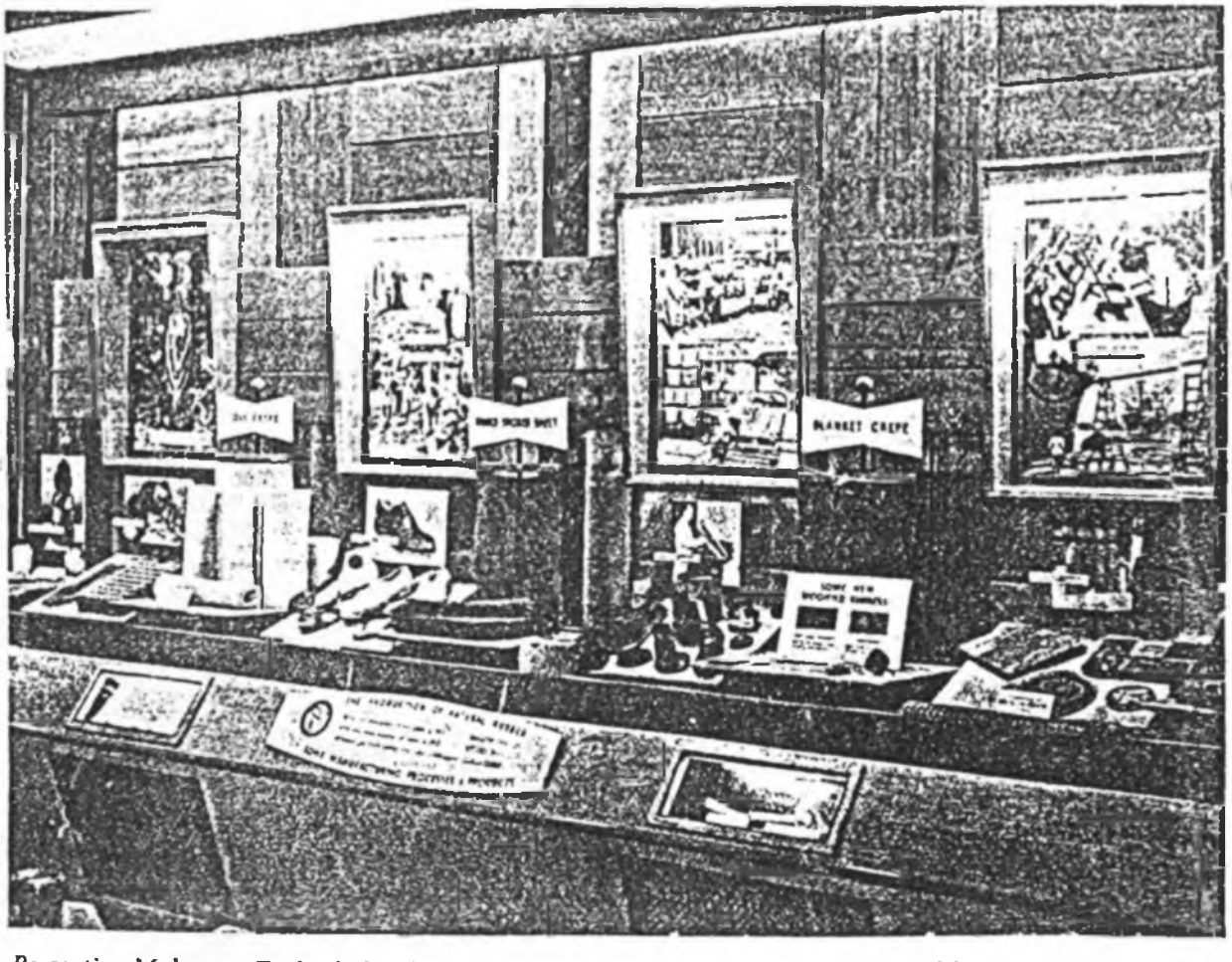
APPENDIX

Preparation of rubberized emulsified bitumen

The emulsion conforming to the specifications was rubberized during the process of emulsification of the bitumen. The asphalt, water, emulsifying agent and natural rubber latex were combined and emulsified simultaneously. The rubber latex was added at the rate of 0.25 to 1 per cent. by weight of the emulsion.

Emulsified bitumen can also be rubberized by adding the natural rubber latex directly to the emulsion. These should be mixed thoroughly to ensure uniform dispersion of the rubber. If they are combined in a storage tank or tank distributor the rubber latex can be dispersed by re-circulating with a pump. The time required to blend the two materials uniformly will depend upon the quantity of emulsion and the capacity of the pump. For example, rubber latex can be dispersed uniformly in 1,000 gal. of emulsion in one hour by re-circulating with a pump having a capacity of 300 gal. per minute.

If the latex and emulsion are to be blended by hand stirring, it should be done in relatively small batches to ensure a uniform dispersion of the rubber.



Presenting Malaya to England, this showroom recently opened at Malaya House, Trafalgar Square, the Rubber section of which is shown here, is a cleverly planned shop window for Malayan products. The display is open to the public during office hours

As a result of Mr. Fairbairn's visit, a local office has been rented and a firm appointed on a temporary basis to handle local arrangements; the Board's literature is being distributed to the appropriate industries; an exhibition showing the applications of rubber to building has been held and valuable contacts have been established with prominent manufacturers in the Union.

Based on the preliminary work carried out by Mr. Fairbairn, which is greatly appreciated by the Board, it is hoped that a permanent arrangement will eventually be made whereby the Board will have a local office in South Africa.

Pneumatic Tyres
FOR CORN PLANTERS

According to a recent announcement, what is believed to constitute one of the final steps in the evolution of steel wheels to rubber tyres for farm implements is a new smooth-tread tyre now being produced by the Goodyear Tire & Rubber Co. of Akron. The tyre is designed primarily for use on corn planters, one of the few farm machines for which steel wheels are still used.



The new tyre is of the 6.50-16 size, of two-ply construction, and it operates at extremely low pressure, with only 2lb. of air recommended. Chief among its advantages, according to Goodyear, is the fact that its smooth tread does not pick up moist or sticky soil, thereby making corn planting less dependent upon dry weather.

The smooth tread and low pressure are also less likely to cause "soil packing."

The smooth tread of the tyre does not materially affect its wearing qualities, since corn planters operate in soft ground, and normally on an average of but from one to two weeks during the year.

CARE OF RUBBER HOSE

The Goodyear Tyre and Rubber Co., Ltd., of Wolverhampton have recently issued a pamphlet on the manufacture of industrial rubber hose, in which they have included some useful notes on hose maintenance. These cover illustrations of the right and wrong ways of fixing couplings, avoiding local strains and stresses on the hose and other useful hints, which will be of value to any industrial and domestic users of rubber hose.

Rubber in Road and Airport Construction in the United States

by **WARREN S. LOCKWOOD***

THE prominent American business publication *Business Week* quotes Col. E. R. Needles, President of the American Road Builders' Association, as stating that to get the United States highway system into shape to handle future traffic probably will take about $60,000,000,000 of expenditure during the next 15 to 20 years. Road building in 1949 will be at the highest level in United States history and spending this year on new roads and on maintenance on old ones is estimated to total almost $1,700,000,000. A *Business Week* survey this spring of state highway departments found all of them agreed that there is an urgent need for more and better roads because of new demands on them from three sources: one, a sharp rise in traffic volume; two, growing urban congestion; and, three, national defence requirements.

*Director, Rubber Development Bureau, Washington.

At the present time more than 600,000 miles of highway are included in a Federal aid plan whereby the national Public Roads Administration allocates Federal funds to states for highway construction and maintenance, with each state required to appropriate money of its own to equal the Federal aid, dollar for dollar. The remaining roads, consisting of city pavements maintained by towns and cities throughout the country and more than three million miles of rural roads maintained by the states, do not receive Federal assistance, but provide, of course, a fertile field for future improvement. Nearly a million miles of rural roads, for instance, are entirely unimproved.

The great problem facing the road-building industry in the United States is how to get the most value out of the highway dollar. In other words, how to reduce maintenance costs by building roads which will last longer with less necessary repairs.



Natural rubber powder as received from the Far East

For this reason the British Rubber Development Board and the Rubber Development Bureau considered that the excellent results obtained by the Dutch in Holland by utilizing rubber powder with asphalt in road construction should be brought to the attention of Federal and state highway authorities in this country. The test roads built in Holland and Indonesia which have now been down for over ten years would seem to substantiate the claims of the Rubber-Stichting, which can be briefly summarized from



Delivery of first load of mixed binder material

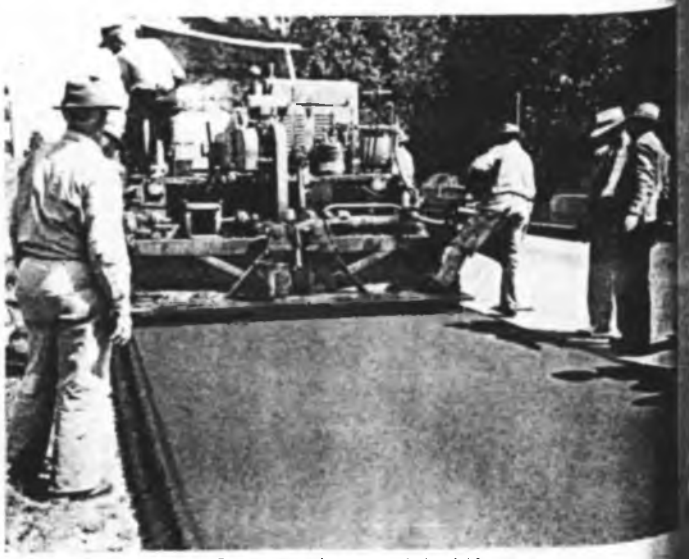
the introduction of the excellent booklet published this spring by Ir. F. T. Bokma of the Rubber-Stichting, Delft, entitled " The Use of Rubber in Bituminous Road Constructions and Some Other Applications of Rubber Containing Bitumen " as follows :

" Rubber powder slowly absorbs certain constituents of the asphalt, and irrespective of weather conditions has the following advantages:

(*a*) The road surface lasts longer.
(*b*) The road foundation is better protected.
(*c*) The costs of upkeep are lower.
(*d*) Congestions of traffic due to repair work are less frequent and of shorter duration.
(*e*) The road surface is dustless and therefore more hygienic.

The technical data published by the Rubber Stichting was supplied by the Rubber Development Bureau in Washington to the Public Roads Administration in Washington and, through the co-operation of the Public Roads Administration, to the highway departments of the States of Virginia, Ohio, Minnesota and Texas. Everyone interested in this development should study Mr. Bokma's pamphlet referred to above as it was studied by these national and state authorities. But to the layman the essential claim is that by utilizing rubber powder with the asphalt the resulting mixture makes a road surface which is less soft in summer and less hard in winter and which has the tendency of protecting the foundation of the road by helping to seal out surface water from leaking through into the foundation.

The official and state engineers in this country felt that the idea of mixing rubber powder with asphalt in order to obtain these claimed improvements was worthy of a very careful test because it has been recognized for many years that asphalt needs improvement in the field of resistance to temperature change and in resistance to rain penetration.



Rubber wearing course being laid

International Co-operation in Organizing Tests

Following personal interviews by officials of the Rubber Development Bureau with the state authorities in Virginia, Ohio, Minnesota and Texas, agreements were reached in each state to lay an official state test road stretch. The manner in which this was carried out was an example of international co-operation really working in the development of a major new use. The British Rubber Development Board in London, which sponsored the projects through the Rubber Development Bureau in Washington, received the co-operation of the Rubber-Stichting in Delft, which loaned Mr. Bokma for a six-week period this spring to provide technical assistance to the states laying the roads, and the Indonesian Rubber Research Institute provided the powder so that the states could be given sufficient material for a suitable test without charge. All other expenses were borne by the British Rubber Development Board.

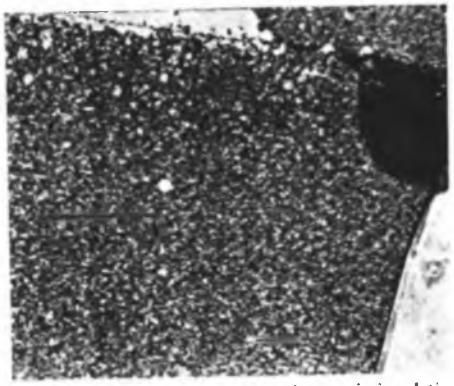
The status of the projects is that the Virginia test road was laid in the middle of May, the Ohio road at the end of May, the Minnesota road at the end of July, and the Texas road in August as this issue goes to press. The tests in these states gave the development not only an amazing volume of national publicity and created the most widespread interest in constructional and governmental circles, but also because of the variety of climates experienced in these states and the differing methods of applying the rubber powder, will tend to show where the best immediate market lies for future development.



Commencing the laying of the second strip

Although in an article of this kind we cannot attempt to detail the exact technical manner in which the test roads were constructed, it can be stated that the test stretches range from 1,000 ft. to one mile in length and the surface course utilizing the rubber powder from $\frac{1}{8}$ to more than $\frac{1}{2}$ in. in thickness. Rubber powder was added to the asphalt at the rate of approximately 6 per cent. of the weight of the asphalt used and the rubber and asphalt mixture was in turn approximately 5 to 7 per cent. of the total aggregate used. From these figures it will be clearly evident that only a fraction of 1 per cent. of the surface course of the road was rubber powder and, of course, the surface course is only one of three principal layers of average road construction in this country. The fact that so little powder can be used with such important effect is most important in evaluating the economic prospects of this development.

In the Virginia test, for instance, where the wearing course was applied very much thicker than in the tests in Texas and Ohio, 8.4 lb. of powdered rubber was added per ton of mix and, at this rate, 4,813 lb. of



Close-up of Rubber wearing course (note coin in relation to texture)

rubber powder would be required per mile of pavement 30 ft. wide.

The illustrations in this article show various stages in the installation of the demonstration road stretch in Virginia.

The Potential Market

In evaluating the potential market for rubber in road construction in the United States the Rubber Development Bureau calls attention to the Worthington, Minnesota, test, which was just completed as this article is being written. The Mayor of Worthington, Mr. Jack C. Boote, read about the development as a result of Rubber Development Bureau publicity. He inquired whether a test could be made in Worthington. In view of the fact that our previous test programme had not included a state so far north as Minnesota we welcomed the opportunity to co-operate with him and Mr. Bokma and our United States consulting engineer, Mr. Harry K. Fisher, visited Worthington and co-operated with the city engineer and the contractor in laying the road. Many obstacles had to be overcome, including the availability of materials, an inexperienced contractor and poor equipment.

The Rubber Development Bureau has, however, just received letters, both from the mayor and the city engineer, expressing pride in their rubber paving and great interest in the entire development. The letter from the mayor was signed by five councilmen of Worthington and informed us that they were sending an order for 4 tons of powdered rubber for their 1950 street improvement programme. The letter from Mr. George A. Claydon, the city engineer, stated :

" We have had many visitors, such as " engineers, contractors, and council mem- " bers from many cities, viewing and " riding over our rubber-paved street, and " all have remarked, 'You really have " something there.' "

The letter from Mr. Jack C. Boote, the mayor, stated :

" The visitors calling from all over the " west have been terrific . . . I just now had " a call from Seattle, Washington, and " from several other states who want to " try and see it. . . . Many newspaper " reporters are coming from different " parts of the country to see it."

The Worthington story is important because Worthington is a city with a population of 8,000. It does not require much imagination to figure out the enormous potential if larger cities, federally-aided state highway and rural road departments should find this development equally interesting.

We here in the Rubber Development Bureau foresee a market potential of perhaps 1,000 tons of rubber powder for test purposes during the next six months. We then foresee a market potential of perhaps 1,000 tons per month for the following year for larger and more widespread tests and for the numerous " Worthington " throughout the country which can be sold on this development. The potential market at that level, of course, would be only scratched.

Use for Airfields

To date we have not discussed airports in this article because we have not yet arranged an airport test. We expect, in our experimental programme in 1950, to investigate the airport field thoroughly because the properties rubber gives asphalt are especially important in airport construction and the interest being exhibited by airport authorities is great.

The Rubber Development Bureau has received various inquiries for rubber powder from many state highway departments throughout the country and one of their officials is currently visiting California to contact their highway department. We have had inquiries from as widespread places as Florida, Louisiana, the West Coast and Quebec. Trade papers and road industry publications are intensely interested, as are contractor organizations throughout the country. But the really interested man is the highway engineer. He wants more for his highway dollar and rubber in road construction seems like a really good opportunity for him to stretch that dollar. In 1949 it is expected that the average mile of new road construction in this country will cost $36,000.00. The cost of one or two tons of rubber powder per mile of road in relation to the possibility of materially longer wear and less repairs is insignificant. It is even possible that the wearing surface made with rubber powder may be applied with a thinner-than-normal coating, so that the saving in other materials would offset the cost of the powder.

In any event, the road engineer in the United States is willing to try anything new which promises to improve roads and certainly his reaction to this development would indicate that here is one of the most promising possibilities in road construction for many years.

From the rubber consumption standpoint it is the most potentially interesting development in rubber consumption since the pneumatic tyre.

RUBBER IN TENNIS COURTS



Fernden 'Elastico' Tennis Court

TENNIS courts, until recently, could be divided into those which required no upkeep but which were far from ideal from the playing point of view, and those which gave satisfactory playing conditions but which needed considerable regular maintenance. A prominent manufacturer of tennis courts now claims to have produced a court which combines the advantages of both. Attempts have been made to increase the resilience of the surface by superimposing one of the various types of materials such as fibre, paper, ground cork, etc., but apart from the expense adhesion to the base has always presented a difficult problem.

The " Elastico " court which has been provisionally patented, contains a substantial proportion of natural rubber in its construction and the makers claim that it offers the nearest approach to the perfect surface which has yet been produced. The rubber is incorporated throughout the full thickness of the material and although this obviously adds a little to the cost, there are always some owners, particularly private owners, who are prepared to bear some extra expense if it shows advantages such as are enumerated above.

The experimental work in connection with this new surfacing was carried out by the makers with the assistance of the British Rubber Producers' Research Association, of Welwyn Garden City. Further details, are contained in a leaflet which can be obtained upon application to Fernden Contractors, Ltd., 45 High Street, Godalming, Surrey.

(69) 179/

Rubber In Road Construction.

Druiez, M.M

Rubber Development. 4; 1951

Rubber *in* ROAD CONSTRUCTION

by **M. M. DURIEZ.**

Chief Government Civil Engineer, Director of the Laboratory of the National School of Roads and Bridges

THE idea of using natural rubber in road construction—already some 20 years old—seems to be coming into greater prominence, especially in the United States of America. This is shown by the ever-growing number of test sections laid down since 1945, both there and in other countries, at the instigation of the four rubber development organizations: Rubber-Stichting in Holland, Institut Français du Caoutchouc in France, the British Rubber Development Board in Britain and their American office, the Natural Rubber Bureau in the U.S.A.

More than a hundred miles of road surfaces incorporating rubber have been constructed in the U.S.A. since the end of the war, principally in Virginia, Ohio, Minnesota, Texas and Massachusetts. Further sections have recently been constructed in Canada in the province of Quebec, in England in Leicestershire (and in Aberdeen, Somersetshire, Leeds, Bradford, London, and in other parts of the United Kingdom), in France in the neighbourhood of Paris and in Holland at Flushing.

The improvement of the properties of road-surfacing compositions by the addition of a small quantity of rubber (of the order of 5 to 7 per cent.) has already been cited many times: increased penetration, a raising of the softening point, reduced flow characteristics and improved adhesion in certain aggregates (principally porphyry and quartzite). Broadly speaking, it may be accepted that rubber exercises a favourable action in the three following cases:

(*a*) The thermal susceptibility of the composition.
(*b*) Ageing.
(*c*) Skid resistance.

The laboratory tests carried out in Malaya and Holland, and in France at the Roads and Bridges (Government Civil Engineering) Laboratory have shown that the logarithmic susceptibility of rubberized bitumen is similar to that of a blown bitumen and permits rubberized compositions to remain plastic at low winter temperatures and, on the other hand, remain stable at high summer temperatures. Rubberized bitumen thus differs from a filled bitumen in that the addition of a filler to a bitumen, though raising the softening temperature, decreases the penetration at low temperatures. From that fact, the graph of logarithmic susceptibility of a filled bitumen is very similar to that of a standard bitumen, the angular coefficient, i.e. the thermal susceptibility, remaining the same. On the contrary, with rubber the softening point and the penetration at zero being increased, the graph of logarithmic susceptibility of rubberized bitumen cuts that of the standard bitumen, the angular coefficient being clearer.

For instance, at the Highways and Bridges Laboratory, it was found that with a bitumen of 180-200 pen, the angular coefficient of .0427 changed to .0343 when a 10 per cent. addition of rubber powder was made.

This may be understood if it is considered that, the rubber having absorbed a part of the hydrocarbons constituting the maltenes, the asphaltene content of the asphaltene-maltene colloidal system is found to be increased, thus leading to a bitumen of greater hardness than the original.

Apart from the asphaltic composition's own properties, the addition of rubber to bitumen seems to confer skid-resistance qualities to the surface. Particularly was thus so in the U.S.A., where braking tests on test sections showed a decrease in skidding where there was a rubberized bitumen base. For instance, on the surface laid on September 22, 1949, in the vicinity of Goodland, Va., on route 250, it was observed after six months that for a vehicle travelling at 50 miles an hour the stopping distance on a damp surface was 130 ft. where the surface contained rubber and 160 ft. on the control section.

There are two principal methods for incorporating rubber in bitumen: in powder form or as liquid latex.

There are various kinds of rubber powder that may be obtained from natural latex, but that most commonly used is "Mealorub" flocculated latex crumb, manufactured by the Indonesisch Instituut voor Rubber-Onderzoek at Bogor, Indonesia. Where powdered rubber is used in the manufacture of bituminous carpets, the manufacturing processes do not differ from those normally employed. "Mealorub" is added to the aggregate in the mixing plant in the same manner as a filler, and before the addition of the bitumen.

Recently in France particular study has been given to the problems of incorporating natural latex with bituminous emulsions, and spreading tests of these latex emulsions have already been carried out under the auspices of the Institut Français du Caoutchouc, principally at Saint-Germain-en-Laye, where excellent results were obtained.

Latex is a natural emulsion of rubber hydrocarbon. The maximum particle dimensions are of the order of one micron. The emulsion is maintained by the natural proteins, which confer on the rubber particles negative electric charges. Natural latex stabilized with ammonia has a *p*H very similar to that of bitumen emulsions. Consequently, it is possible to mix latex directly with a bitumen without provoking flocculation. With bitumen-latex mixtures, contrary to the practice when using a rubber powder, the mixing of the two substances is carried out at the time of heating the bitumen; the rubber particles of latex, having a diameter five to six times smaller than that of the bitumen particles, are to some extent occluded by the bitumen when its particles fuse during the heating process. From this fact, the rubber mixed with the bitumen in this way is much more finely dispersed throughout the bitumen than in the case of powdered rubber, and this gives the advantage of better and quicker swelling of the rubber particles.

The studies made in the Highways and Bridges Laboratory in this connection with "Colas" bituminous emulsions and hevea latex from French Indo-China show that the best results may be obtained by using a concentrated latex with a 60 per cent. rubber content in normal mixtures containing 50 per cent. bitumen. For such mixtures with 5 per cent. rubber to the bitumen content, viscosity in particular undergoes little modification. It is interesting to remember this, in view of the well-known importance of emulsion viscosity at the actual time of laying.

As a result of tests undertaken since 1943, one application in the use of latex may be mentioned—in very small quantities in surface maintenance work on roads, in conjunction with hydrocarbon binders. This work was carried out in 1950 on a rather large scale, covering several kilometres, by the Chief Engineer, Monsieur Leroux, on state highways and local roads in the department of Eure-et-Loire.

This technique consisted of incorporating latex not in bituminous emulsions, but in anthracenic oil emulsions, used for regenerating the surface binder.

What are the future prospects of rubber in roadway construction? First, the price of rubber would seem to prohibit its use, considering that its addition to surfacing emulsions increases the manufacturing costs by nearly 30 per cent. Nevertheless, in view of the magnitude of the development work done in this field in the U.S.A., it seems significant that there is a growing interest on the part of American highway constructors. On the other hand, it is obvious that if the addition of rubber to surfacing emulsions increases their life by a considerable amount, with the same materials or even better ones the additional 30 per cent. on initial cost would, in fact, be a substantial economy.

But it is the future behaviour of those rubberized surfacings being laid today that will show if these hopes are well founded and if there is a future for rubber in road construction.

(71)

Rubber Roadways

A Review

By

J. D. Hastings

RUBBER ROADWAYS

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As far back as 1870, at St. Pancras Station, London, a road leading to the arrival platforms was paved with rubber slabs. These were two inches thick and while some have been taken up, replaced or relaid, there are in use at the moment some of the original slabs still in good condition, a striking testimony to the life of rubber as a road making material. Little more seems to have been done until 1913, when the Southwark Council was approached for permission to lay a small experimental stretch of rubber paved road. This was allowed and a section of two or three square yards of rubber-capped wooden blocks was laid at the junction of the New and Old Kent roads. After a year and nine months, the blocks were taken up for examination; little surface wear had taken place but the anchorage of the cap to the block was unsatisfactory and there was wear between the under side of the cap and the top of the wood. In 1915, Rubber Roadways Ltd., a Company to foster the use of rubber for roadways, was formed under the auspices of the Rubber Growers' Association for collaboration with manufacturers and inventors to try out many of the ideas and patents that the earlier test had brought forth. Many of these were unsatisfactory, due to the difficulty of anchorage of the cap. In 1918, the Leyland and Birmingham Rubber Company Ltd., evolved the Leyland block and in the early part of 1920 a section of road in Southwark was laid with these blocks. These had a rubber cap attached to vulcanite which was fixed to a steel plate with projections on the under side, these being embedded in the wet concrete foundation of the road at the time of laying. Within a short time, some 15 per cent. of the blocks had shifted from the plates, and accordingly, half the area was taken up and replaced with blocks having a plate of expanded metal with projecting lugs embedded in the vulcanite: these were an improvement.

The anchorage of the cap continued to be the chief difficulty, the actual wear on the surface being negligible, and the position with regard to the use of rubber as a road surfacing material is expressed in the statement of the Chairman of Rubber Roadways Ltd., who said in 1922 "there is no question of the wearing and

rubber properties claimed—the problem is now one of attachment to foundation."

Further investigation by the Leyland and Birmingham Rubber Company Ltd., led to an alteration in the design of their block, and in 1923, the improved type was laid in another section of road in Southwark. The block now consisted of an upper portion, half an inch thick, of rubber similar to the old cap and a lower 2½ inches of very hard rubber, the two being vulcanised together. These proved very satisfactory and when removed in 1926 shewed little wear. That a great deal of investigation was being carried out is evident in the statement made in 1925 by Rubber Roadways Ltd., that over 70 patents for the use of rubber as road material, mainly in the form of blocks, had been granted within the previous few years.

Today the anchorage question has been completely overcome, and there can now be seen in England and Scotland, as well as on the Continent, a number of sections of roadways paved with one or more of the following five principal blocks:—

(1) The Leyland block previously mentioned, laid in 1924 on a stretch of roadway at Fresh Wharf, London Bridge.

(2) The North British block laid in Edinburgh and Glasgow in 1923. A feature of this block is the size of the concrete base which is smaller than the rubber cap and thus ensures improved grouting when the blocks are laid.

(3) The Cowper block in Thurloe Place; an interlocking, all rubber 3 layer block, grooved and recessed on the sides, giving a very good surface joint, laid in 1928 after earlier trails had proved very successful.

(4) The Gaisman block, a rubber cap vulcanised to a hard highly vitrified brick base, laid in 1926 in New Bridge Street, London.

(5) The Cresson block, a rubber cap fixed to a base containing stone, sand and other ingredients mixed with latex, all of which are pressed together and vulcanised when dry. Laid in Croydon at the end of 1928 following its successful use in Singapore since 1922 where blocks removed in 1927, apart from a slight surface cracking due to the tropical sun, were in excellent condition with practically no wear—incidentally the road adjoining had been repaired three times within that period.

All these trials now taking place are in areas where traffic is heavy. In addition to shewing no sign of wear, the reduction in noise and vibration is particularly noticeable. In 1922 a series of

sound records were taken near the Cenotaph, London, after rubber paving had been laid. The paving, although unsuccessful as far as the maintenance of the road was concerned, provided valuable data on the use of rubber as a vibration absorbing medium. The actual measurements shewed a 30 per cent., reduction in noise as compared with that transmitted by the adjoining wood paving and the remaining sound was less objectionable.

Late in 1927, more accurate measurements on vibratory conditions in buildings adjoining the rubber road in New Bridge Street were made on behalf of Rubber Roadways Ltd., and proved conclusively that vibration was much decreased with less damage to foundations of the buildings in consequence.

The present situation with regard to rubber blocks is that while every test indicates that wear is reduced to a very small amount and vibration is largely absorbed, the initial cost of laying the road is too high for large scale work. Considerable reduction in cost has been effected; when trials were first started the cost per square yard was approximately £5; at the Annual Meeting of Rubber Roadways Ltd., 1930, the Secretary was able to state that Firms were prepared to produce at £2.10.0 per square yard. This compares favourably with granite setts at £2.0.0. Moreover, in 1929 two areas were laid, on which the manufacturers gave a free maintenance guarantee for 5 years.

As alternative to the use of rubber-capped blocks there are the possibilities of slabs of rubber laid on similar lines to the early experiment at St. Pancras Station. Quite recently a trial has been started in Paris in the Quai de la Rapée using long slabs of rubber, laid on a cement foundation with hot melted asphalt between the rubber and the concrete as the binding material. The slabs were 8 to 9 metres long and 0.80 metre wide, made in two layers, the top being much thinner than the bottom which is in direct contact with the foundation. So far, no reports are available; there is a section of Gaisman block quite near, laid in 1929, so that a comparison will be of great interest. About one year ago, in the Ipoh district, trials with rubber carpeting embodying very similar ideas were made by two local inventors. Reference to a trial of this product by the Institute is made later.

The possibilities of using rubber incorporated with ordinary road materials have received attention from a number of investigators, and many patents have been taken out for preparations. As long ago as 1904, rubber had been incorporated with asphalt and laid at the Place de la Gare, Cannes, where traffic was said to be especially heavy. This is still in existence, while large stretches of rubberised asphalt are to be seen at Monaco and Cannes laid in 1912 and still in good condition. Little information is available

relating to costs, and it seems difficult to see how the quantity of rubber introduced—which is from 2 to 5 per cent—could effect the improvements in quality of the road surface to the large extent claimed.

In 1922, a trial was made in England and Ceylon by boiling down low grade rubbers in open pans yielding a tarry residue which was applied to the road. The result was not satisfactory, and at the same time the process lost the distillation products of the rubber which were not collected.

Much work has been done on the destructive distillation of raw rubber, and the oil obtained has many possible applications. Rubber oil, in common with bituminous oils, has a solvent action on rubber itself, and its utility as a solvent for rubber and asphalt or bitumen has been investigated. In spite of the mass of patents granted and literature written on the incorporation of raw or vulcanised rubber into ordinary road materials, it is not evident from the practical results that a cheap and satisfactory compound has yet been produced by these means. In fact a recent text book on roads dealing very fully with all classes of roadmaking materials does not even mention rubber asphalt compositions.

As another alternative to the block there is the possibility of starting with rubber in the form of latex and from this evolving a material that can be laid by spreading.

Investigations at the Rubber Research Institute.

As a result of discussions late in 1930 between the Chief Secretary to Government, Federated Malay States, the President of the Board and the Director of the Rubber Research Institute it was agreed that investigations on the possible application of latex products to roadways were desirable and that such investigations could be best carried out in this country where supplies of latex are available.

It was also agreed that it was essential in the first instance to carry out chemical investigations in the laboratory and that the co-operation of roadway engineers was only possible at a later date.

The Board of the Institute accepted the recommendations put forward and agreed to allocate funds from its income towards the cost of the investigations and to appoint a chemist to undertake the work.

It was decided that the work should be controlled by a Committee of the Board of the Institute entitled the Rubber Roadways Committee, consisting of the President and two other members of the Board together with the Director and an officer

of the Public Works Department, Federated Malay States, appointed by the Director of Public Works, F.M.S.

The Committee applied for and obtained a contribution from the Rubber Experimental, Research and Propaganda Fund Advisory Board for the financing of practical road trials with any promising product which might be evolved.

The Director of Public Works, Federated Malay States, also promised the co-operation and advice of his staff in connection with such trials.

Work was commenced in March 1931 in the Chemical Division of the Institute, Dr. E. Rhodes being the Executive officer, and has been continued since May 1931 by Mr. J. D. Hastings who was appointed as special chemist to continue the work under the supervision of Dr. Rhodes. Dr. Rhodes proceeded on leave in May till the end of the year and made a number of valuable enquiries and contacts in relation to the problem while on leave.

The work done and the problems encountered are best dealt with under the following headings:—

Compositions made from latex.
The Laboratory testing of the compositions.
Rubber Roadway Compositions of Public Interest.

Rubber Compositions made from Latex.

A rubber road material made from latex laid on the road as a paste necessitates the incorporation of other bodies as fillers. Rubber blocks like motor tyres are not made of pure rubber. Non-rubber constituents are added to give hardness, resistance to abrasion, long life to, and mask some of the characteristics of pure rubber that would be undesirable; moreover the larger proportion of these constituents must be cheap.

The choice of a filler when using latex as the rubber base will depend on the state of division in which the filler is obtainable, or to which it can easily be reduced. The state of division or particle size affects the ultimate strength of the filled rubber very considerably; in general the finer the filler the stronger the resulting product. Carbon black which is used extensively in the motor tyre industry is obtainable in an extremely fine form and to this largely owes its value. The use of mineral bodies as fillers for latex as a road material are therefore limited to those which can be obtained in a very fine form such as the clays.

A great deal of time has been spent on the problem of incorporating mineral bodies and compounding latex with various types of filler. We have made a large number of mixtures in the laboratory embracing the use of all the possible materials available.

Each class of filler has been found to have its peculiarities and effect on the ultimate product, to confer in some cases desirable, and in other cases undesirable, properties. For example the incorporation of carbon black while being of great value is only achieved with difficulty, and its use in large quantities renders control of the mix uncertain and difficult.

Many of the mixes prepared in the laboratory have shown possibilities; at the same time it was thought that they would not behave in the same way when used in practice. In order to obtain information on this point a small section of road foundation was laid at the Institute, similar to that used in ordinary road construction.

In using latex as the source of rubber, there is the difficulty of working with a relatively unstable liquid as compared with the stable and solid condition of ordinary rubber. Before the incorporation of any kind of filler can be attempted the latex must be stabilised. Many classes of substances useful for this purpose are known, in general protective colloids such as the soaps, casein, gums and others. These have been used during the work, which has shown that the uniform incorporation of fillers is not easy; moreover as the mix becomes more paste-like the difficulties increase. Liability to coagulation becomes greater which means that larger quantities of stabiliser are necessary; this is a disadvantage in the final product when applied to the road owing to retarded coagulation and increase in "setting" time.

Our experiments have shown that a material made from latex and applied to the road as a paste must have the contained rubber in an uncoagulated condition. This is essential for natural anchorage. Once coagulation has taken place these materials have lost their paste characteristics and cannot be laid on the road with the expectation of a firm anchorage; neither can one piece of material be joined to another by pressure alone.

The work on the anchorage problem indicates that if applied as a paste, when "setting up" (coagulation of the contained latex) does occur, a firm hold is obtained on the surface of the road, and from this point of view a foundation that is not graded up to the fine surface known as "blinded" is preferable. It was at first thought that consolidation subsequent to laying, which causes a thinning out of the material might destroy the anchorage established by the "setting up." This does not appear to be so.

Our work with field latex very soon showed that the principal problem was the removal of the water content from the mix. The water can only be lost in two ways, viz., by drainage or surface evaporation. The latter is very much faster and it does not appear possible, assuming a mix to give an excellent material when freed

from water, to get it on the road in such a state with any degree of thickness. The drying out subsequent to laying causes cracking. Thinner surface films are possible.

Attempts to limit the initial water content have been tried, such as concentration of the thinner mixes by creaming, the use of concentrated latex, and the preparation of extremely thick pastes by the use of large quantities of filler. Concentration of thin mixes by creaming was unsuccessful. The cream was unstable and separation of fillers took place. It has not yet been possible to investigate the question of concentrating compounded latex by evaporation, plant of a special type is needed similar to that used in the manufacture of Revertex. The experiments tried have so far indicated the inadequacy of ordinary laboratory methods.

The use of concentrated latex has been investigated. Results show there is more possibility of avoiding the cracking experienced with field latex, the use of which has been practically abandoned on this account. The form of concentrate mostly used at the present time is that obtained by creaming methods. Research on creaming is being undertaken in the Chemical Division of the Institute and a supply of concentrates of different types is readily available.

The difficulties of compounding concentrated latex are greater than with field latex; the uniform introduction of large quantities of filler is more difficult. Unless a large amount of stabiliser is used very thick pastes cannot be compounded; the presence of excessive amounts of stabilisers is however undesirable as such bodies tend to delay coagulation when the mix is laid and retard hardening. The disadvantages of heavily compounding concentrated latex are recognised in those manufacturing processes using very thick compounded mixes and it is more general to concentrate compounded latex.

It has already been mentioned that the uniform introduction of filler into a thick paste is not easy; the thicker the paste the more difficult does it become to achieve uniformity. From the experience gained in the laboratory, working on a small scale by hand under very definitely controlled conditions, it was thought that mechanical mixing, or mixing that could be applied to roadside practice would present considerable difficulty. By the courtesy of a local company it was possible to use an internal mechanical mixer of a well known type. The results were not satisfactory, difficulty was experienced in getting a uniform paste of the same even consistency as that obtained by hand in the laboratory.

Our earlier work on the use of fibrous bodies and cements as fillers has led us to continue on these lines; while an enormous

amount of work remains to be done, it appears that the use of certain types of these fillers may be of great value. Mixtures have been made which are less liable to crack on drying, while the use of cement to remove the water by chemical means has shown promise.

A paste mill has been installed at the Institute and has been of great help in connection with work on fibres. So far it has not been possible to use it successfully with the work on cement, because of the difficulty of controlling coagulation.

The early difficulties of uniformly incorporating, to any desired degree, chemically dehydrating fillers such as cement and Plaster of Paris, have been overcome. The time spent on this problem has been justified and from the small scale laboratory experiments it has been possible to make mixes on a large scale with the same measure of success, at the same time the methods employed are applicable to the incorporation of other types of filler.

A good deal of work has been done on the incorporation of bitumen and asphalt into latex with a view to preparing a paste material. It is not possible to introduce bitumen direct. Its incorporation as an aqueous emulsion is simple, but the implied fact of any added water is a disadvantage. The problems connected with the compounding of a latex bitumen mix are similar to those already described for ordinary latex pastes. Investigations on the use of bitumen emulsion in combination with latex as a surface dressing have been carried out at the Institute but there is no proof yet that such preparations are an improvement on the ordinary bitumen emulsions now in use, from an ageing and wear point of view. Further, such a combination applied as a thin dressing will be of no value in relation to absorption of vibration.

Preliminary work on the use of vulcanised latex has been studied. Attempts have been made to follow the changes due to the use of certain ultra accelerators with variation in time of standing for different quantities of accelerator; using an uncompounded latex with a view to ascertaining whether its behaviour when used in a compounded mix is comparable to that when used in latex alone.

Laboratory Testing of Rubber Compositions made from Latex.

Work on the compounding of latex and incorporation of the various fillers has led to the need for a testing technique. This is an entirely new field of work, for at present there is no technique, and nothing is known about testing latex base materials for rubber roadways.

In common with all articles containing rubber the life and wearing properties of a rubber roadway mix will almost certainly depend on the state of vulcanisation of the contained rubber. It is necessary to be able to follow any changes in the rubber that occur with time, more especially in the early stages of its life. The ordinary testing methods, such as permanent set or stress-strain relationships cannot be applied to latex mixes of the type suitable for road application. The determination of free and combined sulphur content and hence vulcanisation coefficient by the usual methods of sulphur determination commonly applied to rubber have been found unsatisfactory when applied to road mixes and inadequate as a measure of the degree of vulcanisation.

Investigations on the rate of change of swelling in organic solvents with time have been carried out, although it has not been possible to correlate the amount of swelling with degree of vulcanisation, small changes in this are detected. In conjuction with swelling tests, stress-strain relationships have been studied where possible and qualitative conclusions regarding the state of vulcanisation have been deduced in agreement with tensile measurements. With a road mix containing bitumen or other constituents soluble in organic solvents this test is not applicable and so far there does not appear to be a line of approach for such materials. Variation in degree of vulcanisation at different depths added to large differences due to small changes in size and shape of the pieces under test make the evolution of a standard test difficult and unlikely.

With regard to abrasion testing several types of instrument have been tried, all of which have not proved completely satisfactory. A machine capable of dealing with very small samples giving a complete surface abrasion in a manner akin to the type of abrasion to which the material will be subjected is necessary. At present there is no machine suitable for these needs available here. Our experience has however indicated on what line work should be continued.

The artificial ageing of compounds can now be investigated. A Bierer Davis Oxygen bomb has been installed and its use on roadway mixes followed by chemical examination may enable us to predict how materials will age under normal conditions.

Development in testing technique are more likely to be directed towards the evaluation of physical rather than purely chemical tests. Should a material be satisfactory under such tests as abrasion, swelling, tensile strength, permanent set, hardness or plasticity followed by chemical examination before and after ageing we are certainly better fitted to predict its behaviour under

actual road conditions than to apply only the test of service which at present is apparently the only criterion.

In a wet mix the evalution of a test for shrinkage and its rate at different temperatures also becomes of great importance.

RUBBER ROADWAY COMPOSITIONS OF PUBLIC INTEREST.

The laying of experimental areas in Singapore of a proprietary roadway composition have been watched. Visits have been made, the actual laying of the paste observed and its subsequent behaviour on drying. The paste used was of the same general type as those with which we had been experimenting for some time. The problem of incorporation of suitable fillers does not admit of much variation. The drying of the paste was only obtained at the expense of contraction and resultant cracking. For any material to be successful the possibility of water penetration must not exist.

A bitumen emulsion from England has been investigated in connection with its use with latex. Laboratory tests have shown it to be very similar in behaviour to Colas, an aqueous bitumen emulsion made by the Asiatic Petroleum Company. On standing, separation of the bitumen from the latex rapidly takes place. Test strips were laid at Petaling with a bitumen and latex mixture in the proportions recommended. These were unsatisfactory and a further trial, using different methods of application, was laid. It is yet too early to pronounce definitely but indications of wear show that the mixing of latex with bitumen already emulsified yields too thin a product, at the same time an elastic surface skin is formed which is more easily peeled off, the plastic nature of the bitumen being masked. Trials have recently been made by the Asiatic Petroleum Company with preparations of latex and bitumen. The preparations used by them differ from simple mechanical mixtures of latex and bitumen emulsion in that the bitumen is emulsified not in water but in latex itself; the product therefore contains less water than is present in a mechanical mixture of two aqueous media.

The preparations have been patented by the above company and contain approximately 10 per cent., of rubber. Trials have been made at Colombo and also in Java, but the results are still inconclusive.

Following a favourable report on the "Silent Roadway" experiment carried out at Lahat by Messrs. Kendall and Graham in which thick rubber matting in strips was used, a similar trial under the supervision of the Rubber Research Institute has been laid with the co-operation of the Public Works Department at Petaling New

Bridge, about 6 miles from Kuala Lumpur. It appears that the problems of anchorage and the prevention of water entering the foundations are likely to prove of far greater importance than wear and life of the rubber composition itself. A traffic census taken soon after laying gave the average weight passing over the area during the day as just under a thousand tons. This experiment is too recent to enable any definite conclusion to be recorded.

In addition to the trials recorded above, several samples of material for road making have been sent to the Institute for examination and report. The tests which have been carried out here have shown them to be unsuitable.

Conclusion.

It will be seen from the foregoing that of the various methods which have been envisaged for the application of rubber to road making, only in the case of block paving has a satisfactory material so far been evolved. The difficulties of laying have been overcome and the chief obstacle to the wider application of the rubber paving block seems to be a reluctance to face the capital expenditure involved.

Attention has recently been focussed upon the possibilities of wet mixes prepared from latex, the underlying idea being that it should be cheaper to lay a material which can be poured or spread. This line of work has been actively investigated at the Institute and experiments are still proceeding. Sufficient experience has been gained to indicate that such a method though simple in conception is extremely difficult to perfect in practice. The difficulties encountered are numerous and it may be stated that, of a very large number of different preparations which have been made at the Institute, no single one can yet be judged as satisfactory from all points of view, although some have definite promise.

The experiments which have been made by outside authorities with proprietary materials of this type have all had some disappointing features. There can be no doubt that the really satisfactory wet preparation has yet to be evolved.

The prospects of success seem at present to be uncertain and if ever it is achieved it will be only as a result of the most patient enquiry.

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RUBBER ROADWAYS ; THEIR ADVISABILITY AND PRACTICABILITY.

By.

COX, W. F. V

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query, vulcanised latex could be employed, but the method of procedure indicated in the lecture gave desirable results which were not otherwise obtainable. The lack of uniformity in latex supplies was for some time undoubtedly a great drawback to the use of latex in manufacturing processes. This was now, however, a thing of the past. The latex used in the manufacture of latex thread was bulked at the rubber plantations in several thousand gallon lots, which permitted a much greater degree of uniformity than was usually obtainable in the case of Para or plantation rubber. Furthermore, the centrifuging process to which reference was made contributed greatly to the homegeneity and uniformity of the latex. With regard to Professor Davis's question concerning resistance to perspiration, the resistance of latex thread had been found to be exceptionally good. The particular use mentioned would probably be somewhat drastic, but if Professor Davis would make trials with round thread in its most recent form the lecturer did not anticipate that he would be dissatisfied with the results. In reply to Mr. Petit, the time was fast approaching when the association of Para rubber with an elastic garment would no longer imply that it contained the best quality rubber thread.

Rubber Roadways; their Advisability and Practicability

By W. F. V. COX.

At a meeting of the West of England Section of the Institution of the Rubber Industry, held at the Town Hall, Trowbridge, on 2nd November, 1932, Mr. F. W. Hinde in the chair, Mr. Cox read the following paper.

THE object of this paper is to review the present position of rubber used as a surface for pavements or roads; to outline the progress that has been made, and to indicate steps that might be taken to expedite the adoption of rubber as a surface for pavings and roads.

Roads, what are they made of; how long they will last, and how they behave, is a subject of universal interest. It is felt, therefore, that no opportunity should be lost, even at the risk of reiteration, to inform the industry and the public what steps have, and are, being taken to utilise rubber as a surface for roads.

An interesting survey of the history of the early experimental rubber roads and pavings can be found in pamphlets entitled *Rubber Roadways*, issued by Rubber Roadways Ltd., in 1929 and 1931.

The author has obtained the following information with regard to the experimental stretches of rubber roads now in existence from the same source.

NORTH BRITISH BLOCK.

The block is manufactured by the North British Rubber Co. Ltd., and consists of a 9 by 4½ by 2 inch rubber-cap mounted on a slightly smaller concrete block. The rubber is in two parts, the cap 1 inch thick is of semi-hard rubber, vulcanised, and the "tread" of hard rubber compound 1 inch thick. A "key" or flat piece of steel or iron with two rivets is embedded in the lower part of the tread, the rivets serving as an anchorage in the concrete half of the block. The smaller dimensions of the concrete base allow space for the grouting to obtain a key on all sides. The blocks are laid on concrete and a bed of 1 inch of 3 to 1 sand and cement slightly damped down and are then grouted with hot pitch.

GAISMAN BLOCK.

The block is manufactured by the Universal Rubber Paviors, Ltd., measures 10⅜ by 8⅝ by 4½ inches, and consists of a resilient rubber-cap approximately ⅝ inch thick, with a hard intermediate layer of rubber which is vulcanised onto and into the recesses of a high vitrified brick base, of the engineering brick type.

COWPER BLOCK.

The improved Cowper block is a three-piece built-up rubber slab, tongued and recessed on all four sides. The size is 13⅜ inches in length, being made up of two half areas each 9 by 4½ inches, which overlap 4½ inches. It is 2½ inches thick, composed of three different classes of compounds of rubber of equal depth, the middle layer being a hard composition, and the others of softer and tougher material. The surface is adequately roughened to prevent slipping.

CRESSON BLOCK.

This block measures 9 by 3 by 3¾ inches in depth, and consists of a hard composition base made of stone clippings, sand and other ingredients combined with rubber latex, which, after compressing and drying, is vulcanised, together with a rubber-cap ⅝-inch thick. The composition base is extraordinarily hard, dense and non-porous.

LEYLAND BLOCK.

This block measures 8 by 4 wide by 3 inches deep, with vertical sides. The lower 2½ inches of the block consist of hard rubber, on which a ½ inch cap of soft rubber is mounted.

From a study of the early experiments carried out by Rubber Roadways Ltd., and Mr. A. Harrison, the late Borough Engineer [illegible] Southwark, together with the experimental stretches still in [illegible]nce, it will be appreciated that rubber has withstood the [illegible] time and wear under varying conditions of traffic and [illegible] and that the difficulty of overcoming the tendency to [illegible] has been overcome.

[illegible]annot look upon the early history of rubber roads without [illegible]g one's admiration for the patient and prolonged thought [illegible]arch; the confidence in face of early failures, and the [illegible] money expended by all connected with these experi- [illegible]One is safe in stating that without the subsidies and [illegible]ssistance granted by Rubber Roadways, Ltd., very [illegible]ress would have been made.

[illegible]wing are some of the advantages claimed for a rubber [illegible] absorption of vibration and mitigation of noise; [illegible]; (*c*) dustlessness; (*d*) cleanliness; (*e*) ease of main- [illegible]nding, gritting, etc.); (*f*) not slippery; (*g*) good [illegible] and (*h*) long length of life.

In view of the changed, and changing, conditions of traffic, these advantages have been analysed to see what weight they are likely to carry at present and in the future.

(*a*) *Absorption of Vibration and mitigation of Noise.* It has been proved conclusively that a rubber road will reduce the vibration caused by traffic. Particulars of interesting experiments carried out by the National Physical Laboratory can be found in a booklet entitled *Rubber Roadways*, issued by Rubber Roadways Ltd., in 1931. These experiments contrast the vibration caused by vehicular traffic on wood paving in various conditions and granite sett paving with the rubber paving in Newcastle and Glasgow. All the tests were definitely in favour of the rubber road.

With regard to the mitigation of noise, it was stated at a meeting of the London Society, held on the 17th April, 1931, that the New York Commission, investigating the problem of noise, had reported that the worst of all noises were the roar, thump and rattle of resonant vehicles, or loosely loaded vehicles passing over ill-surfaced roads, and that where tyres are pneumatic 70 per cent. of the cause of the noise is the road surface. (*Rubber Roadways*, p. 12, pamphlet issued by Rubber Roadways, Ltd., November, 1931.)

The Road Traffic Act states that "all existing" heavy motor vehicles must be fitted with pneumatic tyres before the 1st January, 1940, and, with certain exceptions, to any vehicles registered for the first time, on or before the 1st January, 1933.

The position with regard to the horse-drawn vehicle is an interesting one. So far there are no regulations as to its abolition in the future, or restriction as to the type of tyre it shall use. Further, there are no signs that the use of such vehicles is diminishing, in fact, it is stated that there is a tendency for certain business concerns to revert to the use of the horse for the transport of goods in cities where there are enforced hold-ups of traffic, which minimises the superior speeds of motor vehicles, and waste of petrol, due to the engine running during such stops. Further, if the proposed increased tax on commercial vehicles is levied and no additional tax is placed upon horse-drawn vehicles, then an even greater reversion to this type of transport might reasonably be expected.

It is hardly conceivable, however, that with the ever increasing congestion of city streets, that slow moving, unwieldy and insanitary traffic of this nature will long be tolerated.

Granted that with the abolition of the heavy pounding of the solid rubber and steel tyre, and the clatter of horses' hoofs, some of the causes of vibration and noise will cease to exist, it is stated by Col. Chapman that with improved traffic regulations, the pace of traffic will increase, with the consequence that the surface

impact of the traffic, which increases as the square of the speed, will be greater than it has ever been, and the vibration and noise-resisting qualities of a rubber road will always be an important advantage in favour of its use.

(*b*) *Evenness.* Smoothness in a road surface is a characteristic much to be desired. A road surface that develops "pot holes" and "waves" causes loosely packed commercial vehicles, even with pneumatic tyres, to rattle and thus contribute much to the noise of the traffic. The experiments on vibration already referred to prove conclusively that the more uneven the road surface, the greater the vibration. It is claimed that a properly constructed rubber road surface would remain even.

(*c*) *Dustlessness.* In view of the fact that a rubber road would not require gritting or sanding, there would be no dust or sand from this source.

(*d*) *Cleanliness.* Because rubber is non-absorbant it is easily cleaned. Snow and hoar frost do not adhere to rubber.

(*e*) *Ease of Maintenance.* (Sanding, gritting, spraying, etc.) A rubber road requires neither tar-spraying, gritting nor sanding.

(*f*) *Not slippery.* A properly constructed rubber road should neither be slippery to the motorist, bicyclist or the pedestrian.

(*g*) *Appearance.* A properly constructed rubber road has an excellent appearance. The absence of grit embedded in the surface, cracks and mended patches, "pot holes" and "waves" is strikingly noticeable. The neatly defined lines between the blocks and the smooth even surface of the rubber is pleasing to the eye.

(*h*) *Long Length of Life.* This advantage, the most important of all, is the one most earnestly claimed for a properly constructed rubber road, yet it is the one advantage that has not yet been conclusively proved to the satisfaction of the road engineers, because no rubber road surface has yet been down long enough. It has been proved that rubber slabs have lasted for over 45 years, and by reason of their resilience have withstood abrasion better than any other material. With the rapid advance in the technology of rubber manufacture it is possible to produce a suitably compounded rubber that will withstand the traffic and climatic conditions longer than the majority of existing road surfaces in general use.

The importance of long life to a road cannot be too strongly accentuated. The losses and inconvenience caused by road repairs are incalculable.

As the advantage of length of life may well prove to be the in reason for the adoption of the rubber road, the author has ught the opinion of various authorities on this subject. They ead as follows:—

(i) *From Mr. Wallace E. Riche, General Secretary of the Roads' Improvement Association.*

"The loss sustained by commerce and industry due to obstructions upon the heavily trafficked streets in busy central areas, runs into big figures. No precise cost has been taken, as this would involve taking a record of every vehicle affected. Careful estimates have, however, been prepared and the resultant figures are accepted in official circles as being sufficiently accurate to act upon. For example, the loss due to congestion at the Iron Bridge, Canning Town (now being replaced by a more modern structure), was fixed at over £1,000 per day; at Sunningdale it is estimated the level crossing costs road transport in delays, over £16,000 annually. A repair job in a London street, involving one way traffic, causes a loss of anything from £500 per day upwards.

Obstructions in busy streets are, however, not always due to the repair or replacement of a surface. They are often due to work upon underground services—gas, water, sewers, electric light, telephones, etc. Every effort is now made by those responsible for underground services so to carry out their work that the need for opening up roads or footpaths is reduced to a minimum.

Equally, attention is always concentrated upon constructing a street surface that will need the least attention and give the longest life.

If a road surfacing material can be evolved that shows potentialities of giving a life of only three to five years longer than that of the present first class road surface, then it unquestionably merits the closest investigation, and if such investigation proves that such a road surface can be evolved, there is little doubt that Local Authorities would be very sympathetic towards its adoption."

(ii) *From Mr. C. J. Dixey, Secretary of the Bond Street Association Ltd.*

"I can say without hesitation, that road repairs have a very bad effect on business and cause considerable loss to traders, especially in a narrow road such as Bond Street. The Westminster City Council, recognising this fact, have of late consulted with us as to the best time of year for carrying out repairs, and have arranged for the work to be carried on night and day in order that the interruption to business may be as short as possible.

If rubber roads would lessen the vibration, it would be a great blessing, as heavy traffic without doubt, does an extremely serious amount of damage to property."

Replies Received from City and Borough Engineers on some of the Experimental Stretches of Rubber Roads now in Existence.

With a view to obtaining the latest authoritative information as to the behaviour of seven of the experimental stretches laid in this country, the author approached the appropriate authorities, who, without exception, have kindly reported on the present condition of the various rubber roads under their care.

As the period these experimental stretches have been down differ, and the weight, type and speed of the traffic, they have had to bear are not the same, no useful purpose would be served

by tabulating the opinions in detail. It is only necessary, therefore, to summarise the opinions to obtain a general view as to the manner in which these seven stretches of rubber roadways are standing up to traffic and fulfilling the advantages claimed for them. Those wishing to obtain more detailed information can apply to the proper quarter in the usual way. All the experimental stretches are comparatively small, and many of the inherent advantages of rubber are mitigated owing to grit and mud being carried to the rubber from the adjacent road surfaces.

Much of the interest of this paper would have been lacking without the co-operation of the following road engineers, to whom the author expresses his indebtedness:—Messrs. E. E. Finch, M.Inst., C.E., F.S.I.; J. R. Findlay; H. W. Longdin, M.Inst.M. and C.E.; L. S. McKenzie; Edwin J. Messent, Assoc. M.Inst.C.E.; Thomas Somers, M.Inst.C.E. and W. J. Steele, O.B.E., M.Inst.C.E.

The summary is as follows:—

(*a*) *Absorption of Vibration and Mitigation of Noise.* The general opinion is that the noise caused by loosely packed commercial vehicles is reduced; that occupiers of adjacent buildings have noted the absence of noise and that a rubber road lessens vibration.

(*b*) *Evenness.* Every reply under this heading has stated that the rubber road has retained a smooth surface.

(*c*) *Dustlessness.* Many comments upon the fact that the rubber paving is free from dust.

(*d*) *Cleanliness.* Every reply under this heading states the rubber surface is easily cleaned.

(*e*) *Ease of Maintenance.* (Sanding, gritting, spraying, etc.). No special observation seems to have been made on this point, but many state definitely that the rubber surface does not require gritting.

(*f*) *Not Slippery.* In view of the different length and situation of the experimental rubber stretches and the different type of rubber surface, the opinions on this point vary, and in view of the fact that any type of road surface becomes slippery under certain weather conditions it is difficult to arrive at a useful comparison. Where special efforts have been made, however, to produce a non-skid surface, no mention of the surface being slippery has been recorded.

(*g*) *Length of Life.* The practical unanimity of the replies under this heading is extremely satisfactory. "The surface shows no sign of wear"; "the area is in excellent condition"; "the blocks do not show any appreciable wear," are a few of the replies.

(*i*) *Appearance.* The general opinion is that the appearance of the rubber paving is good.

(*j*) *Accessibility to Underground Works.* In the majority of cases it has not been necessary to disturb the rubber road surface, but where there has been necessity, no particular difficulty has been experienced.

(*k*) *Impervious to Water.* The rubber block being itself quite impervious to water, the replies confined themselves as to whether the method of jointing kept the water from the foundation. No complaints were recorded on this account.

Having regard to the volume and nature of the traffic passing over the various experimental areas it can be safely concluded from the above summary, that the tests are fulfilling the claim made for rubber as a road surface.

Further, it would seem that all the experiments have succeeded where the earlier experiments failed, namely, the rubber block has remained anchored to the road, and has resisted that inherent tendency to creep. Not only have various successful methods been found to make the block stay in position under heavy traffic conditions, but in the majority of cases different successful methods have been found to unite the rubber cap to the base of the block. Further, it would seem that the various rubber caps, in the main, are standing up to wear.

It appears from published reports that only a few inventors have paid special attention to the production of a rubber which would minimise the danger of skidding or surfacing the block to bring about the same result. The efforts that have been made in this direction, however, would appear to have been successful, and there is no doubt that in the light of these experiments, a properly compounded rubber block will be less liable to skid than other road-surfacing materials.

Easy accessibility to underground workings is unfortunately a desirable quality in a road surface. Despite efforts that have been made to effect some measure of co-operation between the various public utility services in respect to repairing and renewing underground workings, the fact remains that a road is still subject to upheavals at the hands of various authorities at different and arbitrary periods. From the experimental stretches described above it would seem that it is possible to move and replace a rubber road block, and in view of the fact that it would presumably not have lost in height, as is the case with some types of road surface, it could be replaced without disturbing the evenness of the road.

In arriving at a conclusion as to whether rubber road blocks are advisable as a road surface, it is impossible to avoid comparing rubber with other road-surfacing materials. Whilst it is not suggested that rubber will take the place of all such materials, it must be stated that a rubber road has definite advantages in certain specified circumstances, over those offered by other road-

surfacing materials in existing use. Further, it must be admitted that those advantages are of a weight sufficient to warrant the utilisation of an entirely new material.

Assuming that one, or all, of the blocks described above, or from a combination of the merits of those blocks, a rubber paving is produced that possesses the advantages claimed for it, to what extent do those advantages outweigh the qualities possessed by other well-tried materials?

One of the serious disadvantages of most road surfaces is unevenness. The tendency in course of time is to go into "waves" or "pot-holes." Unevenness causes noise and vibration. The damage being done to buildings and underground workings not designed to withstand the vibration caused by present-day traffic is well known. A properly compounded rubber surface does not form "waves" or "pot-holes." The vibration reduction properties of rubber in itself constitutes a real and important reason why it should be used in certain circumstances.

If it were proved that a rubber road could not last as long as roads made of other materials mentioned, it would indeed be difficult—but not impossible, to secure its adoption. But as the advocates of rubber claim that a rubber road will last longer than roads made of other materials, then surely it is not only advisable, but a public duty, to use the rubber road in order that certain highways can be left free from obstruction for as long a period as possible.

A thoroughfare is only a thoroughfare as long as it is open. If a road surface can be found possessing the necessary qualities demanded by present traffic conditions (whether it is made of rubber or any other material), that will keep that thoroughfare open longer than other materials, then that surface should be used.

From the vast strides made in the technology of rubber manufacture, and the results of the experiments in rubber road construction outlined above, the author is convinced that a rubber road can be made that will withstand the wear and tear of modern traffic, and the deleterious effect of age and climatic conditions, and outlive other materials that are not inherently able to do so.

When time has proved this belief, the world will thank those few enthusiasts who, despite many setbacks, and in face of discouragement—not only from without the industry, but from within it—have had faith in the rubber road. Rapid, unhindered and easy movement is the life blood of a big city, and if the Rubber Industry can play a part in keeping the public highways open for the unhampered movement of the automobile, which the rubber tyre has made possible, then those pioneers will not have laboured in vain.

Rubber Paving Laid Specially to Reduce Noise and Vibration.

Mr. O. E. Parratt, a director of London City Buildings, Ltd., has kindly given the author the following interesting report on the stretch of 400 sq. yards of rubber road laid in 1924 at Fresh Wharf, Adelaide House, London Bridge.

"When it was decided in 1920 to pull down the old "Pearl" Building and build a palatial block of offices, we were faced with several serious problems, not the least of which was the very considerable noise caused by the traffic on the road paved with granite setts, which ran at the rear and under the existing building, and which gave access to a very busy warehouse and wharf.

It was realised that unless some material could be discovered which would eliminate practically the whole of the noise of this traffic, the offices overlooking this road would be almost uninhabitable, as the lines of the building at the rear formed a shaft up which this noise would travel, even as far as the top floor.

A considerable amount of thought was given to this, and many forms of road surfacing were examined, and it was finally decided to pave this roadway with rubber blocks. This roadway is steeply graded, and it was feared that unless some precautions were taken, the rubber blocks would tend to creep, and such tendency would be considerably helped by the pressure of the traffic. It was then decided to divide the roadway into sections of about 12 feet, with tee irons which were bedded in the concrete and which would have the effect of checking this tendency, or confining within a very small area.

The roadway has been a great success and has practically eliminated noise and vibration.

We have only one complaint with regard to this road surfacing, and that is although the rubber itself has not shown any considerable signs of wear, the thin layer of rubber used as a topping has in several instances become detached from its base. If this defect can be overcome I see no reason why this block should not have a very long life.

In addition, the slope being steep, there is a tendency for horses to slip, but this could in future be overcome by using blocks with a grooved surface."

From the above report there would seem no doubt that there are great possibilities for rubber as a means of reducing noise and vibration in special circumstances, such as in front of public buildings, hospitals, hotels, etc.

Rubber Paving for Bridges.

As it would seem that the vibration-absorbing properties o rubber would be eminently suitable for preserving the fabric bridges, the following particulars from the City Engineer Chicago and the Chief Engineer of the Terminal Railroad As tion of St. Louis, on the experimental rubber pavings laid Michigan Avenue Bridge and Eads Bridge over the M River, St. Louis, will be of interest.

Michigan Avenue Bridge. The Bridge was paved with possessing interlocking ears.

It has been found that the movement of the tile loosened the nails holding them to the wooden fo

wear on the surface of the tiles was not very great, but there was a tendency to chafe and wear the under side of the tile.

The Bridge was paved with rubber tiles because the original paving of 4 inch wooden blocks had proved slippery, thus causing many accidents.

A skidding test was made on a 100 foot strip of rubber pavement laid on the Eads Bridge. Water was kept running on the rubber and several stops made at a speed of 25 miles per hour. No skidding occurred. On the dry rubber, the stopping distance was shorter than on the wood block pavement, which had just been recoated with small gravel. These anti-skid properties were not so apparent when the tiles became worn and slippery with oils and grease.

The report from which the above abstract was taken was made in May, 1929, and sent by the City Engineer of Chicago to the author in September, 1932, from which it would appear that the tiles have been taken up.

Eads Bridge, St. Louis. An experimental area of 1,000 sq. feet was laid with tiles approximately 1 sq. foot in area by 1 inch in thickness. They were laid on wood decking in a plastic cement.

After approximately two years under heavy traffic, the blocks showed practically no signs of wear. They were removed because no satisfactory way had been found to keep them in place.

Whilst these two experiments are of interest, particularly with regard to the age-resisting and non-skidding properties of rubber, it is a pity that no observation was made as to whether the rubber paving absorbed vibration. One would have thought that this quality would have been one of the chief reasons for such experiments with rubber decking being carried out. Since 1929 there have been several other types of pavement which are now being experimented with, some of these tiles are cheaper and are being received with favour. It has been suggested that the reason for the failure of these pavings was the expansion and contraction of the spans of the bridge.

RUBBER FOOT PATHS.

The advisability of using rubber for footpaths is well worthy of examination.

The following description, therefore, is given of two existing stretches of public footpath in which rubber has been used, together with the opinion of the Borough Engineer.

Hastings. A test area of rubber-concrete pavement blocks consisting of a rubber-cap which is cast on a concrete base, the complete block measuring 9 by 4½ by 2 inches in depth. The [illegible] consists of three varieties of marbled colouring in green, [illegible]tta, and black and grey (*Rubber Roadways*, issued by [illegible] Roadways, Ltd., November, 1931).

[illegible]ney Little, Assoc.M.Inst.C.E., Borough and Water [illegible]r the County Borough of Hastings, states that the [illegible]xceptionally fine and bright and could not be obtained [illegible]material, and the surface has enough resilience to

make it extremely comfortable for walking on. It is very easy to keep clean. Complaints as to its slipperiness have been received, particularly from people wearing either rubber heels or rubber boots.

Kilbowie Road, Clydebank. The footpath of Kilbowie Road, extending 180 yards with an incline of 1 in 10, was laid in September, 1931, with concrete slabs 2 feet by 2 inches thick. The concrete slabs are re-inforced with wire springs throughout. Strips of black rubber, also re-inforced with wire, 4 by $\frac{1}{4}$ by $\frac{3}{4}$ inches, are embedded in a "staggered" formation $1\frac{3}{4}$ inches apart, in the concrete slab, $\frac{1}{8}$ inch of the rubber strip showing above the surface of the concrete.

The Burgh Surveyor, Mr. Andrew G. Merrilles, states that after a year there does not appear to be any appreciable wear on the material, and its usefulness is such that it affords a very good grip for pedestrians.

From the two instances given, it will be seen that the two pavings were put down for different purposes:—(i) To absorb noise; to look attractive; to be comfortable to walk on; to be easy to clean, and (ii) To prevent slipping.

If it is possible to produce a rubber paving that will combine all the advantages of (i) and (ii), then the scope of its adoption should be very wide. It might be well worth the whole of a large store to provide such a paving in front of its shop windows. The advisability of laying a purely non-skid pavement in special circumstances is obvious.

Traffic Lines.

Rubber traffic lines have been laid in the form of rubber blocks with either plain cambered or grooved surface. Birmingham, Leicester and other towns have them in use.

Whether a thing is *advisable* is one matter; whether it is *practicable* or *necessary* is another. The use of platinum may be advisable and even necessary in certain circumstances, but it may not be practicable, because of the scarcity or cost of that metal. Again, it may be advisable to use it, but not necessary, because a cheaper metal, whilst not possessing all the qualities, will serve the purpose.

Not taking into account the latest development in the construction of the rubber road block, made possible by pa experience, it must be admitted that the summary of the opin of the road authorities on the existing experimental stre indicates that the rubber road block is, in the majority o proving itself *advisable* as a road surface. Nothing h found inherently wrong in the use of rubber as a roa whilst its inherent advantages—even though absorptio and vibration are discounted somewhat owing to the

pneumatic tyre—such as length of life, cleanliness, evenness, appearance and the fact that gritting and spraying are not necessary, are sufficient in themselves to commend rubber as a suitable road-surfacing material. It has been proved that a rubber block road will stand up to heavy traffic for nine years, and now no appreciable sign of wear. It has been proved that a suitably compounded rubber will stand heavy wear and climatic conditions for 45 years. It has been proved that a rubber block will even stand up to tropical conditions.

Further, it has been proved that it is possible to overcome the tendency of rubber to "creep" under traffic, and by suitable compounding and marking to reduce the possibilities of skidding to at least the same level as other road surfaces, without recourse to gritting or sanding.

In admitting that a rubber road block is advisable it must be borne in mind that with the advance in rubber technology, it is possible to produce a rubber in different degrees of texture and softness to meet the various conditions of traffic and climate.

It now remains to consider to what extent it is *practicable* to use the rubber road block in existing circumstances.

Undoubtedly the cost of the rubber road as compared with those made of other materials is a vital factor, and in considering cost, the following points must be taken into account:—

(i) *Type of Block.* As the types of blocks that are being subjected to test are very different in construction and material used, the initial cost of manufacture and laying will vary considerably.

(ii) *Mass Production.* Until any one type of block is made and laid on mass production lines, it will be difficult to give an accurate initial cost.

The cost that matters to the buyer of roads, is the annual cost which is arrived at by adding the annual maintenance charges to the initial cost, and dividing by the life in years. It will indeed be difficult, even roughly, to estimate the annual cost, firstly, because no rubber road has been down long enough to judge its life; and, secondly, because there is no knowing how long the foundation of a road will last.

The following particulars of the cost and maintenance periods of some of the various types of road-surfacing materials have been given to the author by Mr. Percy Smart, M.Inst.C.E., Borough Engineer and Surveyor for Southwark.

Blocks (according to depth)	from	10/-	to	12/-	per sq. yard.
Mixed rock asphalt (2 in.)	"	10/-	"	12/6	" "
Asphalt (2 in.)	"	10/-	"	12/6	" "
Setts (according to depth)	"	26/-	"	30/-	" "

The average life of surfacing materials varies according to local conditions, but for central London the figures would be about twelve years for deal and asphalt roads, and twenty years for granite setts.

Periods of free maintenance are generally arranged for, of from one to five years. After which contractors are generally prepared to accept maintenance at prices of 2d. to 6d. per sq. yard from the sixth to tenth years or thereabouts.

These figures do not include the cost of sanding, gritting, etc., which forms part of the ordinary street maintenance charges, and may, according to *Rubber Roadways*, 1931, page 11, amount to 1/- or over per sq. yard per annum.

It would appear that another method of buying roads is for a contractor to agree to lay and keep maintained for a fixed period a certain road at a fixed annual payment. Unfortunately figures are not obtainable. Whilst this method of purchasing roads has the advantage of simplicity and limits the actual cost of the road—apart from gritting, etc.—it does not, of course, take into account the cost of delays both to frontagers and the general public, should a road be subject to extensive repairs that impede the progress of traffic.

Despite the impossibility of giving an initial price comparable with other material, 1,200 sq. yards of the improved Gaisman block has been recently laid in a part of the street fronting the new Huddersfield Municipal Building. These blocks were laid at £2 10s. per sq. yard and a free maintenance guarantee was given for ten years. (*R. G. A. Bull.*, 1932, 14, 513.)

It is extremely satisfactory and encouraging that a public body has now had the initiative to purchase a rubber road, and that a contractor has had sufficient courage and confidence to bear the cost of maintenance for as long a period as ten years. Undoubtedly this Huddersfield stretch constitutes an epoch in the history of the rubber road.

In the earlier experiments rubber was a costly commodity, and the chief selling point was the absorption of noise and vibration. With rubber at a much reduced price, the main selling argument may easily prove to be length of life. The longer its life, the cheaper its annual cost and the wider its potential application.

It would seem, then, that the only method of expediting the use of the rubber road block is for the road contractor to estimate and guarantee the life of the road and by charging a fixed price per annum, to bear the consequent financial risks. The public authority would then only have to face the possibility of a complete failure, which in the light of the experience gained from the experimental stretches now in existence, seems negligible.

The tyres of commercial vehicles are often [illegible] on a mi[illegible]

basis the longer the tyre lasts the greater the income to the supplier. It is suggested that if some such method could be adopted it would bring rubber roads into general utilisation much sooner than if the initial cost price were demanded. There is little doubt that the life of a properly constructed rubber road would be such that the annual cost would compare favourably with other roads.

In short, if a contractor would offer to lay a rubber road at a fixed price per annum as long as it remained in use, and that price was in the neighbourhood of the ruling prices for other roads, then many of the difficulties in selling would be removed. In effect the contractor would be insuring the life of his road—the longer it lasted the more he would make, and the more the frontagers, general public and public authorities would gain—apart altogether from the inherent advantages of a rubber road.

Assuming that a contractor could be found willing and able to adopt such a scheme, what type of road would be suitable for such an undertaking? Roads such as Bond Street, Regent Street and Oxford Street, readily suggest themselves, both from the frontagers' and public's point of view. Trafalgar Square, The Bank and Piccadilly Circus, are vital spaces to keep free for traffic. Taking London alone, there is indeed a vast area which could with advantage use any suitable road that would last longer than existing ones. When other cities are taken into account, it will be appreciated that the potential use of the rubber road possessing long life is tremendous.

It is stated that the cost of a mile of rubber road, 30 feet wide, on the basis of £2 10s. per sq. yard, would be £44,000. Whilst this initial cost will no doubt be reduced with the advent of mass production, the sum involved will be considerable.

Directly a well-known thoroughfare has been laid with a rubber road and remained for a sufficient number of years to pay an adequate dividend, and proved sufficiently satisfactory for the authorities to renew it, then it will not be difficult to obtain the financial support necessary to lay further roads; until that time arrives, however, any money put into rubber roads on the basis of a yearly payment must be a speculative proposition.

The fact remains that if rubber roads are to be put down in the near future, before their length of life has been definitely proved, then a risk will have to be taken and that risk borne by the contractor and not the public authority. Whether or not it is a business proposition to take this risk depends on the faith the contractor has in his road.

Whatever happens, however, it would seem necessary that finite steps should be taken to establish some sort of selling ...cy for rubber roads. The potential market is so great, the ...ge that co... be done by a faulty road would be so serious,

and the interests involved so numer
be made to bring together all concerne
forward an united policy.

Already there are numerous types of blocks
patents on the market. Already there is com
the sponsors of these different types. Such a s
can only retard progress. Should the rubber roa
its own, it will mean big business and no single firm w
the market. One bad road will spoil what little market
One promise that remains unfulfilled will tend to set bac
whole industry.

The leading cable manufacturers have arranged to pool tech
nical knowledge in order to ensure the best possible cable being supplied, and it is just as necessary to prevent a bad rubber road being laid.

The selling of rubber roads is neither the rubber producer's job, nor the manufacturer's, nor the suppliers of the other materials, but that of a road contractor familiar with selling, laying and maintaining roads.

Would it not be possible at this early stage for all interests concerned—the producer of the raw rubber, the supplier of the carbon black, concrete, brick and other materials, the various rubber manufacturers and patentees to form themselves into a powerful road construction company, able to decide upon the type and construction of a rubber road block suitable for the specific highway? Such an organisation would not only be in a position to manufacture on a scale large enough to carry out substantial contracts and be able to guarantee maintenance, but it would be powerful enough to ensure its products being brought adequately before those who decide upon the purchase of roads.

Such a pooling of technical knowledge at this early stage would hasten the development of the rubber road and prevent costly failures, it would obtain the confidence and co-operation of the road engineer. For many years one type of block would be offered for one type of road—a block that possessed the backing of a powerful undertaking representing the whole industry. It would merely be necessary for the public authority to decide whether or not to have a rubber road. Once this decision had been reached, it would not be necessary to weigh up the pros and cons of rival road block makers, and eventually decide upon the one that could offer the soundest maintenance guarantee, irrespective of the merits of the different blocks for its particular purpose.

Such co-operation now would prevent the seeds of doubt sown by those wishing to extol the qualities of their own to the detriment of others. The longer such co-oper delayed the more difficult it will be to combine. The

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e.

ther, such a pooling of interests under the auspices of men
utstanding reputation, would secure the substantial financial
upport of the public. To estimate the life of a road would be a speculation, it is true, but one that would, without doubt, appeal to many investors. If rubber roads are coming, then no single firm will retain the market for any length of time, because the business will be too big.

Whilst the adoption of the rubber road will mean a big additional outlet for raw rubber—it is stated that 176 tons of crude rubber are used in a mile of road 30 feet wide—the main advantage will come to the manufacturers or road contractors.

If a road is laid on an annual cost basis, then up to a certain point money will be lost if the road fails, but after that point has been reached money will be made so long as the road lasts.

Briefly, the following conclusions are arrived at:—

(1) That the experimental stretches of rubber road that are now in existence are, in the main, proving satisfactory.

(2) That with the low price of rubber and the advent of mass production and long life of the block, the annual cost of a rubber road surface should compare favourably with the annual cost of other materials.

(3) That the adoption of the rubber road would be expedited if:—

(*a*) the road could be offered on an annual cost basis.

(*b*) those interested were to pool their knowledge and obtain the financial support necessary.

The author wishes to record his sincere thanks to Lt.-Col. T. H. Chapman, O.B.E., V.D., and Mr. Frank G. Smith of Rubber Roadways, Ltd., for their valuable help in preparing this paper, and the Council of the Institution of the Rubber Industry for permission to read it.

Discussion.

CHAIRMAN said Mr. Cox had dealt with a very important subject at important time in its history, and there was no doubt that he had quite a lot of information and had given a most useful paper. tion of samples and specimens taken up from early experiments

was certainly most interesting to those who had not seen the blocks before; it was always good to look back and see the progress that had been made; on the other hand, there came a time when it was good to forget the failures of the past.

Detailed analysis of the construction of the block, the cost of manufacture, the method of laying, the quality of rubber used and the conditions surrounding the test, were items which had to be taken into account if a detailed analysis were to be attempted. For instance, one test might be adjoining wood paving repeatedly gritted with very hard gravel, which was carried by the traffic onto the rubber paving and which was detrimental to the rubber surface. Until a whole rubber street had been laid, rubber would not really ever have quite a fair test, because it always had to bear punishment from material brought on to it which it did not require, and which, in fact, was harmful to it.

He admired Mr Cox's survey up to the last part of his paper, where he was saying that it would be a good thing for manufacturers to pool together the whole of their knowledge, and where he gave what appeared very simple, very straight advice as to the method of selling a rubber road. He, however, could not agree to this, firstly, he said that if a road were sold at so much per yard per year this would be the same as other road material suppliers. Other road material suppliers did not do that, they sold their road at a price, and then in addition to receiving the selling price, they undertook to maintain it for a certain period at a certain maintenance price, which was additional and separate from the purchase price. The only exception to this common practice was the very small area of the City of London. The Corporation of the City of London purchased its streets practically entirely on the basis of so much per annum; it was an old custom which had been applied for a long time, but it only applied to that very small area. In all other cases the material was sold and laid at a price, and maintained at another price.

Now as to the pooling of knowledge, it was extremely difficult to do that in reference to articles which were standardised in the rubber industry, it was far more difficult to do it with an article which was just beginning, where many had got different ideas, and where blocks had been tried, others partly tried, and still others that had just been evolved and had not yet been tried. How was it possible to obtain agreement at such an early stage in the history of rubber paving? He could not imagine such agreement at present. It might come when the block was established and standardised.

Mr. Cox suggested how the sale of rubber roads should be financed; the finance should come from the various interests in rubber, the sale should be on the hire purchase system previously referred to, and it was not for Public Authorities to risk public money in purchasing rubber roads. This was a time when the Ministry of Transport and many other very important road authorities were taking a rapidly increasing interest in rubber paving and were gradually coming to the conclusion that a rubber road did not involve a financial risk. He did not think it incumbent on the Rubber Industry to evolve a financial scheme which would take all the responsibility from the purchaser, that was a retrograde step.

Mr. PEARCE said he was in agreement that the time appeared to be ripe for laying a much more extensive section of a rubber road. The area which he had noted here was 1,200 sq. yards, which with a width of 10 yards only gave a length of 120 yards, and no matter what material might be adjacent to that section on either side, all sorts of grit, dirt, etc., would be carried on to the rubber patch from either side, so that the test had not a fair and reasonable test. What would happen is, the traffic on the recently tarred stretch—traffic will probably cover your rubber materials picked up and will not give that surface a really fair test of the foreign matter brought upon it from an outside source.

a mile of rubber paving, preferably in a country district
uld, between two main points, should be laid and the data
ined which would be most interesting to road engineers.
e of rubber for roads was wrapped up in cost. It was the
rveyors to obtain the best value for money. The figure which
quoted, 50s. per sq. yard, seemed to present a very serious obstacle
se of rubber for roads at present. Mr. Cox had mentioned figures
to 12s. for wood blocks, and 30s. for granite sets, as compared with
bove figures for rubber. The Ministry of Transport allowed all Road
horities a limited term of years in which to repay their loan charges for
umen, it generally amounted to a maximum of about 12 years, and
tumen cost from 10s. to 12s per sq. yard. Rubber was claimed to give
another 5 years life for an outlay of another £2 per sq. yard; it might be
considered, but the Ministry would have to extend the period of loan, and
it seemed they would require very strong evidence before they permitted
such a purchase. He would also like to know whether Mr. Cox was
atisfied with regard to any possible damaging effect grease or oil dropped
rom motor vehicles, was going to have on the rubber surface. There was
o doubt that the roads to-day were collecting hundredweights of grease
r annum. Rubber chemists might have considered this point, but an
surance that grease would prove detrimental was needed. Also on a
sty morning in a rural district a horse had spiked shoes; what effect
d those spikes on the rubber? Another very big point was the ease of
king repairs; would it be necessary to await the arrival of a firm's
cialist before proceeding, and would there be other irritating delays?
With regard to contracts, he was not altogether in agreement with a
ier speaker on that point, because so many of the re-conditioned roads
ie country which were not running contracts were let on a sort of 50/50
s. That is, free maintenance was given for half the road and small
tenance charge made for the remaining half. Even the road in
sham through the main centre of the town was laid on this financial
and it appealed to him that the first people to back a rubber road
be the rubber firms. The rubber concerns should pool their re-
and give such a guarantee to a local authority who might be
lating a rubber road, that they would not suffer any severe financial
'd it prove unsuccessful.

S. PAYNE said at the moment he was interested in bridges, and
oint emphasised by Mr. Cox was the cushioning effect of rubber
ch might considerably lessen the effect of impact on such
With regard to fixing, apparently there were many methods,
like to know what was considered best for laying on plain
how best to ob iate "creeping."

N said he had been interested in rubber roads for the last
d intimately connected with most of the different trials
arried out—in the search for better and better roads.
was the determining factor, and engineers, contractors
rs had to meet his requirements. He would have a good
his voice which carried weight
f recent years there had been a steady and great improve-
of this country, and the English roads were on the whole
of any other country—but still roads wore out, and there
and for something better and more lasting in the way of
was hoped that rubber would prove satisfactory.
ough agreement as to the unsuitability of short lengths
er or any paving. A short length could never be a really
t was bound to be affected by adjacent surfacings, their
d the impact of wheels passing from one class of material to
The difficulty of laying long stretches of rubber was of course
t some method of surmounting this would, he hoped, be arrived

at before long. The rubber blocks were of several patterns, but the resilient rubber cap was common to all. One class of block was laid direct on to the concrete road foundation; and then was laid on ½ inch of rolled sand, while yet another was laid on a thin skin of asphalt, each finally on concrete. In all cases the joints were run in with bituminetic grouting. The interlocking blocks were laid direct on the concrete and tapped into place. A question had been asked as to how rubber would stand the roughing of horseshoes in winter. Experience in Newcastle, where they employed a species of spike in roughing, indicated that rubber took this form of punishment in a satisfactory manner. As to oil, if the rubber was properly compounded for road usage, the oil that dropped on it from traffic would have no injurious effect. In regard to camber and cross fall in roads, rubber would throw off water quicker than any other material, and therefore camber could be reduced to a minimum on rubber roads. Hitherto the rubber laid, being in short lengths only, had had to conform to the general camber of the roads as they existed.

Unquestionably vibration on bridges would be reduced. A series of vibration experiments were carried out in Newcastle and Glasgow for Rubber Roadways Ltd., by the National Physical Laboratory, from which a comparison of effects of traffic on setts, wood paving, and rubber blocks under similar conditions was possible, and indicated that the absorption of vibration on the rubber exceeded materially that by wood paving, and that the difference increased with wear. Rubber did not "wave," and being of a resilient material and texture, quite different from wood, caused no obstruction or "bump" to passing wheels when the surface had been down sometime. The most recent form of rubber paving might be seen in New Bridge Street, Blackfriars, London, where a length of the new pattern Gaisman block had just been put down. The former pattern was laid in the same street 6 years ago, and the old and the new could be seen side by side. Though this road carried 50 thousand tons of traffic in a 12-hour day, the older blocks had not shifted or moved in any way, and the rubber had preserved its contact with the base of the block and the wear had been small. Wood-paving adjacent, and laid at the same time, had lost ¾ inch in thickness. At the time these older blocks were laid the question of preventing creep in the rubber and securing a perfect adhesion of it to the base was so much the problem that the effect of 50,000 tons a day on the cap itself was overlooked, with the result that many scabs and blemishes skin-deep only appeared after a time—which were unsightly and unsatisfactory.

The rubber in the new block had three times the strength and toughness of the old; the shape and size of the blocks were also altered and gave more scope for quicker and more regular laying. It was altogether a finer production, and should prove equal to the extraordinary traffic it had to withstand. With regard to repairs, rubber-capped blocks could be taken up and relaid without difficulty for trenching and such like work.

Rubber was no better proof against skidding in certain weather conditions than other surfaces, but it was generally less slippery. With experience it [illegible] that a rubber would be compounded that would be more proof against skidding than any other substance, but it seemed impossible to eliminate skidding entirely under certain weather conditions, no matter what the road was made of.

He looked forward to rubber becoming of much greater road use in the years to come; people were taking a greater interest in it, and enquiries from all over the country were received, these were good signs.

Dr. PICKLES proposed a vote of thanks to Mr. Cox for his paper, and to the numerous visitors for their attendance.

Rubberised Bitumen From Rubber-Bitumen Masterbatch

By

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Rubberised Bitumen from Rubber-Bitumen Masterbatch

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Eighty parts by weight of premasticated flat bark were mixed with 20 parts of straight-run bitumen 40/60 and 5 parts of powdered oxalic acid on an open mill, and the mixture was used as a rubber-bitumen masterbatch for rubberising bitumen. The properties of the bituminous cement rubberised with this masterbatch are studied. The effects of sulphur on the ductility and tenacity of the material are discussed.

Rubberised bitumen has been proved to be a superior paving material, and numerous investigations have been carried out on the properties of rubberised bituminous cement and its mixtures. Rubber has been used for this purpose in various forms, among which are ground tyre and other scrap rubber (FOL AND BIJL, 1931), Pulvatex (VAN ROOYEN, 1938), Mealorub (VAN DER BIE AND WIJNHAMER, 1941), latex (BROOME, 1937; FOL AND PLAIZIER, 1937), and various types of solid rubber (PARKER AND WALKER, 1957), etc.

In spite of these investigations, rubber provided for this purpose was not necessarily of the most economical type. For instance, latex and rubber powders such as Pulvatex and Mealorub were too expensive, though they were easily dispersed in bitumen. Scrap rubber powders were provided cheaply, but could not be dissolved in a short time.

It was found by NACHTIGALL AND SCHOON (1955) that rubber-bitumen masterbatch could be easily dispersed in hot bitumen, and since these masterbatches can be made from low grade rubber such as flatbark, earth scrap, etc. they were considered to be the most economical materials.

The most suitable recipe for the rubber-bitumen masterbatch for this purpose has been determined, and the properties of bitumen rubberised with this masterbatch are described. The effect of sulphur is also discussed.

MATERIALS

The rubber used is flatbark, masticated on an open mill to a Goodrich plasticity of 0.70 at 100°C. When necessary, mastication was controlled to give other plasticities. The bitumen used is straight-run bitumen 40/60 made by the Nihon Petroleum Company. Oxalic acid (industrial grade), in the form of crystals, was crushed and powdered with a ball-mill, and passed through an 80-mesh Tyler sieve.

METHODS

In order to discuss the suitability of the mixing process, the time required for preparing a homogeneous masterbatch on a 2-inch open mill was measured.

To examine the dispersibility in hot bitumen of the masterbatch thus obtained, the time required for the complete dispersion was measured under the following conditions:

Temperature = 150 ± 2°C, Stirring velocity = 150 r.p.m.

Penetration, softening point, and ductility, were tested under the usual conditions. When the standard hemisphere is drawn out from the bitumen at a constant speed, a force-elongation curve is obtained which shows a maximum force immediately after the start, decreasing, at first steeply and then slowly, to zero load. The area under the curve at the last stage is generally defined as tenacity, and the area under the whole curve as toughness; in this paper, however, the area corresponding with tenacity was deducted from the area corresponding with toughness in order to compare the maximum forces on different samples (BENSON, 1955; WELBORN AND BABASHAK, 1958). According to this definition, a high degree of toughness corresponds to a high maximum force.

The brittleness point was defined as the temperature at which bitumen film was cracked by bending under constant conditions. A thin film of bitumen sample, held at a low temperature, was bent in about one second along a constant curvature, and it was observed whether the film was cracked. Temperature control was maintained by dry ice-ethanol. The test temperature was selected at intervals of 5°C from a lower limit of −15°C to an upper limit of + 10°C. For the given sample, the highest temperature at which the film was cracked was recorded as the brittleness point. This point was measured for various curvatures.

Impact resistance was measured by a pendulum type impact tester resembling Charpy's machine, and the minimum impact energy at break was observed; this figure and a corresponding one for non-rubberised bitumen were expressed as a ratio. Size of the specimen was 1.5cm × 2.2cm × 10.0 cm. The pendulum consisted of an arm 50 cm in length and 96 g in weight fitted with a sharp metal head of 88 g in weight.

Flow at 60°C was measured as follows: 2.5 g of each sample were put at the bottom of a test tube (1.5cm in diameter, and 16.5 cm in length). This test tube was placed in a vertical position in an air oven and kept there for 10 minutes at 60°C. Then the test tube was inclined with the opening downwards at an angle of 45° to the horizontal, and held in this position for 30 minutes. The flow distance of the sample under these conditions was measured.

Ageing in sunlight was measured as follows: 200 g of bitumen sample were poured on a plane surface 30 × 30 cm in area at a temperature of 150°C, and, after cooling, the sample was placed horizontally in sunlight. This test was carried out in summer (July 3 – September 25), when the sunlight was most intense. Sampling was done every two weeks, and the softening point (ring and ball) was measured.

RESULTS AND DISCUSSION

Recipe of the Masterbatch

Various combinations of components incorporated with rubber are possible, but the combination of masticated flatbark (Goodrich plasticity = 0.70 at 100°C), bitumen and oxalic acid was selected for the following reasons.

1. Mastication facilitates dispersion, but the rubber has little effect on bitumen when mastication has gone too far.
2. Bitumen in the masterbatch, when heated, is melted from the inside and accelerates dispersion. Other thermoplastic materials can be used, but the effect of these is to be discussed elsewhere.
3. Oxalic acid is decomposed by heat and causes swelling, and thus the dispersion of the masterbatch is accelerated by its bubbling effect from the inside. No residue remains.

The effects of these components on the workability on a mill and on the dispersibility in bitumen are shown below.

Because it was not easy to mix more than 20 parts of bitumen with rubber and the effect of bitumen on dispersibiljty was at the maximum at about 20 parts, the bitumen content was fixed at 20 parts by weight on 80 parts by weight of masticated flatbark.

TABLE 1. RECIPE OF THE MASTERBATCH

Component	MBo	MBs
Flatbark (p = 0.70)	80	80
Bitumen (40/60)	20	20
Oxalic acid (80 mesh)	5	5
Sulphur (300 mesh)	—	5
Total	105	110

For similar reasons the oxalic acid content was fixed at 5 parts by weight on rubber (80 parts) plus bitumen (20 parts). The recipe of the masterbatch MBo in *Table 1* is recommended.

When this masterbatch (MBo) was added to bitumen, the ductility was reduced as shown in *Figure 4* and did not meet the JIS specification (more than 50 and 100 cm at 15 and 25°C, respectively), though the sensitivity of ductility to the effects of temperature was decreased and flexibility at very low temperatures was thought to be increased as shown in *Figure 5*. Dispersion was completed in 30 minutes at 150°C, but heating was continued to 1.5 hours after the addition. (cf. heating of MBs-bitumen).

It is reported by Wellborn and Bahashiak (1958) that the ductility of rubberised bitumen is increased by sulphur-treatment, and this phenomenon was taken into account in this study. The effects of sulphur on ductility are shown in *Figures 6* and *7*. Masterbatch MBo was dispersed first (30 minutes at 150°C) and then treated with sulphur at 150°C.

It was concluded from *Figure 6*, that 90 minutes' heating at 150°C might be enough and, from *Figure 7*, that the amount of sulphur should be 5 parts by weight or more. For convenience, this amount of sulphur was incorporated with the masterbatch, which is shown as MBs in *Table 1*.

This masterbatch with sulphur incorporated is vulcanised when heated, and the change in plasticity is shown in *Figure 8*.

TABLE 2. TIME REQUIRED FOR DISPERSION UNDER DIFFERENT STIRRING CONDITIONS

Stirring conditions	Rotation	Masterbatch MBo	Masterbatch MBs
By glass rod	100 r.p.m.	50 min.	90 min.
	150	30	40
	200	15	15
By screw	300	10	10
	400	10	10

Because of this vulcanising effect, it was feared that MBs would not be dispersed in hot bitumen, but in practice this was not the case, provided constant stirring was carried out (*Table 2*).

As seen in *Figure 5*, heating is essential for making the effect of sulphur to be complete. As tenacity was in line with ductility in this case, the heating conditions were related to tenacity as shown in *Figure 9*.

The heating time which gave the maximum tenacity was plotted against the temperature in *Figure 10*. The heating time which gave the minimum plasticity of MBs was also plotted, and it was found that both plots gave nearly similar curves. This fact suggests that the activation energies of both phenomena are very close, and that the high ductility and high tenacity of sulphur-treated rubberised bitumen may derive from the partial cross-linking of rubber in bitumen.

This assumption is confirmed by viscosity measurements on a 10% benzene solution of rubberised bitumen treated with sulphur (*Figure 11*).

The shape of the curves for rubberised bitumens was quite similar to that of the curve given by the change in modulus of compounded rubber with heating time (PETER AND HEIDEMAN, 1957) and the maximum viscosity corresponded to the maximum tenacity. Gel fraction was not increased to an observable extent by the sulphur-treatment.

Other Properties of Rubberised Bitumen.

The penetration, softening point, and toughness were plotted in *Figures 12 –14*. These data practically coincided with others previously reported by other authors on Mealorub, Pulvatex etc.

MBs bitumen mixtures were found to give nearly the same penetration index as MBo-bitumen mixtures, but latex- and Mealorub-bitumen mixtures gave slightly higher indices (*Figures 12* and *13*).

The logarithm of penetration is plotted against temperature in *Figure 15* and the penetration index against rubber content in *Figure 16* for MBo-bitumen mixtures.

Brittleness point, impact strength at 0°C, flow at 60°C, and change in softening point with ageing under sunlight are shown in *Figures 17 – 20*.

Brittleness point was lowered by the addition of the masterbatches, but no difference was found between MBo and MBs (*Figure 17*).

Ageing of bitumen was improved by the addition of the masterbatch, but sulphur had a slightly adverse effect.

Consistency of Rubberised Bitumen.

The rubberised bitumens obtained above were much more viscous than the original one obtained at high temperatures, and the operating temperature was considered important. Results of Furol viscosity measurement (JIS–K–2298) are shown in *Figure 21*.

To obtain the same Furol viscosity, rubberised bitumen must be heated at temperatures higher than for untreated bitumen by 10°C per 2 parts per hundred of bitumen (P H B) of the masterbatch. There was no appreciable difference between non-treated and sulphur-treated rubberised bitumens.

Effect of Accelerators

It was assumed that the increase of ductility and tenacity of rubberised bitumen is due to the partial crosslinking of rubber in bitumen with sulphur, and the effect of the addition of accelerators to MBs was examined.

TABLE 3. RECIPES OF MASTERBATCHES INCORPORATED WITH ACCELERATORS

Recipe	Masterbatch					
	A	B	C	D	E	F
Flatbark	80	80	80	80	80	80
Bitumen	20	20	20	20	20	20
Oxalic acid	5	5	5	5	5	5
Sulphur	5	5	5	5	5	5
ZnO	5	—	5	5	5	5
PbO	—	5	—	—	—	—
Hexamethylene tetramine	—	—	1	—	—	—
Diphenylguanidine	—	—	—	1	—	—
Mercaptobenzothiazole	—	—	—	—	1	—
Tetramethyl thiuram disulphide	—	—	—	—	—	1
Total	115	115	116	116	116	116

TABLE 4. STORAGE STABILITY OF MASTERBATCHES

Plasticity at 60 C	Masterbatch						
	A	B	C	D	E	F	MBs
Before storage	0.710	0.771	0.764	0.802	0.806	0.813	0.664
After storage	0.715	0.762	0.736	0.797	0.206	0.809	0.700
Difference	- 0.005	— 0.009	— 0.028	— 0.005	— 0.600	— 0.004	+ 0.036
Stability	Good	Normal	Normal	Normal	Bad	Nomal	Good

Accelerators and auxiliaries were mixed into previously prepared MBs, and the masterbatches shown in *Table 3* were prepared.

When these masterbatches were used instead of MBs, heating for 45–60 minutes at 150°C was sufficient.

These masterbatches incorporating accelerators had less storage stability in some cases, and a large change in Goodrich plasticity was recorded after storage at 70°C for 18 hours. The results are shown in *Table 4*.

CONCLUSIONS

The recommended composition of rubber-bitumen masterbatch for rubberising bitumen is as follows: 80 parts by weight of masticated flatbark (Goodrich plasticity = 0.70 at 100°C), 20 parts by weight of bitumen and 5 parts by weight of oxalic acid.

To obtain high ductility, 5 parts by weight of sulphur should be incorporated with the above mixture.

The high ductility and tenacity of sulphur-treated rubberised bitumen is assumed to be due to partial cross-linking of rubber molecules in bitumen with sulphur.

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DISCUSSION

(Paper presented by Mr Kunisawa)

THE CHAIRMAN called upon Dr Mullins, the author of a related paper, to make a contribution to the discussion.

DR MULLINS pointed out that rubberised roads gave decided advantages over straight bitumen roads under severe conditions. The matter of cost was very important and one should therefore consider carefully the effectiveness of the various materials in relation to their cost. At present several materials were used in bitumen, for instance latex, unvulcanised rubber, and Mealorub, and their effectiveness on a weight for weight basis was in that order. The effectiveness of the material, he stated, was dependent on the molecular weight of the rubber. It was necessary to find where the masterbatch fitted into this pattern, particularly bearing in mind the degradation during mastication, and to know to what extent this affected the cost, compared with latex, of obtaining a given improvement in properties.

DR MULLINS then asked whether the author had any data on the weight for weight effectiveness of the masterbatch compared with other types of rubber. MR KUNISAWA agreed that the high molecular weight of latex made it the best material for use in rubberised roads, but said that if molecular weight was the criterion for good properties it would seem advantageous to produce large molecules by vulcanisation of a cheap rubber, such as was achieved by the masterbatching technique.

MR G. MARTIN said that it was rather difficult to know which properties one should measure to determine the advantages which rubber conferred on bitumen. If viscosity was measured, then he would estimate that five or six times as much masticated flat bark crepe would be needed to produce the same effect as latex rubber and he therefore felt that a latex rubber was still very much cheaper than masticated flat bark crepe. He also emphasised that in order to learn whether rubber really conferred advantages on bitumen roads, it was necessary to vary the proportions of rubber in bitumen about a mean concentration and to lay down an ample number of replications. MR KUNISAWA stated that the masterbatch had been used for experimental stretches of road in Hokaido but no test results were yet available.

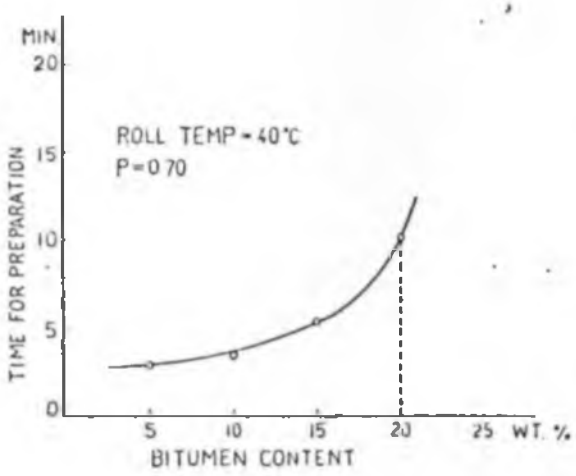


Figure 1. Time required for preparation of flatbark-bitumen mixtures on a 2 inch open mill.

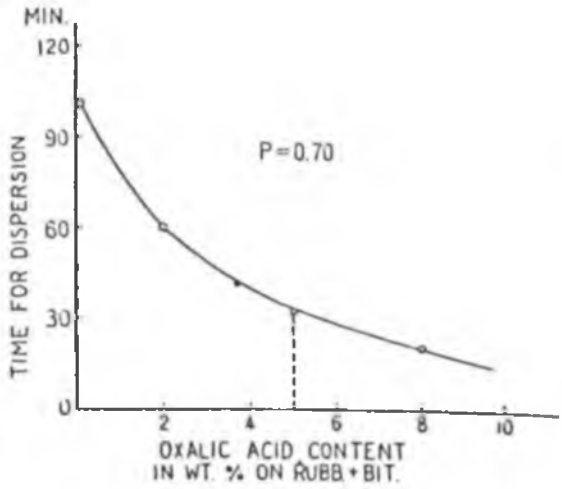


Figure 3. Time required for dispersion of flatbark-bitumen (80:20) — oxalic acid mixtures in hot bitumen.

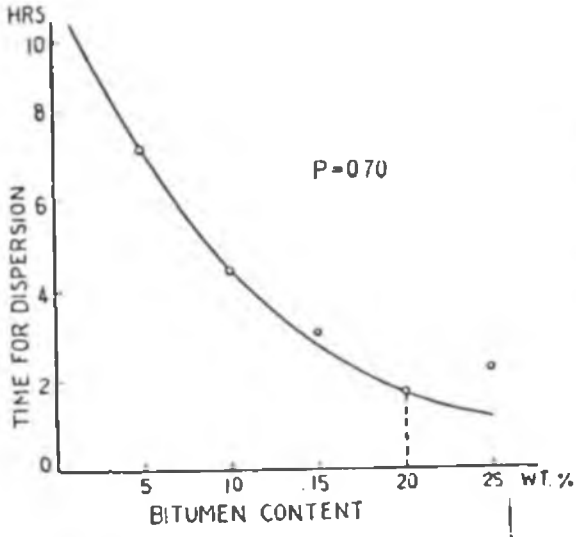


Figure 2. Time required for dispersion of flatbark-bitumen mixtures in hot bitumen.

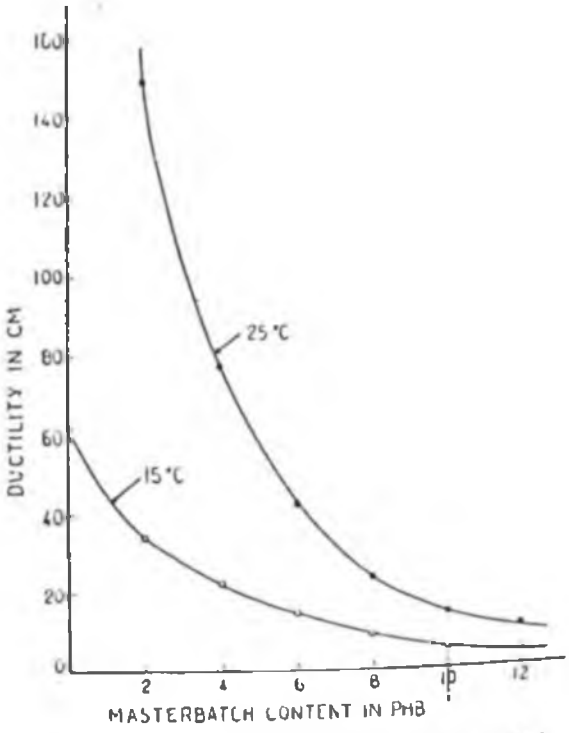


Figure 4. Ductility at 15° and 25°C plotted against masterbatch

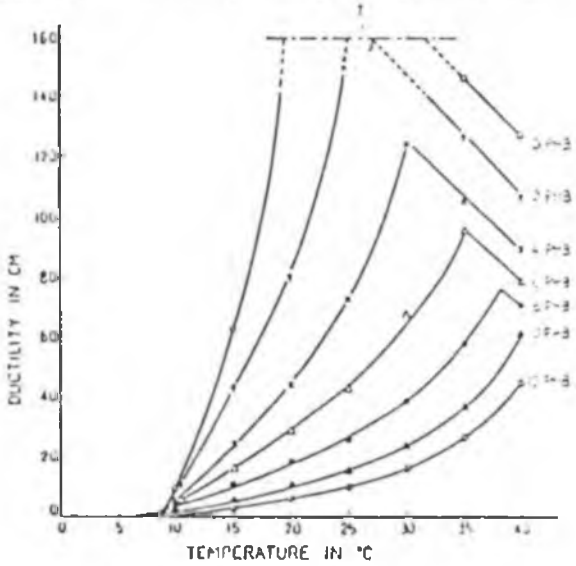


Figure 5. Ductility plotted against temperature.

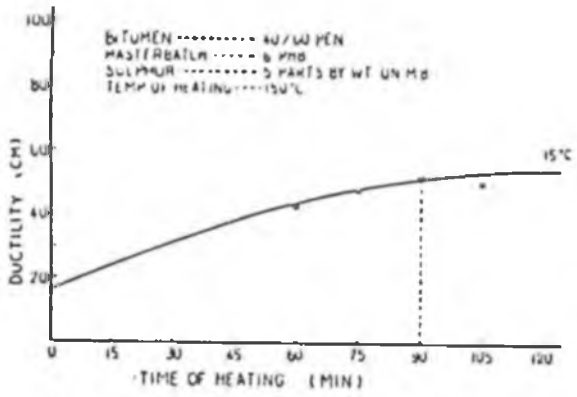


Figure 6. Change in ductility with heating time of rubberised bitumen containing sulphur.

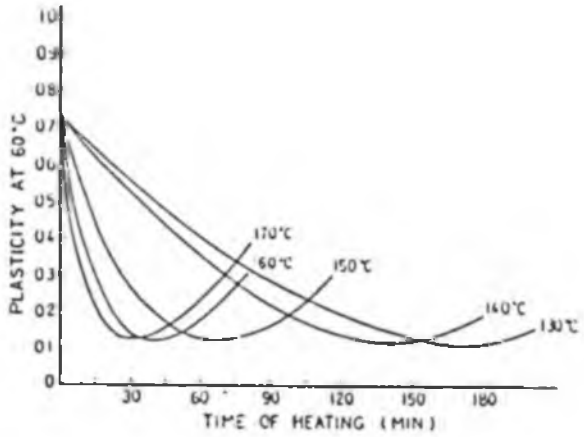


Figure 8. Change in Goodrich plasticity of MBs (minus oxalic acid) with heating time.

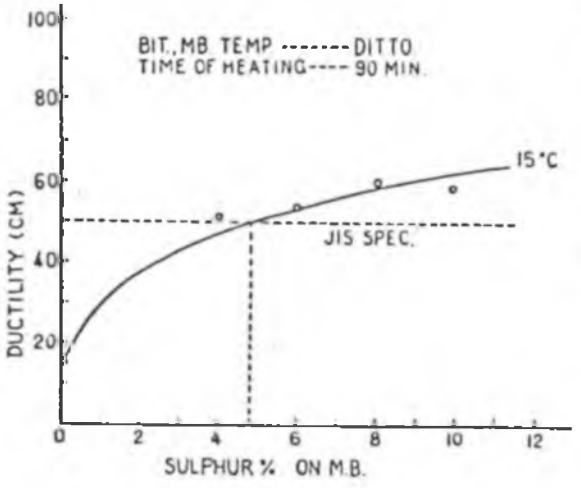


Figure 7. Change in ductility of rubberised bitumen with sulphur content.

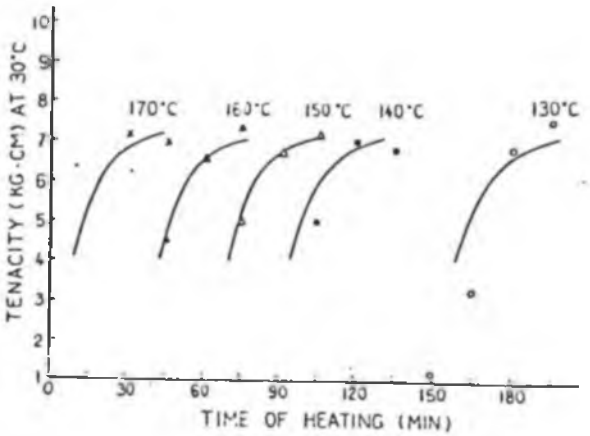


Figure 9. Change in tenacity of rubberised bitumen with heating time.

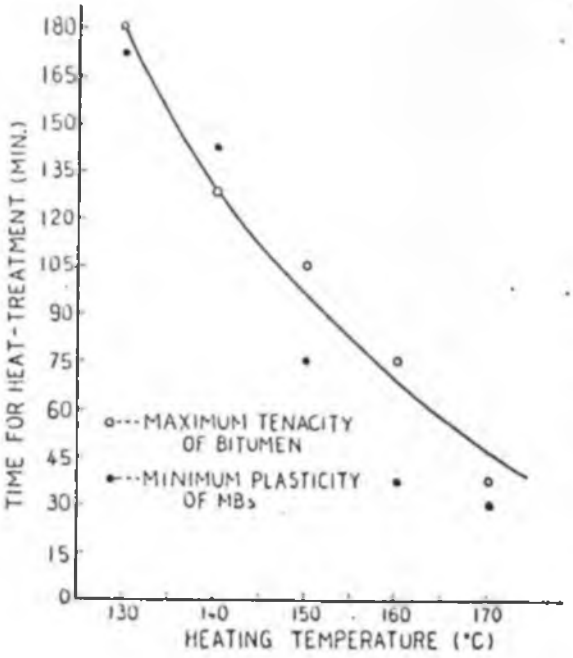


Figure 10. Change in heating time for maximum tenacity of rubberised bitumen and minimum plasticity of MBs (minus oxalic acid) with heating temperature.

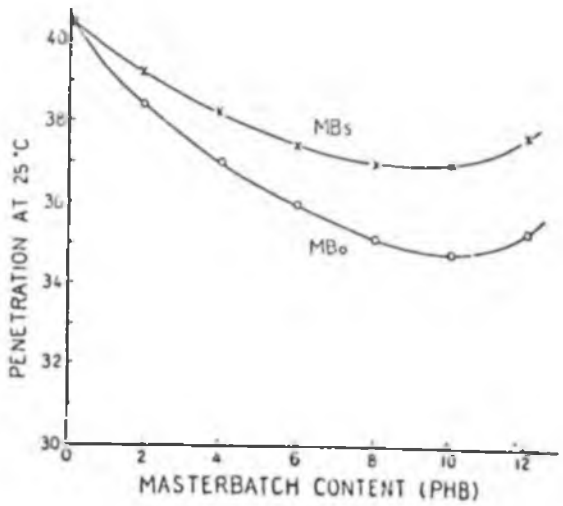


Figure 12. Change in penetration of bitumen with masterbatch content.

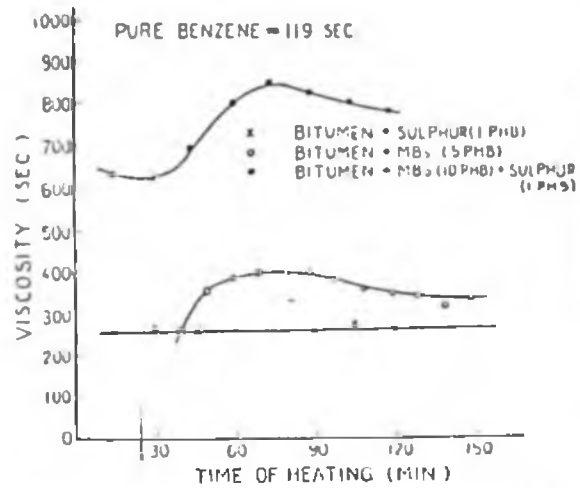


Figure 11. Change in viscosity of 10% benzene solution of sulphur-treated bitumen.

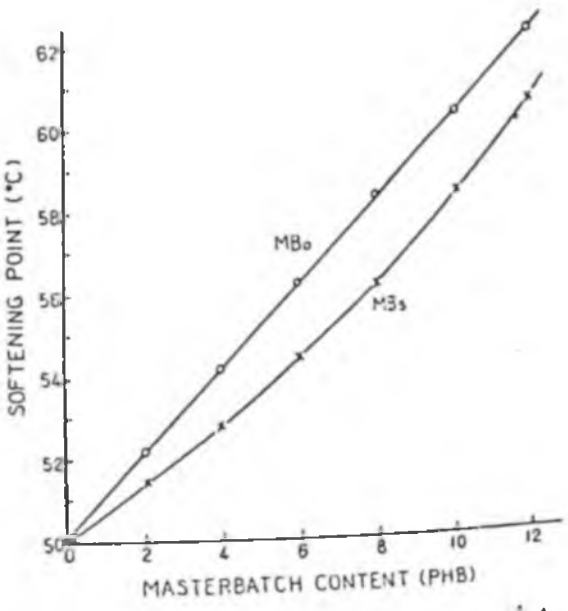


Figure 13. Change in softening point of bitumen with masterbatch content.

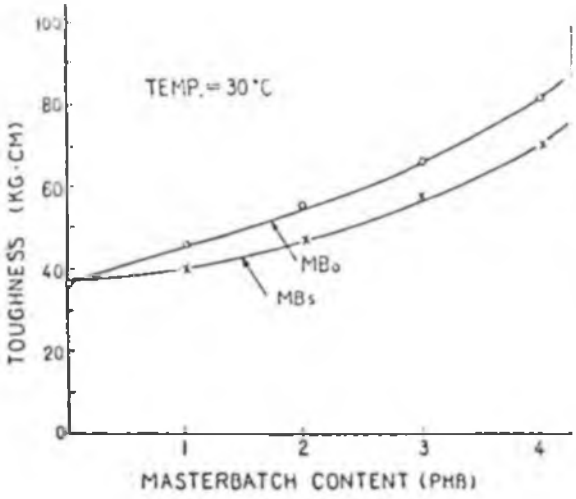


Figure 14. Change in toughness of bitumen with masterbatch content.

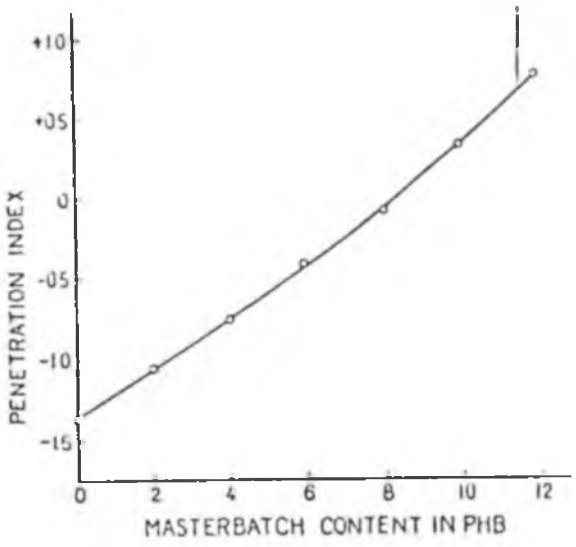


Figure 16. Penetration index plotted against masterbatch content.

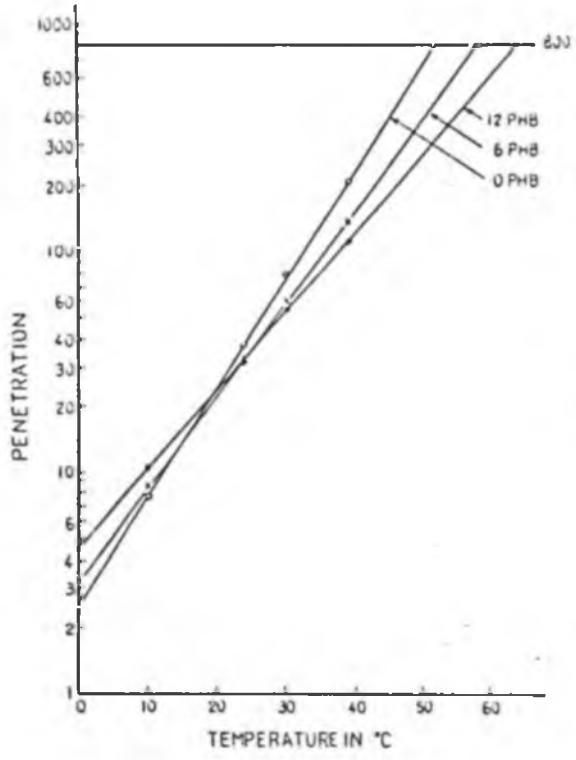


Figure 15. Penetration plotted against temperature.

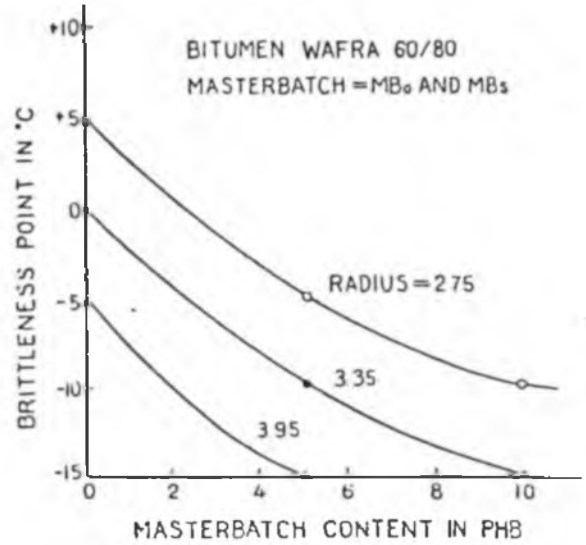


Figure 17. Brittleness point plotted against masterbatch content.

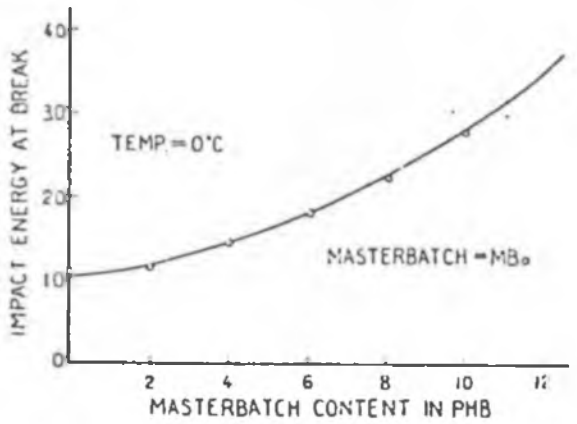


Figure 18. Impact energy at 0°C plotted against masterbatch content.

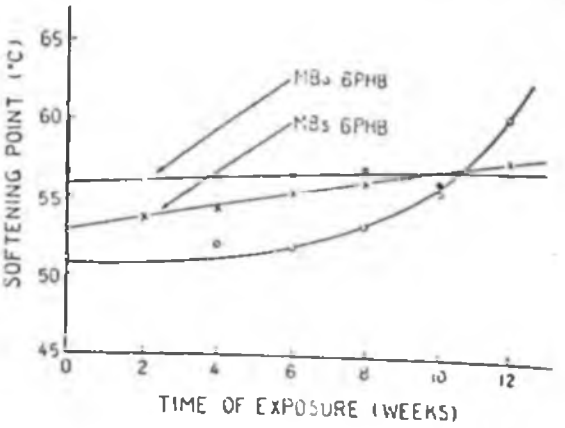


Figure 20. Change in softening point of rubberised bitumen with time of exposure to sunlight.

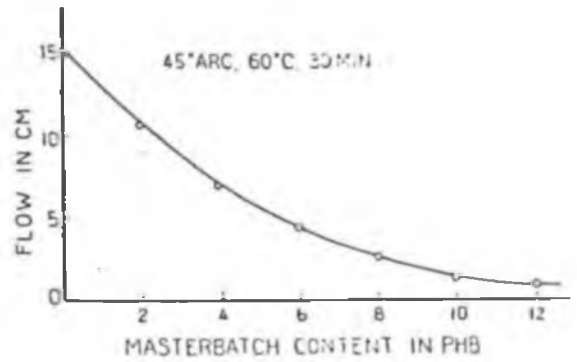


Figure 19. Flow at 60°C plotted against masterbatch content.

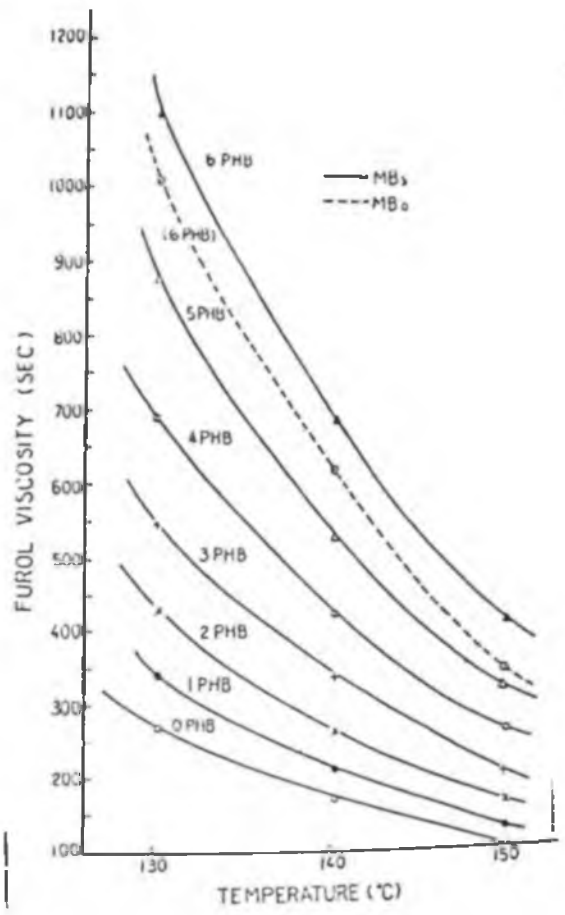


Figure 21. Change in consistency with masterbatch content.

Rubberized Roads

Donald A. Kalin.

RUBBERIZED ROADS *produce a much improved asphaltic pavement. The advantages include impermeability, increased adhesion and cohesion, better low temperature ductility and flexibility, and improved stability at elevated temperatures. Here are some of the tests that show why.*

BY DONALD A. KALIIN
CHEMICAL DIVISION, GOODYEAR TIRE & RUBBER CO., AKRON, OHIO

THE tire business depends on good roads, and it stands to reason that the rubber industry is vitally interested in more and better roads at less ultimate cost. To this end, the industry has conducted an extensive research and development program to establish the benefits derived from the addition of rubber to asphalt.

Interest in the use of rubber in roads started when high-speed traffic first began to batter pavements. The early experiments involved the use of rubber blocks held together by means of a tongue and groove type of construction. The blocks were laid in 1925 and withstood heavy traffic for more than 25 years. However, the rubber paving blocks were prohibitively expensive and therefore impractical.

In the early 1930's, the natural rubber interests were trying to find uses for the oversupply of natural rubber, and one of their projects was the evaluation of rubber in asphalt. They found that the addition of rubber improved many of the properties of asphalt. This led to the installation of test roads. In these installations, asphalt containing from 5 to 7.5 per cent rubber was mixed with sand to form a top dressing which was applied over a coarse bituminous concrete base. A section of road paved in this manner was put down outside of Rotterdam, Holland, in 1936. It withstood the heavy traffic of the German invasion and retreat. When visitors from the rubber industry were in Holland after the war, this "rubber road" was called to their attention. They were impressed sufficiently to begin work on a similar project in this country.

The early work was done with a powdered rubber. Development progressed over the years from a powder containing 20 per cent rubber and 80 per cent pigment, to one containing 80 per cent rubber and 20 per cent pigment. It is evident to anyone familiar with the techniques of synthetic rubber preparation that the properties and composition of the product can be varied with a much wider latitude than the natural or reclaimed products. As a result, in the past few years, there has been a trend toward use of synthetic rubber latex. In other words, a synthetic rubber can be "custom made" for a particular use.

Rubber Preparation

The "customizing" of a latex to vary the effect on the properties of asphalt takes into consideration the variables in composition and polymerization technique. All types have been evaluated; however, for this presentation, the concern shall be with SBR (styrene-butadiene rubber), a general purpose rubber. The two monomers—styrene and butadiene—are copolymerized in a water emulsion, resulting in a milky dispersion of rubber called latex. The ratio of butadiene to styrene was one of the variables studied. When mixed in asphalt, 100 per cent butadiene has the best low-temperature flexibility, while polystyrene

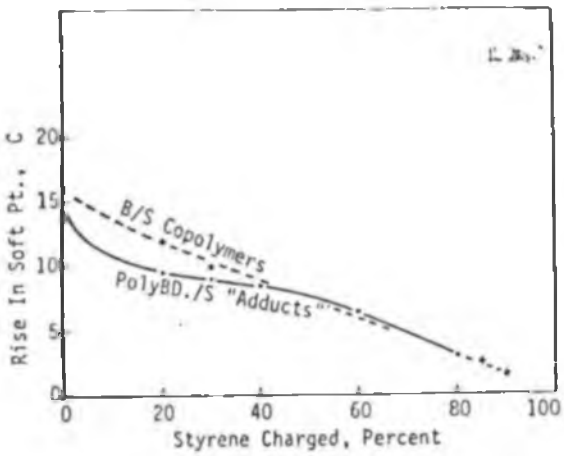


Figure 1—Styrene Content and Softening Point

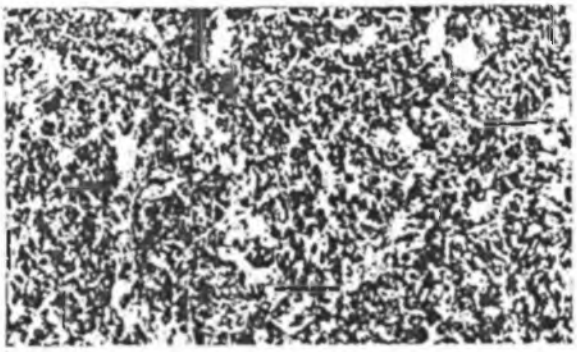


Figure 2—Rubber Network with Good Structure in Asphalt

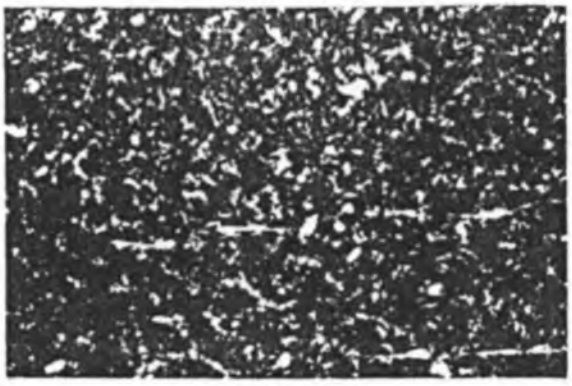
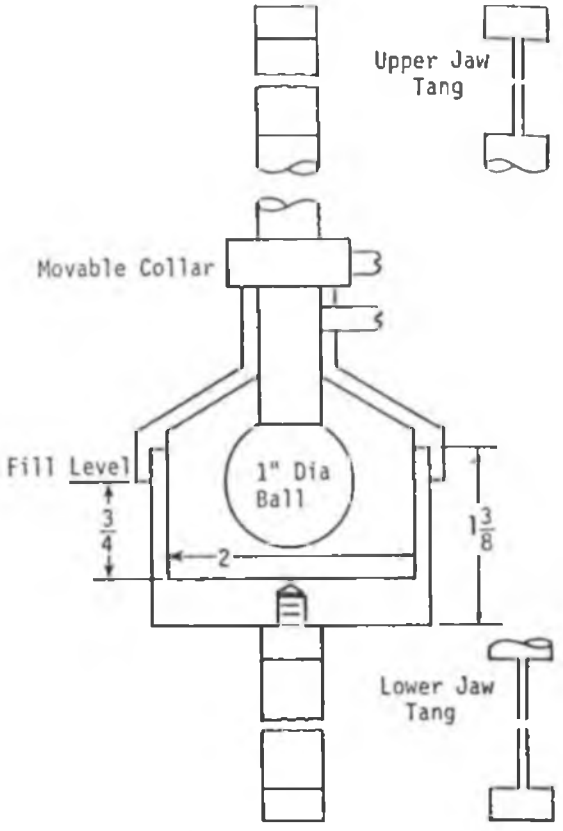


Figure 3—Rubber Network with Poor Reinforcing Structure



Apparatus For Rheological Study Of Asphalt

Figure 4—Cup and Ball Arrangement

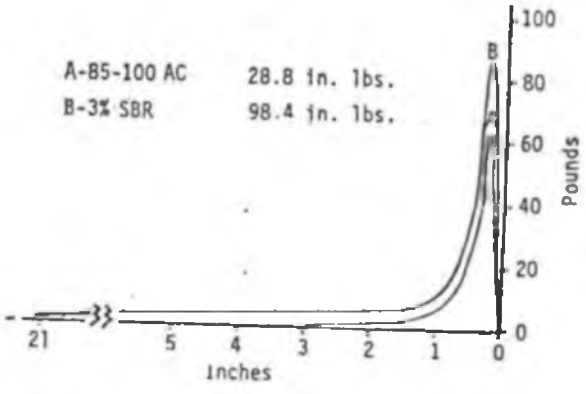


Figure 5—Asphalt Control Curves

is a brittle plastic at room temperature. The intermediate copolymers fall somewhere between these two extremes.

The general purpose SBR contains approximately 23 per cent styrene and 77 per cent butadiene. Figure 1 shows that as the styrene content is decreased, the softening point is increased. Based on these findings, the balance of this paper is directed to the laboratory and field results obtained from one general purpose SBR.

Rubberized asphalt used in highway construction usually contains from 2 to 5 per cent rubber, but more, and less, have been used for special applications. The effect of the rubber is purely physical, so the distribution and dispersion of the rubber in the asphalt should be as uniform as possible. Very good

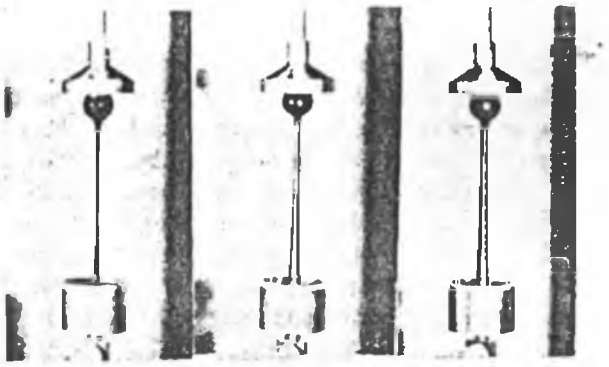


Figure 6—Variations in Thickness at Constant Elongation

and rapid dispersion can be obtained by adding the latex directly to the hot asphalt. Powdered rubber will require a longer mixing time, and crumb rubber is more difficult to disperse satisfactorily.

The procedure for blending rubber with asphalt is usually quite simple. In the laboratory one adds the latex from a separatory funnel while stirring the hot asphalt (300-350°F.) with a propeller stirrer. The heat and agitation are continued for about an hour, or until a uniform dispersion is obtained. This can be determined by microscopic examination under moderately high (100-150 ×) magnification.

Figure 2 is an example of a good rubber network structure in asphalt.

Note the uniformity of this structure compared with the example of a poor reinforcing structure as shown in Figure 3.

In the preparation of hot mixed asphaltic concrete, the asphalt can be pre-rubberized, or the rubber can be added to the mixture in the pug mill. When the rubber is added in the pug mill, the normal dry mix cycle is recommended, with the asphalt and latex then added simultaneously. The latex can be conveyed to the measuring bucket from a storage tank or drum by air pressure, pump or gravity feed, depending upon the plant facilities. The latex line from the measuring bucket discharges into the mixing box just below the asphalt spray bar. The latex addition is most easily controlled by a button that actuates a piston which opens a quick-throw valve. This can be the same button that controls the asphalt.

Properties of Asphalt

Laboratory tests, field trials and several thousand miles of rubberized seal coat and bituminous concrete in use today prove that it will improve the following properties of asphalt:

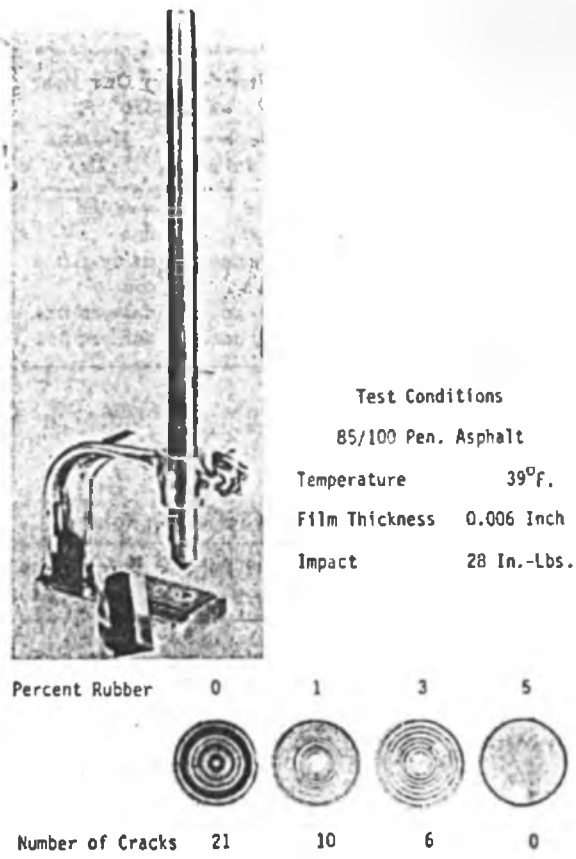


Figure 7—Gardner Impact Tester

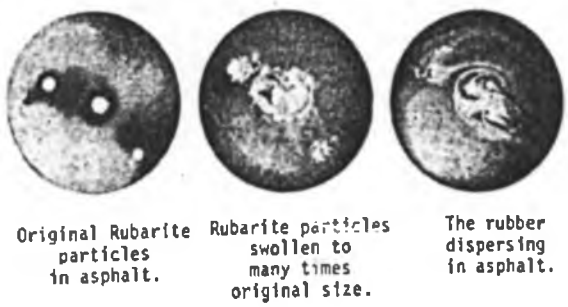


Figure 8—Rubber Dispersing in Asphalt

(1) Temperature susceptibility and low temperature ductility
(2) Toughness and impact resistance at low temperatures
(3) Recovery or elasticity
(4) Softening point and cold flow
(5) Tack and adhesion
(6) Bleeding resistance

Table I—Microscopic Appearance of SBR In Asphalt

Asphalt Source	Grade	Parts Rubber	Microscopic Appearance After Stirring One Hour at 350-370° F. Dispersion Rating	Structure Size
Arkansas	120/150	2.4	good	medium
Texas	120/150	2.4	good	fine
New Mexico	120/150	2.4	very good	delayed fine
Arkansas	85/100	2.4	good	coarse
New Mexico	85/100	2.4	very good	delayed fine
Illinois	85/100	2.0	very good	delayed fine

Table II—Effect of SBR on Softening Point

Asphalt Source	Grade	Softening Point °F. Control	2.4% SBR	Increase in S.P. °F.
Arkansas	120/150	113.0	124.0	11.0
Texas	120/150	108.5	125.5	17.0
New Mexico	120/150	107.5	115.5	8.0
Arkansas	85/100	113.0	124.5	11.5
New Mexico	85/100	111.0	117.5	6.5
			(2.0% SBR)	(2.0% SBR)
Illinois	85/100	115.0	122.0	7.0

Table III—Effect of SBR on Toughness

Asphalt Source	Grade	Tough-ness Control	77° F. (inch-lbs.) 2.4% SBR	Improvement per cent
Arkansas	120/150	17.0	65.0	280
Texas	120/150	14.0	77.0	450
New Mexico	120/150	17.5	100.0	470
Arkansas	85/100	28.0	63.5	125
New Mexico	85/100	24.0	152.0	530
			(2.0% SBR)	(2.0% SBR)
Illinois	85/100	33.0	95.0	185

Toughness

Some of these unique properties imparted to asphalt cannot be measured by conventional asphalt tests, so new tests were developed to evaluate these properties. Notable among these are the toughness and low-temperature impact tests developed by Goodyear and the DuPont torsional recovery test. As the name implies, toughness is a measure of the resistance the material offers to deformation. In this case, it is the work in inch-pounds required to extract a steel ball from the asphalt. The cup and ball arrangement is illustrated in Figure 4.

The ⅞-inch-diameter ball, a speed of 20 inches per minute, and a test temperature of 77°F. were all standardized. An Instron was used as the testing instrument. It will record and integrate the load deflection curve automatically. Figure 5 shows a typical curve for an asphalt control and the same asphalt containing 3 per cent SBR.

Figure 6 shows three mixtures taken at the same elongation. Note the increase in the thickness of the thread with the increase in rubber.

Low Temperature Properties

Although rubber toughens asphalt, it serves as a plasticizer at low temperatures, increasing the low temperature ductility or flexibility. Another way of demonstrating the improved low-temperature properties is by an impact test on thin films. A procedure was developed using the Gardner Impact Tester, which is shown in Fig. 7.

Very briefly, this consists of spreading a 0.006-inch-film thickness on a tin plate panel, conditioning it at 39°F. for 16 hours, and then subjecting the panel to an impact of 28 inch-pounds with a ½-inch-diameter ball point over a 19/32-inch-diameter hole. The crater is then examined for cracks; the number of peripheral cracks can be counted with the aid of low-power magnification. The advantage that accrues from the addition of rubber is shown at the bottom of Figure 7.

Table IV—Effect of SBR on Temperature Susceptibility

Asphalt Source	Grade	Penetration 32° F. Control	32° F. 2.4% SBR	77° F. Control	77° F. 2.4% SBR	Susceptibility Control	Susceptibility 2.4% SBR
Arkansas	120/150	40.0	39.0	124.0	99.5	3.1	2.55
Texas	120/150	33.0	30.0	133.0	92.0	4.0	3.05
New Mexico	120/150	27.0	23.0	127.0	94.0	4.7	4.1
Arkansas	85/100	26.5	26.5	84.5	70.5	3.2	2.65
New Mexico	85/100	20.5	19.0	97.5	73.0	4.75	3.8
			(2.0% SBR)		(2.0% SBR)		(2.0% SBR)
Illinois	85/100	19.5	19.0	70.5	65.5	3.6	3.4

Prior to examining the data showing the effect of rubber on asphalt, it will be necessary to discuss briefly the variation in asphalts. Besides the difference in penetration grades and viscosity type, there is the chemical difference due to the source of the crude. The main difference, as far as the dispersion of the rubber is concerned, is due to the amount of aromatic and aliphatic constituents. If substantial amounts of aromatic and naphthenic compounds are present, the asphalt will be a good dispersing medium for rubber. However, if the fluid constituents are primarily aliphatic, the asphalt will be a poor solvent for rubber. Nevertheless, rubber will substantially improve the properties of most asphalts.

Note that Figure 8 and Tables I-IV show the effect on the source of asphalt, although the exact crude is not designated. Figure 8 shows rubber dispersing in asphalt, and Table I shows the effect on the degree of dispersion. Table II shows the effect of SBR on the softening point; Table III, the effect on toughness; and Table IV, the effect on temperature susceptibility.

Viscosity

An important variation of asphalt is the viscosity, high or low, for a given penetration grade. A specific dividing line between high and low viscosity asphalt may not be established, but the work of Dr. R. N. Traxler indicates this would be about 150 seconds, Saybolt-Furol, at 275°F. for an 85-100 penetration grade asphalt.

Table V is taken from Dr. Traxler's report and relates viscosity to the "tenderness" of the mix on the highway. "Tenderness" in this case means that the mixture may show excessive shoving and cutting while rolling, and deformation and gouging-out when open to traffic. In severe cases, this will result in a delay in opening the road to traffic and may require additional rolling a day or two after application. In other words, a "tender mix" requires loving care, and this is costly.

Table VI shows the effect of the concentration of rubber on the properties of a low viscosity, 85-100 penetration grade asphalt. One and a half per cent rubber raises the viscosity from the "tender" range (below 135) to a very safe level. In addition to this, the other properties are considerably improved. The toughness is equal to that of the high viscosity asphalt with 1.5 per cent rubber (Table VII).

This is a case where a small amount of rubber may give the desired improvements, although a little more would be even better. Here one can see the effect of rubber concentration on the properties of a high viscosity asphalt. In addition to the significant improvements of properties listed here, rubber also improves, or decreases, the temperature susceptibility of the mixture.

Table V—Data from Dr. R. N. Traxler

Viscosity At 275° F.		
Stokes	Saybolt Furol, sec.	Contribute To Tenderness
3.5 or above	160 or above	no
3.1 – 3.4	136 – 159	doubtful
3.0 or below	135 or below	yes

Table VI—Effect of Pliopave Rubber on the Properties of a Low Viscosity Asphalt

Per Cent Rubber	0	1.0	1.5	3.0
Viscosity at 275° F., SSF	87	124.0	191.0	800
Penetration at 77° F.	75	75.0	73.0	68
Softening Point (R & B) °F.	130	132.8	133.7	145
Toughness, inch-lbs.	19	45.0	65.0	105
Ductility at 45° F. (5 cm./min.)	8	19.0	28.0	150

Table VII—Effect of Pliopave Rubber on High Viscosity Asphalt

Per Cent Rubber	0	1.5	3.0	4.5
Penetration at 77° F.	85.0	77.0	70	66
Softening Point (R & B), °F.	111.2	115.7	130	159
Toughness, Inch-lbs.	32.0	67.0	87	156
Ductility at 45° F. (5 cm./min.)	15.0	150.0	150	150

Table VIII—Effect of Thin Film Oven Aging on Low Temperature Ductility

	Ductility at 45° F. (5 cm./min.)			
	Low Viscosity Asphalt		High Viscosity Asphalt	
Per Cent Rubber (Pliopave L170)	Original	Aged	Original	Aged
0.0	8	3.3	15	5
1.5	28	13.0	150	150
3.0	150	29.0	150	150
4.5	150	34.0	150	150

Table IX—Effect of Pliopave Rubber on Properties of Asphalt Emulsion Residue

Asphalt Emulsion	RS-2	TD-2R (2.4 Pliopave L170)
Per Cent Residue		
Original — 3 hrs./325° F.	67.1	68.0
24 hrs./325° F.	64.0	65.5
Penetration at 77° F.		
Original — 3 hrs./325° F.	125.0	120.0
Plus 5 hrs./325° F.	109.0	120.0
Plus 21 hrs./325° F.	26.0	50.0
Ductility at 39.2° F.		
Original — 3 hrs./325° F.	16.0	150.0
Plus 5 hrs./325° F.	12.0	150.0
Plus 21 hrs./325° F.	0.4	8.0
Softening Point (R & B)		
Original — 3 hrs./325° F.	110.0	119.0
Plus 5 hrs./325° F.	120.0	131.0
Plus 21 hrs./325° F.	150.0	136.0

Table VIII shows the effect of rubber concentration on the ductility after thin-film oven aging for 5 hours at 325°F. The film thickness for this test is about ⅛ inch, as designated in ASTM D 1754, which is more severe than the loss on heating a test run in an ointment tin. Please note, as well, that the ductility tests were run at 5 cm./min. speed rather than the conventional speed of one. This, again, is a more severe test. For example, a material that has a ductility of 35 at 5 cm./min. speed may give 150+ at 1 cm./min. These results point up the original benefit from the addition of rubber, plus the improved durability or aging characteristics. Although it is known that rubber will degrade on aging at 325°F., the difference between the high and low-viscosity rubberized asphalt indicates that the aging characteristics of the asphalts are the controlling factors in this case.

Table IX shows the effect of rubber on the properties of the residue from asphalt emulsion. The residue is obtained by oven evaporation for 3 hours at 325°F., ASTM D 244, rather than by distillation, which requires a temperature of 500°F. and would degrade both the asphalt and the rubber. In addition to improving the original properties, rubber improves the aged properties. After 5 hours at 325°F., similar to the ASTM D 6 loss on heating test, there is much less severe degradation of properties in the rubberized asphalt than in the control. After a very severe 21 hours at 325°F., the rubberized asphalt is still superior to the control. This improved durability is an important factor in the service behavior of an asphalt pavement.

Relevance to Contractor

First, and probably most important, is the additional business profit derived from increased annual tonnage, which is not a matter to be dismissed lightly. This does not mean that profit comes from charging extremely high costs for using rubber. Profit is

Table X—Quantities and Costs for Pliopave L-170 Latex in Rubberized Hot Mix

	Asphalt Cement Content in Hot Mix, %[1]						
	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Asphalt cement per ton hot mix, lbs.	120	130	140	150	160	170	180
Rubber content per ton hot mix, lbs.							
3% rubber	3.6	3.9	4.2	4.5	4.8	5.1	5.4
5% rubber	6.0	6.5	7.0	7.5	8.0	8.5	9.0
Pliopave L-170 latex per ton hot mix, gal.							
3% rubber	0.66	0.72	0.77	0.83	0.89	0.94	1.0
5% rubber	1.1	1.2	1.3	1.4	1.5	1.6	1.7
Cost of rubber per ton hot mix							
3% rubber	$1.60	$1.74	$1.86	$2.01	$2.15	$2.27	$2.42
5% rubber	2.66	2.90	3.14	3.38	3.62	3.86	4.10
Cost of rubber per sq. yd. 3% rubber							
½" thick (50 lbs.)	4¢	4.4¢	4.7¢	5.0¢	5.4¢	5.7¢	6.1¢
¾" thick (75 lbs.)	6¢	6.6¢	7.0¢	7.5¢	8.1¢	8.5¢	9.2¢
1" thick (100 lbs.)	8¢	8.8¢	9.4¢	10.0¢	10.8¢	11.4¢	12.2¢
Cost of rubber per sq. yd. 5% rubber							
½" thick (50 lbs.)	6.7¢	7.3¢	7.9¢	8.5¢	9.1¢	9.7¢	10.3¢
¾" thick (75 lbs.)	10.0¢	10.9¢	11.8¢	12.7¢	13.6¢	14.5¢	15.4¢
1" thick (100 lbs.)	13.4¢	14.6¢	15.8¢	17.0¢	18.2¢	19.4¢	20.6¢

[1] Based on 5.4 lbs. rubber per gallon of Pliopave L-170 latex. These costs are approximate and based on extra cost of rubber only in hot mix. Additional charges for contractor handling, if any, not included.

derived from the additional road surfacing done with thin lift overlays, which formerly were treated by a seal coat of some kind. This is a new market. Roads that formerly carried a few hundred vehicles per day now carry thousands, necessitating a higher type of maintenance application. In addition, thin bituminous lifts are used in lieu of seal coats for the following reasons:

(1) Smoother surface
(2) No bleeding
(3) More accuracy in skid resistance control
(4) Quieter riding surface
(5) Increased surface life.

Even with these advantages, thin lifts sometimes present such problems as shoving, rutting, rippling and other surface deterioration. Addition of rubber to these thin lifts will solve some of these problems.

Costs Involved

The addition of rubber is always based on the weight of the asphalt content in the design of the mix, as may be seen in Table X.

With a mix design specifying 6 per cent asphalt, the total asphalt cement weight amounts to 120 pounds. A 3 per cent rubber content, based on the weight of asphalt, amounts to 4.2 pounds of rubber solids per ton of hot mix. Since the latex is a liquid, it is necessary to know the solids content of the specific latex in order to prepare the proper number of gallons to be introduced in the mixing box. In this instance, it would amount to 0.66 of a gallon per ton of mix or, in most cases, 1.3-1.5 gallons per batch. Table X is based on a cost of $2.42 per gallon of latex, the highest cost east of the Rockies for a minimum 1-drum shipment.

Assuming this cost and the proportions already mentioned, the additional cost of rubber per ton would be $1.60. The additional cost per square yard for a thickness of ½ inch, approximately 50 pounds of mix, would be $.04. In calculating these costs, one must remember that this is the additional cost of the rubber *only*. Any charges over, above and beyond this in quoting rubber mixes is a sum total of handling, additional equipment cost, and profit.

Practical Considerations

One can work with rubberized mixes in the field as easily as with conventional mixes. This observation is based on experience with rubber, since there is a difference in handling various rubber mixes. This "difference" is a result of a combination of things, but essentially of the increase in viscosity of the mix and temperature. There has been no problem in laying, casting, raking or rolling when recommendations are followed. They are not much different from the procedures one would normally follow



Figure 9—Typical Rubber Blending Unit

with conventional mixes. As has been noted, the viscosity of asphalt increases with the addition of rubber. This holds true for hot mix as well, and with low temperatures it can cause a great deal of aggravation in laying the material. For the easiest handling on the job, the following mixing procedures should be followed:

(1) The temperature of the aggregate used should be sufficiently high to give the finished batches of modified mix an approximate temperature of 325°F. It should not, however, exceed 350°F.

(2) The dry aggregate mixing cycle should consist of 10 seconds mixing.

(3) Pliopave L-170 latex should be added simultaneously with the asphalt spray operation.

If the recommended mixing procedures are followed, no difficulty should be encountered in handling the material. The wet mixing cycle should be somewhat longer than is done in some areas; however, this is a specific thing to be handled on each individual job, since aggregate size, amount of fines, asphalt content and rubber content all enter into the picture.

Making Rubberized Mixes

Figure 9 shows a typical rubber blending unit at the plant site. It's somewhat makeshift but it is effective, costs little, and saves labor. The latex flows from this pipe either by gravity or pumping into the funnel here. The amount has been predetermined, taking into consideration all the factors previously presented. This quick release valve is connected to

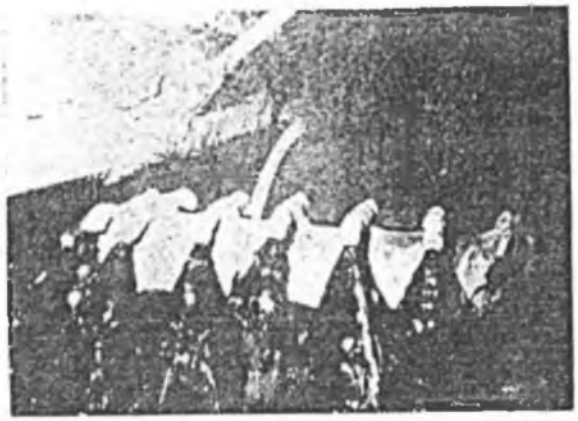


Figure 10—Latex Being Introduced into Mixing Box

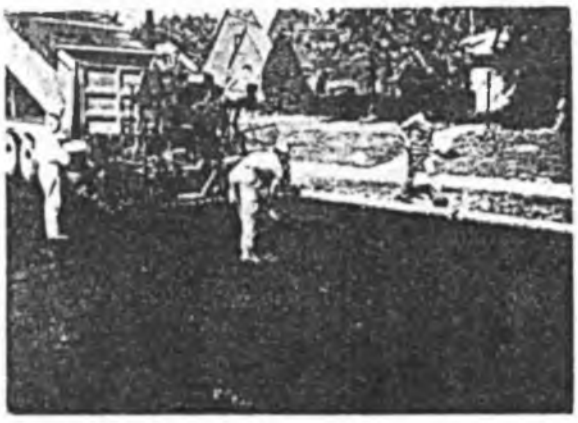


Figure 11—Laying of the Mix

the asphalt release button, which will release the latex and asphalt simultaneously.

The pug mill mixing method has one principal advantage over a pre-blended material: one can produce both rubberized and conventional mixes simply by opening or closing the valve controlling the latex flow, thus allowing the trucks coming in to obtain the type of mix desired.

Figure 10 shows latex being introduced into the mixing box. The mix is then conveyed to the job and laid in the conventional manner, as may be seen in the photograph in Figure 11.

Figure 12 shows the finished surface.

Advantages of Rubberized Mixes

The impermeability of rubberized mixes is an overall advantage regardless of aggregate size. This statement is based on impermeability on a paper industry test in which two samples of material, one rubberized and the other conventional, are weighed, immersed, and reweighed to determine the amount of water absorption. In each and every case, the rubberized specimen has at least 50 per cent less absorption than the conventional specimen. Rubber can improve the low temperature flexibility of any mix and improve flexure-fatigue resistance.

The asphalt content can be increased in a rubberized mix depending on the aggregate gradation. The rubber content will control any flushing or bleeding that might occur if the same increase were made with a conventional mix.

This paper has covered the history of rubber in paving, the physical property improvements in asphalt achieved by the incorporation of rubber, mixing of rubber, both pre-blending and pug mill mixing, and advantages of use of rubber in mixes.

There are many other factors that add impetus to the rubber industry's belief that rubber has a place in the paving market. The proper rubber added to asphalt results in an increase in adhesion and cohesion, or toughness, along with an increase in low-temperature ductility and flexibility and improved stability at elevated temperatures. These characteristics of a binder, along with increased durability, result in an improved asphaltic pavement. □

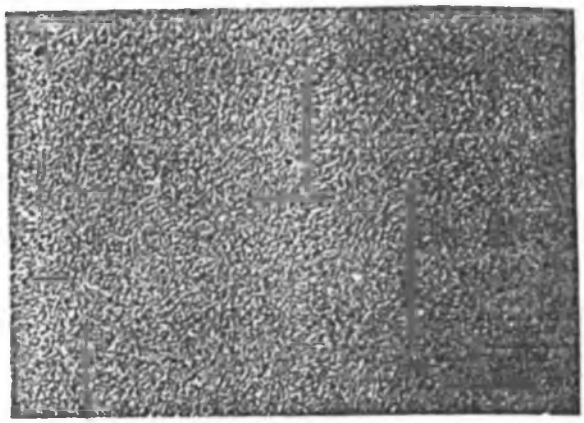


Figure 12—Finished Surface



Interested Londoners watching "rubber blocks" being laid in New Bridge St. shortly after World Wor I.

RUBBERISED ROADS FOR INDIAN CONDITIONS

KS Gopalakrishnan,
Director (T&TC), Rubber Board

For the development of any country, efficient and adequate systems of transportation are inevitable and of the different means of transportation, road transport is the most significant one. India is a very vast country with an area over 3.3 million sq.km. With our population reaching900 million, the country has to have an efficient, dependable and fast transport system for meeting its developmental needs. India's rich mineral resources and agricultural wealth are distributed not evenly over the country and the demand for passenger services is insatiable. All the above points indicate the imperative need for the meticulous planning and implementation for the development of an excellent transport infrastructure for the country.

Table 1 below points out the definite shift in the share of freight and passenger traffic from rail to road during the past four decades.

Table 1
Rail and Road Traffic from 1950-51 to 1992-93

	Freight Traffic %		Passenger traffic %	
Year	Rail	Road	Rail	Road
1950-51	88.0	12.0	68.4	31.6
1960-61	83.0	16.2	49.0	51.0
1970-71	69.0	31.0	36.0	64.0
1980-81	61.9	38.1	27.8	62.2
1992-93	40.2	59.8	14.9	85.1

Factors that have contributed to the shift in favour of road transport are flexibility, door-to-door service, reliability and speed. However, the main road network comprising of National and State highways has not

matched with the growth in traffic. It is pertinent to note that the number of vehicles has grown from 0.3 million in 1951 to 25.3 million in 1994 and it is expected that the total number of vehicles will increase to 54 million by 2001. Inadequate road networks as well as inferior quality of roads has lead to high transportation cost and has severely eroded the international competitiveness of Indian economy. Particulars of growth of road network from 1951 to 1995 with targets for 2001 are given in Table 2 below.

Table 2

Growth of road network (KM)

Category	1951	1995	2001
Expressways	Nil	Nil	2000
National Highways	19,811	34,000	66,000
State Highways	60,000	131,000	145,000
Other roads	318,000	1935,000	2510,000
Total	400,000	2100,000	2723,000

It is reported that of the 2.1 million Km. length of roads in India, only about 48% is surfaced and among that bituminous roads form the lion's share. Of the 1,65,000 km. of National and State Highways, only 2% is 4 lane, 34% double lane and 64% single lane.

Apart from the above, it is also to be noted that owing to many factors such as increased traffic, poor maintenance, adverse weather conditions, inferior quality of road building materials, use of inadequate quantity of materials, etc, the life of roads is getting reduced and need for frequent maintenance increases. It is also to be noted that in the context of spiralling cost of road building materials, difficulties in getting the right type of materials, increase in labour wages, etc, the cost of construction of road is found to be consistently on the increasing trend. However, the budgetry resources for road work show a decreasing trend. In view of the above, it is imperative that the effective service life of bituminous roads has to be increased drastically for which improved technologies like rubberisation of roads have to be practised.

What is rubberisation of bitumen?

Bitumen is basically a thermoplastic material and rubber (whether natural or synthetic) is an elastic one. Addition of a small quantity of rubber into bitumen followed by its uniform distribution in bitumen is found to drastically change the characteristics of the binder. Rubber can be added into bitumen in forms such as properly preserved latex, sheet rubber, powdered rubber, ground vulcanised rubber, reclaimed rubber, etc. Thus bitumen admixed thoroughly with 2-5% rubber is generally called rubberised bitumen.

Advantages of rubberised bitumen

The main consequences of the addition of rubber to bitumen follow from the changes in the viscosity, strength and elasticity characteristics. Small quantities of rubber in bitumen, say 2-5% will result in large favourable changes in penetration and softening point of bitumen. Thus rubberised bitumen is more resistant to deformation at high temperature and yet at the same time less brittle at lower temperature. Incorporation of small quantities of rubber into bitumen makes the bitumen rubbery. This is shown by the pronounced resiliency, elasticity and tenacity of rubberised bitumen. Rubberised bitumen also shows improved adhesion with aggregates.

Method of incorporation and type of rubber

The extent to which the physical properties of bitumen are altered by the addition of rubber depends upon both the quantity and type of rubber and the temperature and period of heating. Results of comprehensive studies conducted by Smit.L.M (Journal of Applied chemistry 1960, 10, 296) indicated that Natural Rubber (NR) in latex form is the most effective followed by unvulcanised NR, unvulcanised Styrene Butadiene Rubber (SBR) and vulcanised NR. Effect of blending different kinds of rubber on the softening point of bitumen is shown in figure 1.

The Road Research Laboratory, London carried out investigations on the factors affecting the incorporation of rubber into Asphalt. Effect of blending time on temperature of mixing is given below..

Table 3

Blending time for NR with Asphalt

Blending temperature °C	Blending time in minutes	
	Unvulcanised NR	Vulcanised NR
140	25	360-480
150	15	180-240
160	10	120

NR is an unsaturated polymer which will get degraded on prolonged heating especially at higher temperature. As the rubbery properties of the degraded NR are poor, time and temperature of incorporation of rubber into bitumen has to be properly chosen. It is also to be noted that rubberised bitumen should not be stored at higher temperature for longer duration. Allowable storage times for rubberised asphalt at different temperatures are given below.

Table 4

Allowable Storage time for Rubberised Asphalt

Temperature °C	Storage time (hrs)
Normal room temp.	Indefinitely
130	72
140	48
150	18
160	12
170	4

Field Experiements

In India, a number of field experiments on rubberisation of roads have been conducted since 1974. Most of the trials were carried out incorporating specially preserved NR latex into bitumen and using the rubberised bitumen in place of ordinary bitumen for laying roads making use of conventional road building equipments. Most of the stretches were

1 KM in length and ordinary bitumen roads were also laid under identical conditions. 2% Natural rubber was used in most of trials. In 1995, 13 KM stretch of road on the way Sabarimala, (a pilgrim centre) was also rubberised by the Malanadu Development Society, Parathode with the active involvement of the public in the area. In general, it is observed that rubberised roads performed comparatively well over the conventional bituminous roads. Reports of many trials conducted world over also indicate that rubberised roads gave a minimum extended life of 50% over the conventional bitumen control roads.

Cost of Rubberisation

Estimates of Natural Rubber Producers Research Association in 1971 show that 12 to 15% additional cost will have to be incurred for seal coats using 2% rubber and 16% additional cost for rolled asphalt with 4% rubber. Trials conducted by the Rubber Research Institute of India showed that the additional cost involved for rubberisation would be about 16% with 2% rubber.

Future of rubberised roads under Indian Conditions

Results of laboratory as well as field trials indicate that rubberised roads have the following advantages over the conventional bituminous roads.

1. Increase in service life
2. Better resistance to fatting up
3. More resistance to stripping
4. Improved skid resistance

Thus rubberised roads combine savings with safety. However, rubberised roads are yet to become popular in India. Natural rubber which is an excellent polymer for favourably modifying bitumen for road surfacing is also readily available in the country. The authorities concerned with road construction at the state and national levels may take appropriate measures for extensive rubberisation of roads. Results from such trials will clearly establish the techno economic superiority of rubberised roads

over the conventional bitumen roads. To start with, it is suggested that each Municipality in Kerala may rubberise at least 5 kms. length of roads and every Corporation may do this 10 kms. State PWDs may under-take 100 Kms. and National Highways Dept. 200 Kms. of rubberisatiion of roads. Results from such trials will be enough to undoubtedly convince the decision making machinery about the long term advantages of rubberised roads and to go in for rubberisation of roads in a big way. Finally, considering the slight difficulties for admixing NR latex with bitumen at the work sites, it would be highly advantages if bitumen is premixed with NR at refinery following ideal mixing techniques and made available for the rubberisation of roads. This would go a long way in implementing the right technology of rubberisation of bitumen and performance of roads using such rubberised bitumen will be uniform also. It is gratifying to note that the Rubber Research Institutes of India has already taken steps in that direction and results of the trials are expected soon.

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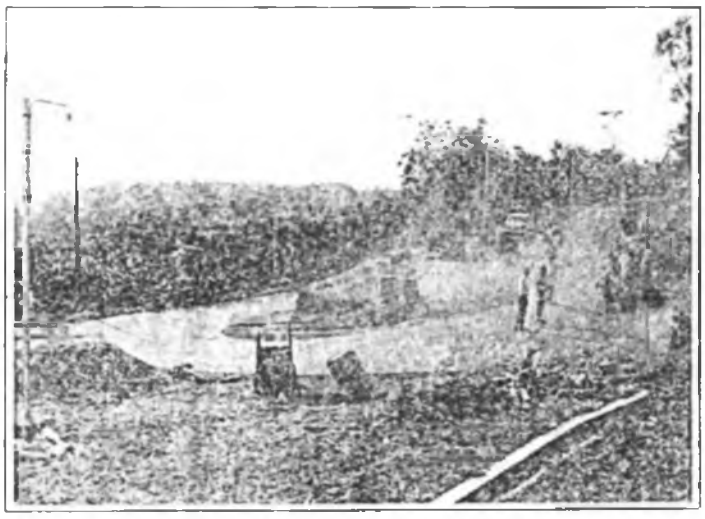
Rubberised roads for superior performance

The results of several full scale road experiments conducted in many parts of the world clearly indicate that use of rubberised bitumen in pavings will undoubtedly lead to saving and safety

K.S. Gopalakrishnan

There is a growing demand now for rubberised roads because of its durability, cost effectiveness and superior performance. The experiments have confirmed the benefits of rubberised roads. Some of the drawbacks of bituminous roads like high susceptibility to temperature variations, tendency to crack, etc. caused engineers and scientists to look for alternative methods of road construction which ultimately led to the use of rubber in road building.

In India, we have over 20 lakh kilometres of roads of which only about 48 per cent is surfaced. Of the surfaced pavements, the lion's share is accounted by bituminous roads. Considering the fact that bulk of the bitumen required for road construction in India is produced from the imported crude petroleum and also considering the paucity of good quality aggregates for road construction, there is absolutely no justification in building bituminous roads which lasts only for short duration, sometimes a year or even less in certain cases. It is in the above context that engineers are forced to heavily lean on the modification of bitumen using natural rubber and to use the improved quality binder for constructing roads, combining 'saving with safety'.



A rubberised road – superior performance

Basically rubberised bitumen comprises of a bituminous compound into which rubber in a suitable form and proportion is incorporated using an appropriate technique. Rubberised bitumen is then used in pavings using conventional road building techniques. Following the incorporation and uniform distribution of rubber, bitumen undergoes radical changes in its properties to a large extent on the type and grade of rubber used, ratio of bitumen to rubber, and the method of incorporation of rubber into bitumen. It has been clearly established that for maximum effectiveness, the rubber must dissolve in the binder (bitumen). When properly incorporated, rubber increases the viscosity, strength and heat resistance of the system.

Popular belief

Prior to 1950s, the popular belief was that while adding rubber into bitumen, the rubber remained as discrete particles which absorbed some of the oily constituents from bitumen, thus making it harder, but also making it durable as the oily fraction was subsequently not lost so readily during atmospheric weathering. Laboratory studies conducted in early 1950s made it clear that when rubber is added to hot bitumen, it exists in the bitumen at first as a dispersion of fine particles. At this stage its contribution to the mechanical properties of bitumen is not much. On heating, the rubber

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particles swell and finally disperse to give a tough rubbery material. In this condition, the rubber is able to change the mechanical properties of bitumen considerably. Being an unsaturated hydrocarbon, rubber gets degraded on prolonged heating at high temperatures and then its effectiveness is greatly reduced.

Advantages

Laboratory studies conducted have established that the main effect of incorporation of rubber into bitumen are on the viscosity, strength and elasticity of the latter. Even small quantities of rubber markedly change the above properties: Viscosity is increased considerably, susceptibility to temperature is reduced drastically and strength is improved immensely.

When the rubberised bitumen is used in constructing pavements, the following advantages are expected to realise: Improved resistance to cracking, better resistance to fatting up, improved resistance to deformation or flow, higher stability and more resistance to stripping.

These advantages indicate that the performance of rubberised bituminous pavements can be definitely superior to conventional bituminous roads. However, actual full scale trials are the only way to ascertain the cost benefit aspects of the rubberised roads.

The results of several full scale road experiments conducted in many parts of the world clearly indicate that proper incorporation of adequate quantity of natural rubber in appropriate form into bitumen and use of such rubberised bitumen in pavings will undoubtedly lead to 'saving and safety'.

Additional cost

Estimates prepared by the Natural Rubber Producers Research Association in 1971 show that 12 per cent to 15 per cent additional cost will have to be incurred for seal coats using 2 per cent rubber and 16 per cent additional cost for rolled asphalt at 4 per cent rubber. Experiments conducted by the Rubber Research Institute of India show that additional cost involved for the normal type of road surfacing usually adopted in Kerala would be about 16 per cent with 2 per cent rubber. Thirteen kilometres of road on the way to Sabarimalai (a pilgrim centre) has been recently rubberised (with the active involvement of the public in that area) incorporating 2 per cent rubber on the weight of bitumen and the additional cost incurred was about 17 per cent. The additional cost of rubberisation which comes in the range of say 15 to 20 per cent will be more than compensated by the advantage accruing by the use of natural rubber.

Results of laboratory experiments as well as full scale road trials have clearly established the superiority of natural rubber modified bitumen in pavings compared to ordinary bitumen. Natural rubber is produced in adequate quantity in India and available at reasonable price. In a developing country like India, optimum utilisation of resources available in the country deserves prime consideration. As such the authorities concerned with road construction at the State and national levels may take appropriate measures for the extensive rubberisation of roads. To begin with, it is suggested that one kilometre road may be rubberised in every municipality and 5 kilometres in every corporation. State PWDs may undertake rubberisation of 100 kilometres stretch road in every State and the National Highways Department 200 kilometres. The results from such trials will be enough to undoubtedly convince the decision making machinery about the long term advantages of rubberised roads and to go in for rubberisation of roads in a big way. ❑

UNITED RUBBERS

MANUFACTURERS
OF
PRECURE
TREAD
&
TREAD
RUBBER

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Development plot
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A. F. W. WILDEBOER

Rubberized roads on the Continent

Previous articles in Rubber Developments have described the development of the rubberized road in the English speaking world. The author of these notes—who was formerly Road Consultant to the Rubber-Stitching, Delft—reviews parallel developments on the Continent.

THE oldest rubberized roads on the Continent about which anything is known are on the outskirts of Bussum, on the main through road Leeuwarden, and near Schiphol. The two former being 20 years old and the last named 19. Each stretch is about 350 yards in length and each is still in excellent condition whereas the adjacent non-rubber control stretches have had many times the additional initial cost spent on them in repairs, so proving that the extra cost of the rubber was money well spent. During the war no rubber was available and it was only in 1949 and 1950 that the City of Amsterdam resumed the use of rubber in their street construction. Since then about 100,000 square yards of rubberized surfacing has been laid and recent inspection has shown that none of these stretches are worse and most are better than the controls. A final conclusion has not yet been reached but it is expected that in a few years' time a favourable opinion will be expressed.

Other cities in Holland also have trial stretches, which are still too young to show definite results. The new Government roads are mainly built in concrete and the only use for rubber there is in joint sealing compounds.

The interest in the use of rubber outside the country of birth of the system is—as usual—much bigger than in Holland. The only disadvantage is that test stretches are usually laid in places where every other construction failed.

Germany

In Germany, as the result of the complete failure of a bridge surfacing, 12 bridges were laid, or partly laid with stone-filled rubberized mastic. With one exception, due to a mistake in the mixture, all the bridge surfaces stood up well to the hot summer of 1955 and very severe winter. In roadwork it may be said that the general opinion is that rubber asphalt is better; if there is any doubt it is on the score of economy. Test stretches in Frankfurt, Cologne and Hamburg on roads, pontoons and as warehouse flooring are showing definitely better. One of the most remarkable is a stretch on the arterial highway near Oberhausen in the Ruhr which is now three years old and shows a tremendous difference. Between 1951 and 1952, 28 test stretches were laid over cobble pavements in Frankfurt. Only one of these was rubberized and to date this is the only one still in perfect condition.

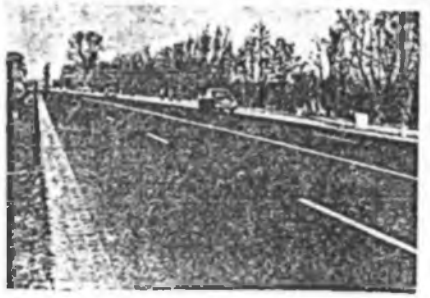


Fig. 1 (a) *A rubberized asphalt surfacing at Bussum on the highway from Amsterdam to Germany, taken 19 years after laying.*



(b) *A control section of ordinary asphalt photographed at the same time. (The rubberized section is in the background)*

Switzerland

In Switzerland the surfacing of the Kirchenfeld Bridge at Berne needed replacement every year; it has now been resurfaced with rubberized asphalt and is standing up well. A recent inspection of six rubberized test sections laid officially in Switzerland showed very favourably for rubber while near Basle, a rubberized section laid in 1953 is held to be the only non-skid stretch on that particular road.

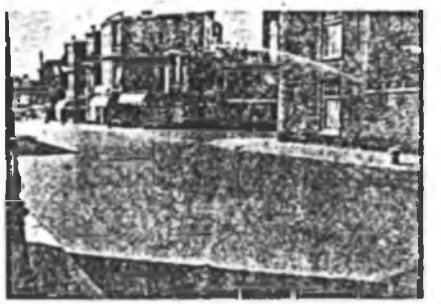


Fig. 2. *Rubber asphalt surfacing on Stuivesantstreet, The Hague*

In Denmark the City of Odense laid 10,000 sq. metres of thin rubber asphalt in 1951. The test stretches show at present a decidedly better stability, less ageing of the bitumen in the road and better cohesion and adhesion of the binding medium. On the Island of Fyn there was a road which cracked up every winter. The rubberized surface dressing laid in 1954 so far shows no cracks. One wooden bridge in Copenhagen, covered in 1954 with a thin rubberized mastic asphalt, is in good shape, where all other methods had to be renewed every year. Amsterdam City are now using rubber in a somewhat similar manner for the wooden decks of some of their older bridges. A light coloured surfacing made by a local firm was found not stable enough for city traffic although satisfactory for main highways. This firm have now laid two rubberized sections, one in Copenhagen and one in Aarhus which are so far showing good results, two similar stretches of about 6,000 sq. metres and 2,500 sq. metres have now been laid in Hamburg.

Other countries

In Austria three test stretches have been laid which are still too recent to show definite results but they are all three slightly better than the controls.

In Sweden rubber powder is being incorporated in road surfaces for special applications and at difficult spots.

In Finland two trial sections have been laid.

All in all the last two years the Continent has laid an estimated surface of 350,000 sq. yds. in rubberized asphalt work. These are not all test stretches. Zurich City are using rubber asphalt on old cracked streets, to eliminate the necessity of breaking up the old surface. The cracks are not coming through and other public works departments are now following suit.

In nearly all the above stretches Pulvatex unvulcanised rubber powder was used, mainly because it dissolves so rapidly in the bitumen, because it can be added in the mixer and does not require extra work—except the weighing—and no extra time in mixing or laying. France is mainly using latex in surface [illegible] good results.

Reasons for success

What now is the reason for the good behaviour of rubberized asphalt constructions? Measurements on road samples in Holland, Germany and Canada have shown a really remarkable [illegible]ovement in stability at high temperatu[illegible] over the same mixtures without rub[illegible] 200 per cent.). The impact resistance at 0° C. shows also an improvement between 55 and 20 per cent. This is all due to the better cohesion in the bitumen and the lower heat sensitiveness of rubberized bitumens.



Fig. 3. *Rubber asphalt surfacing in the Innere Kanalstrasse, Cologne, taken three years after laying. Deterioration is already visible in the [illegible] section in the foreground*

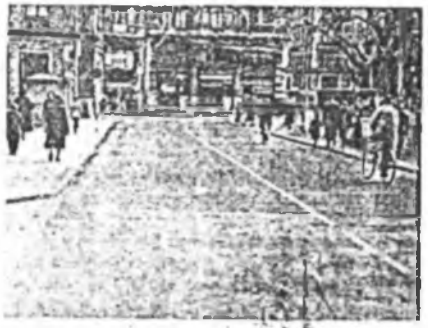


Fig. 4. *Rubberized road at the Pont de l'Ile in the centre of Geneva*

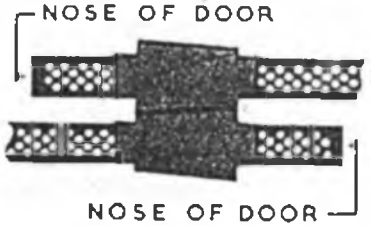
Contrary to the theories expressed by some people, we find in all older roads a really astonishing difference in ageing in favour of rubber. Tests are being carried out to explain this phenomenon, which seems to be a result of molecular rearrangement due to temperature changes, especially in thin layers where the rubber prevents the bitumen from hardening. This difference in ageing is, in our opinion, the reason why the other improvements in the properties of the binding medium are retained so much better and keep the road longer in the condition in which it was laid, thereby extending its total life considerably. This is equally important for open as well as for closed constructions.

Nobody is able so far to judge the extent of the improvement, because the oldest rubberized roads have not yet worn out. The least that can be said is that there is certainly no risk in using rubber in road construction and that there are many indications that rubberized roads are better. It is definite that in certain instances where a normal asphalt construction fails, rubber offers a solution.

There is, however, another angle to the whole problem. Every laboratory can find that the addition of rubber improves the properties of the bitumen. This gives rise to the question of whether there is any possibility of laying different constructions from our present generally accepted standard specifications and so build equally good roads at less cost. From what we have seen on the test stretches in Denmark, the 56 kg/m²* carpet in Frankfurt and the 50 kg/m²† deck on the Kirchenfeld bridge, as well as from some of the Amsterdam city streets, this is quite within the possibilities.

It is quite understandable that Public Works engineers are rather hesitant to try out any revolutionary constructions, instead of the ones which are generally accepted and found good.

All the same it would seem to be worth while to have an extensive scheme of trials in this direction. They might give us the answer much sooner than the present system, viz., waiting 20 years or more until the rubber road shows failures.

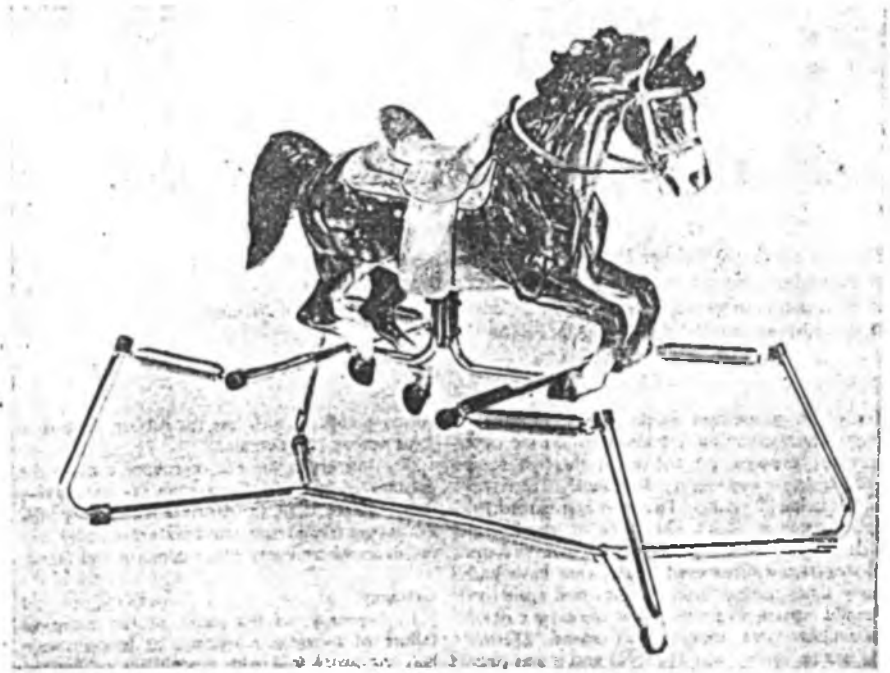


A refinement to the industrial rubber doors marketed by Langley & Co., Ltd., is this magnetic door catch. Available for both light and heavy doors the catch is particularly suitable for draughty positions or where dust extraction plant creates suction. It consists of two permanent magnets let into the rubber panels where they overlap. When the doors close, the magnets come together and hold the panels in position

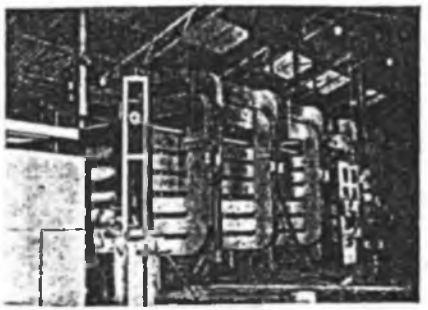


* Approximately 1" thick.

† Approximately ½" thick



A real cowboy rocking horse is now appearing in the nurseries of the United States. Cast in latex in superb detail this new pony sports a Mexican saddle and comes in three colours: chestnut, white and "palomino." An ingenious spring mounting on chrome finished steel gives the correct "bronco busting" effect for the adventurous, while for the nervous there is a safe wooden handle to hold on by. The makers, Rempel Manufacturing Inc., of Akron, Ohio, think this may be the largest hollow rubber product ever moulded in one piece



This forming and bonding plant for rubberized hair was recently completed for the firm of W. H. Paul Ltd., Breaston, at Draycott, Derbyshire. It is stated to be the first fully-automatic plant of its kind to be made in Britain



This "Flexilant" rubber grip, introduced by Rubber Bonders Ltd., Dunstable, Bedfordshire, makes an instant firm attachment on contact. It is shown here fitted to bus seating

(77)

Rubberised Bituminous Materials And Their Use In Road Construction.

By

PARKER, W.D and WALKER, W.D.C.

Journal of Applied Chemistry. 7. 1957

RUBBERIZED BITUMINOUS MATERIALS AND THEIR USE IN ROAD CONSTRUCTION*

By W. D. PARKER† and W. D. C. WALKER

The compatibility of natural and synthetic rubbers and polymers such as polyvinyl chloride with coal tar pitches and bitumens is described. The penetration/softening point and penetration temperature characteristics of a range of modified compositions are examined in relation to those of residual and blown bitumens and of coal tar pitches. A test has been devised for assessing the brittleness of bituminous materials and this is compared with the penetration, ductility and Fraas brittle point tests. Suggestions are made as to how modified tars and bitumens may be used in road construction, with particular reference to the use of tars with reduced temperature susceptibility.

Introduction

Experiments on the use of rubber/bitumen and rubber/tar compositions as binders for road construction have been carried out over a period of many years but it has not yet proved possible to arrive at a definite conclusion as to the merit of using such materials. The problem may be divided into (*a*) the preparation of rubberized bitumens and tars with modified physical properties and (*b*) the utilization of *particular* modifications in road mixes in order to adjust the properties of the mix in a desired direction.

This paper deals with the first aspect of the problem but some suggestions are made for the general lines of road experiments. The inconclusiveness of the majority of experiments hitherto reported may be attributable to (*a*) not achieving controlled modifications of the binder, (*b*) not utilizing correctly in a road mix the modified properties of a rubberized binder, or (*c*) there being no definite merit in using rubberized bitumens and tars for this purpose.

Experimental

Mixtures studied

A number of typical rubberized compositions were prepared and their basic properties measured.

(a) *Bituminous materials.*—These included:

(i) residual bitumens of differing penetration, all from the same Middle East crude oil.

(ii) blown bitumens from a Venezuelan crude oil. Residual and blown bitumens from the same source were not available but the above crude oils yield residual bitumens with identical penetration and softening point specifications. It was not possible to prepare a range of blown bitumens of differing penetration but similar penetration index and therefore the penetration of each blown bitumen was varied by cutting back with a mineral flux oil (275 sec. Redwood I at 140°F).

(iii) coal tars and coal tar pitches all prepared from the same blend of horizontal retort and coke oven tars. For convenience these are subsequently referred to as coal tar pitches.

(b) *Additives.*—The following substances were dispersed in the bituminous materials:

(i) *Carbon black.* A highly absorptive channel black.

(ii) *Asbestos.* Short-fibre Canadian asbestos, Grade 7R.

(iii) *Ground tyre tread.* Clean tyre strippings ground to pass a 30-mesh sieve.

(iv) *Smoked sheet rubber*

(v) *GR-S synthetic rubber.* General-purpose grade based on approximately 23% styrene.

(vi) *Natural latex*, alkali stabilized, solids content approximately 75%.

(vii) *Rubber powder.* Coagulated from lightly vulcanized latex (recommended by the British Rubber Development Board as a replacement for Mealorub, which is no longer available).

(viii) *Neoprene latex*, type 735, solids content approximately 36%.

(ix) *Nitrile rubber.* Butadiene/acrylonitrile copolymer based on approximately 33% acrylonitrile.

(x) *Polyvinyl chloride.* Standard unmodified resin.

(Carbon black and asbestos were included to enable a comparison to be made with the influence of typical fillers).

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* Read at meeting of Road & Building Materials Group [illegible] February, 1956

† Present address: Winn & Coales Ltd., Chapel Road, [illegible]

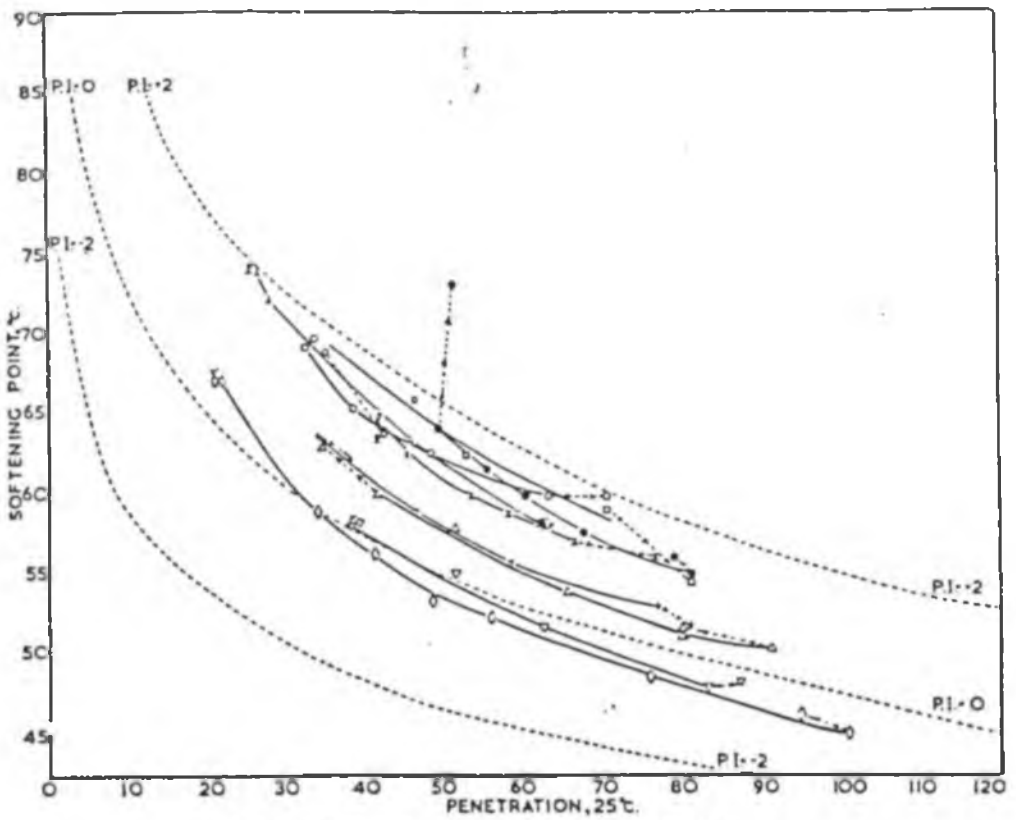


FIG. 1. *Effect of various additives on residual bitumen*

○ residual bitumen (untreated)
▽ residual bitumen + 5% carbon black
△ residual bitumen + 5% asbestos
× residual bitumen + 5% smoked sheet
– residual bitumen + 5% ground tyre tread
□ residual bitumen + 5% rubber powder
● residual bitumen + 5% GR-S
○ residual bitumen + 5% natural rubber latex solids
⊥ fluxed 75/30 blown bitumen (untreated)
– – – – P.I. = 0 penetration index lines
- - → - - → change during heat stability test

was placed in an oven at 200° for six hours. The temperature of the composition rose during this period to 180–190° and the change in penetration and softening point is shown in Figs. 1–3. It is desirable that there should be the minimum change in penetration and softening point during heating, but a movement *along* a particular line (with therefore little change in penetration index) should be taken as indicating greater stability than a movement to either above or below the line (indicating a change in penetration index).

(a) *Residual bitumen dispersions.*—Carbon black in residual bitumen leads to very little change in penetration index. Asbestos and ground tyre-tread are more effective but less so than the three forms of natural rubber and the grade of GR-S used. The latter group of materials gives lines in the neighbourhood of that produced by fluxed 75/30 blown bitumen. During the heat stability test, the natural latex dispersions creamed appreciably although they could be redispersed by considerable stirring. The rubber powder dispersions gave a somewhat greater increase in softening point than the other forms of natural rubber but they still contained incompletely dispersed particles of rubber even after mixing until the softening point reached a maximum and began to fall, and on heating to 180–190° appreciable degradation occurred. This lack of homogeneity caused considerable variations in the individual penetration readings on a particular specimen, in one case from 60 to 87, and in addition, the dispersions had unmanageably high viscosity. It was thus not possible to produce a stable dispersion with the handling

characteristics and softening point and penetration limits required for a bituminous binder. These facts help to explain the variable and unsatisfactory results which have been obtained from road experiments with this type of dispersion.

The smoked sheet mixes gave the best results in the heat stability test while there was a marked tendency for the GR-S mixes to gel strongly to a semi-infusible mass. Using Neoprene latex and polyvinyl chloride it was possible to develop a certain degree of gel structure, reflected in a rise in softening point above the residual bitumen line, but these dispersions were not stable and the compatibility is therefore designated as limited. Nitrile rubber dispersed in residual bitumen but no gel structure or increase in softening point resulted and it is therefore designated as incompatible.

(b) *Fluxed blown bitumen dispersions.*—Fig. 2 shows the characteristics of mixes made from fluxed 75/30 blown bitumen and, as before, the separation of the lines from that of the untreated base line gives a measure of the effectiveness of the additives. The properties of these mixes are also compared with those of a bitumen blown to a higher penetration index (85/40) and fluxed in a similar manner. The characteristics of these compositions and the results of the heat stability tests are summarized in Table II.

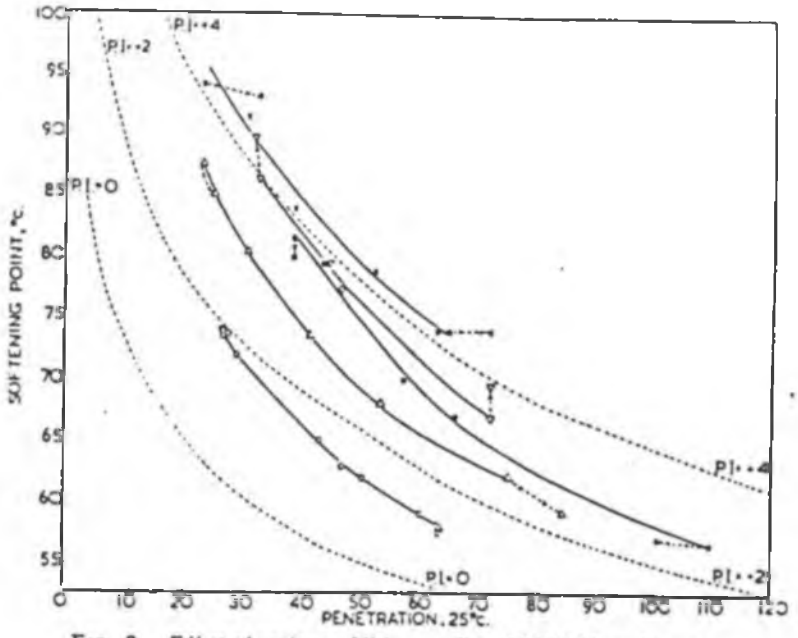


FIG. 2. *Effect of various additives on fluxed 75/30 blown bitumen*

○ fluxed 75/30 blown bitumen (untreated)
△ fluxed 75/30 blown bitumen + 5% ground tyre tread
▽ fluxed 75/30 blown bitumen + 5% GR-S
× fluxed 75/30 blown bitumen + 5% smoked sheet
● fluxed 85/40 blown bitumen (untreated)
– – – – P.I. = ± 2 penetration index lines
→ → → → change during heat stability test

Table II

Effect of 5% of additive on fluxed 75/30 blown bitumen and comparison with a more highly blown bitumen (fluxed 85/40)

Additive	Compatibility	Increase in softening point (at constant penetration), °C	Increase in penetration (at constant softening point)	Heat stability (180–190°)
Ground tyre tread	G	7–9·5	15–25	G
Smoked sheet	G	16–18	38	G
GR-S	G	12·5–16·5	29–34	G
Fluxed 85/40 blown bitumen (untreated)	—	10–15	25–38	G

G — Good

(c) *Coal tar pitch dispersions.*—Fig. 3 shows the effect of additives measured as before on a range varying from a medium coal tar pitch of softening point 55° and penetration 14, to a soft pitch of softening point 40° and penetration 98 (equivalent to a coal tar of equi-viscous temperature [e.v.t.] between 55° and 60°). Nitrile rubber gives a line in close proximity to that of untreated residual bitumen, and polyvinyl chloride one corresponding to an even higher penetration index, but the former shows good heat stability while the polyvinyl chloride dispersions on heating underwent appreciable chemical change accompanied by the evolution of hydrochloric acid, and gave hard, almost infusible residues. None of the forms of natural rubber developed a stable gel structure and there does not appear to be any promise in attempting to prepare commercial natural rubber/tar dispersions. Generally the most effective additives for

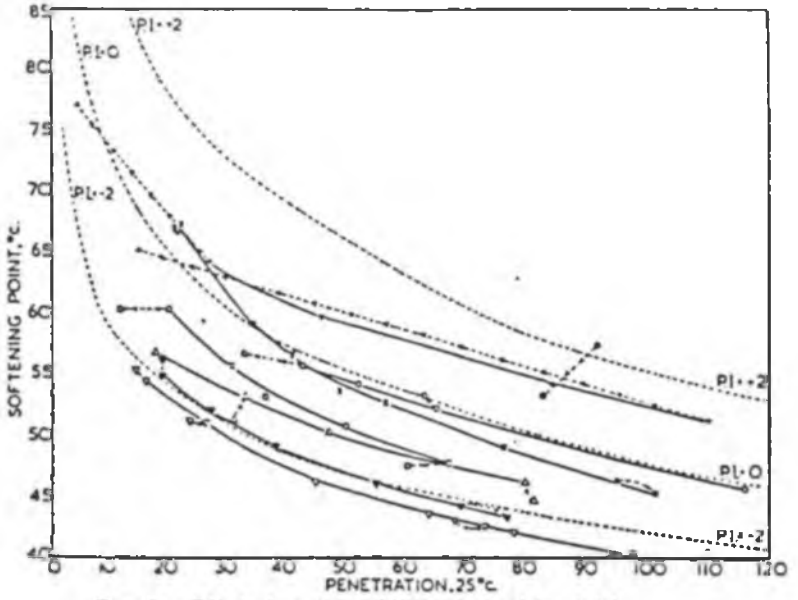


FIG. 3. *Effect of various additives on coal tar pitch*

▽ coal tar pitch (untreated)
▼ coal tar pitch + 5% carbon black
△ coal tar pitch + 5% Neoprene
□ coal tar pitch + 5% asbestos
○ coal tar pitch + 5% nitrile rubber
\+ coal tar pitch + 5% P.V.C.
× residual bitumen (untreated)
● blown coal tar pitch
– – – – P.I. = 0 penetration index lines
– → – → – → – change during heat stablity test

Table III

Effect of 5% of additive on coal tar pitch and comparison with blown pitch and residual bitumen

Additive	Compatibility	Increase in softening point (at constant penetration), °C	Increase in penetration (at constant softening point)	Heat stability (180–190°)
Carbon black	—	1	4–10	Sediments
Asbestos	—	4·5	17–29	Sediments
Ground tyre tread	I	—	—	—
Smoked sheet	I	—	—	—
Natural latex	I	—	—	—
Rubber powder	I	—	—	—
Neoprene latex	L	4–4·5	9–34	L
Nitrile rubber	G	9	30–67	G
Polyvinyl chloride	G	12–14	61–84	Unstable (jellies)
Blown pitch (Untreated)	—	16	80	Unstable
Residual bitumen	—	5·5–8	30–52	—

G — good; L — limited; I — incompatible

bitumens were found to be unstable in coal tar pitch and vice versa. Some, such as Neoprene, were moderately effective in both but not to any useful extent. An experimental blown pitch had a penetration index of more than +2 but this was found to be unstable in the heat stability test.

Penetration/temperature relationship

Consideration is now given to the relationship between the penetration at various temperatures (between 0° and the softening point) and the temperature of measurement. It was shown by Pfeiffer & van Doormal[1] that if the penetration of a bitumen were plotted on a logarithmic scale against the temperature, a straight line was obtained with a slope which is a measure of the penetration index. They also found that on extrapolating this line to the temperature of the ring-and-ball softening point the corresponding penetration was approximately 800.

Fig. 4 shows the penetration/temperature relationship of a residual bitumen, with and without additives, plotted in the above manner. The residual bitumen/rubber mixes give straight lines meeting the 800 penetration line at the softening point, the slopes of the lines being less than that of the residual bitumen and approximately the same as that of 75/30 blown bitumen but less than that of 85/40 blown bitumen. The line for the 75/30 blown bitumen/smoked sheet mix is, however, approximately parallel to that of the more highly-blown bitumen. The only plot which does not meet the 800 penetration line at the softening point is that of the 75/30 blown bitumen/smoked sheet mix, which crosses this line 7° below the softening point. The slope of a residual or blown bitumen plot will depend on the penetration of the bitumen as there is a tendency for the penetration index to increase with decreasing penetration but this effect is relatively small.

Fig. 5 shows results for a coal tar pitch, with and without additives, examined in a similar manner and compared with residual bitumen. The untreated coal tar pitch gives a straight line meeting the 800-penetration line at the softening point and the slope of the line is, of course, greater than that of the residual bitumen. The coal tar pitch mixes containing an additive do not, however, give a straight line and there is a continuous change in the gradient throughout

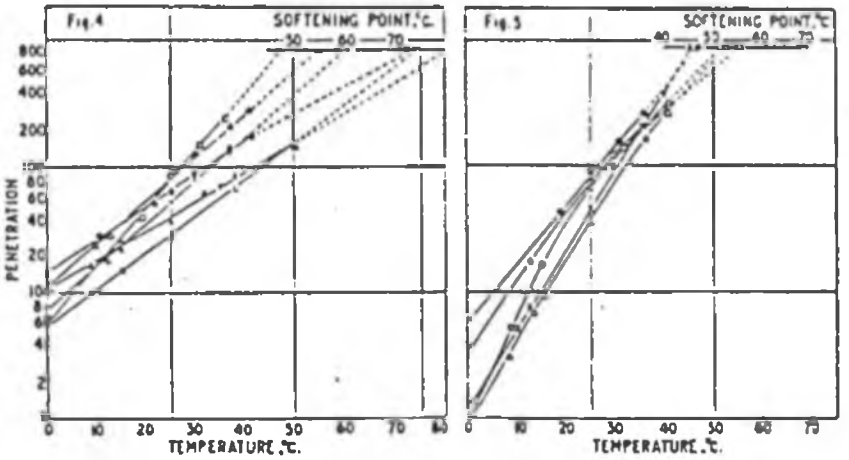


FIG. 4. *Log penetration/temperature relationship of treated and untreated bitumens*

□ residual bitumen (untreated)
△ residual bitumen + 5% GR-S
+ residual bitumen + 5% natural rubber latex solids
○ 75/30 blown bitumen (untreated)
● fluxed 75/30 blown bitumen + 5% smoked sheet
× 85/40 blown bitumen (untreated)

FIG. 5. *Log penetration/temperature relationship of treated and untreated coal tar pitch (compared with untreated residual bitumen)*

× coal tar pitch (untreated)
△ coal tar pitch + 5% asbestos
□ coal tar pitch + 5% polyvinyl chloride
○ coal tar pitch + 5% nitrile rubber
● untreated residual bitumen

the whole temperature range. In the case of the nitrile rubber mix, the slope is approximately equal to that of the untreated coal tar pitch at the lower temperatures but decreases progressively towards the softening point. With the polyvinyl chloride composition, the slope at the lower temperatures is *greater* than that of the untreated pitch reflecting an *increased* temperature susceptibility, but at temperatures of 25° and above, the gradient is *less* than that of the untreated pitch. The mix containing asbestos also gives a line which is not straight at the higher temperatures. Rubberized coal tar pitches can thus exhibit a decrease in temperature susceptibility with increase in temperature.

Low-temperature brittleness test

Consideration has so far been given to variations in consistency between 0° and the softening point as measured by the penetration needle, but the penetration measurement is not necessarily an index of brittleness at a particular temperature. The authors were interested in measuring the brittleness of different compositions when studying the low-temperature characteristics of compounds used for sealing joints in concrete pavements. For this purpose an extension test is carried out in which the compound is poured between two concrete blocks which are then pulled apart at a low speed, usually 0·125 in. per hour, at the test temperature. The performance of a joint, sealing compound under such conditions is dependent on (*a*) its adhesion to the concrete and (*b*) its internal cohesion, inadequacy of which can result in fracture.

Having available an apparatus for carrying out this extension test, it was possible, by eliminating adhesion failures, to study the cohesive quality of various compositions. The method used was to pour the composition, heated to a temperature at which it was reasonably fluid, into a space between two concrete blocks so as to give a test piece, 2 in. × 1 in. × ½ in. (Adhesion failures were avoided by the use of special primers, heating the concrete blocks before pouring, etc. and all results where adhesion failure occurred were ignored.) The specimens were then mounted in the extension machine in a chamber, thermostatically conditioned at $-9° \pm 0{\cdot}5°$, consisting of a stout copper box surrounded by the evaporator coil of a deep-freeze refrigerator unit mounted underneath. The thermostat control element was placed adjacent to the test specimen. The blocks were then separated at a uniform rate of 0·125 in. per hour for 2 hours, thus giving a 50% extension of the specimen. It was found that the specimen either extended by the full amount or fractured at an early stage and this appeared to give the basis for a simple pass or fail test. Fig. 6 shows the appearance of specimens before and after 50% extension and Figs. 7–9 the apparatus used.

In determining the brittleness of a particular type of composition, a series of samples was taken of the same basic composition but of differing penetration (e.g., a range of residual bitumens incorporating a fixed percentage of a given additive). Specimens of decreasing penetration in each series, made by blending two compositions in different proportions, were extended under the standard conditions until it was found that instead of extension, brittle fracture occurred: the lowest penetration (at 25°) where fracture at −9° did not occur was noted and this is subsequently referred to as the ' critical penetration '. Fig. 10 shows the results for residual bitumen, residual bitumen with 4% smoked sheet and fluxed 75/30 blown bitumen, the respective ' critical penetrations ' being 85, 62 and 50. Fig. 11 depicts the same treatment for a range of coal tar pitches untreated and also with 4 and 8% of nitrile rubber. In this case the ' critical penetrations ' were 173, 124 and 66 respectively.

The question then arises as to whether these differences in ' critical penetration ' at 25° merely stem from differences in penetration index or whether they also reflect a property of which the determination of the penetration at the temperature of brittleness is not a measure. An attempt to answer this was made by taking the various compositions with the ' critical penetration ' in each series and plotting the log penetration/temperature relationship (Fig. 12). The lines were extrapolated from 0 to −9°, the former being the lowest temperature at which it was possible to make a significant penetration measurement, thus enabling a comparison to be made between the respective estimated penetrations at the temperature of the brittleness determination. The fact that the lines were found not to meet at −9° indicates that penetration measurements do not enable a direct comparison to be made of the brittleness of different compositions.

It is concluded from Fig. 12, with regard to extrapolation of penetration values to −9°, that (*a*) untreated coal tar pitch has a lower penetration at −9° than untreated residual bitumen with

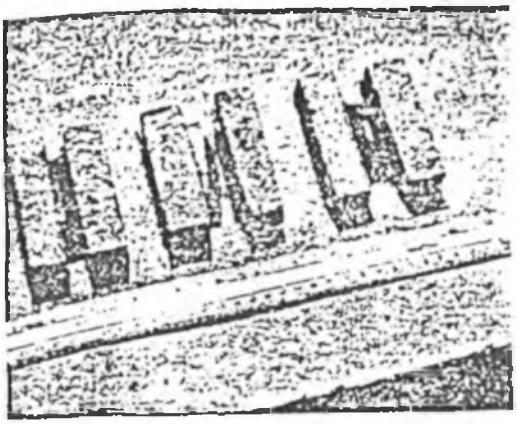


FIG. 6. *Brittleness test specimens before and after 50% extension at −9°*
(the centre one shows brittle fracture; that on the right no fracture)

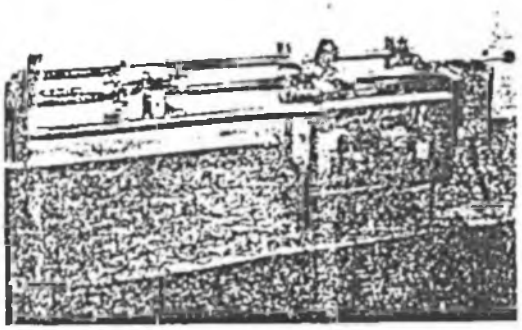


FIG. 7. *Extension machine with specimen in position*

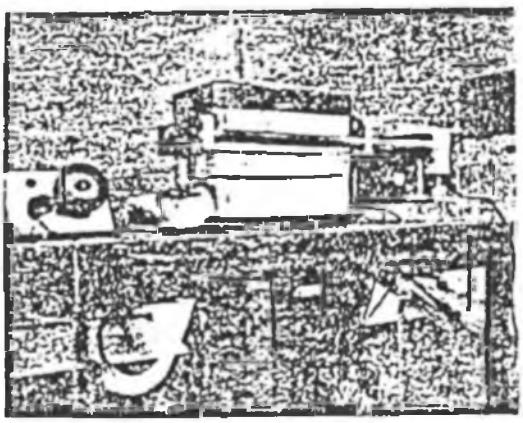


FIG. 8. *General view of extension machine and refrigerator unit*

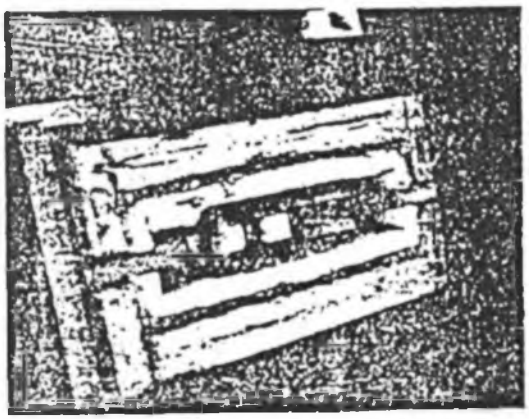
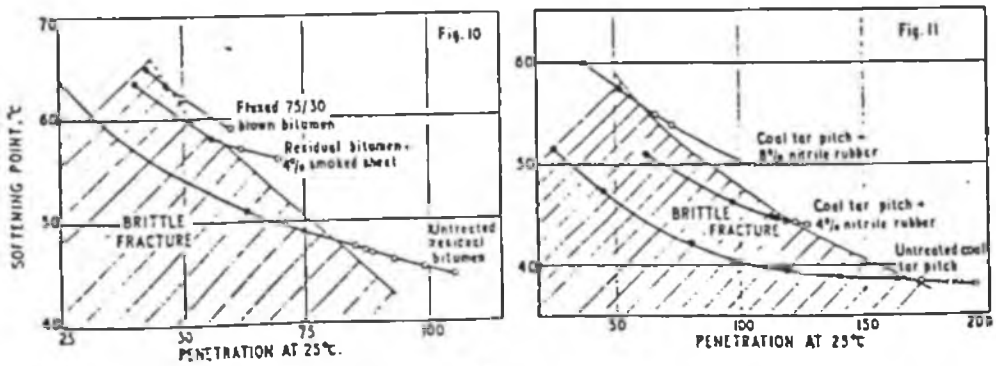


FIG. 9. *Plan view of an extended specimen in position in refrigerated chamber*
(the top clamps have been removed)

the same degree of brittleness. Alternatively, untreated coal tar pitch is less brittle than untreated residual bitumen of the same penetration at −9°; (*b*) rubberized residual bitumen (4% smoked sheet) and untreated fluxed 75/30 blown bitumen both have a higher penetration than untreated



FIGS. 10–11. *Results of brittleness test at −9° on (Fig. 10) treated and untreated bitumens and (Fig. 11) treated and untreated coal tar pitch. (The shaded area represents compositions with [illegible] penetration.)*

● specimen fractured
○ specimen extended without fracture. Extension 0·125 in. per h. at −9°

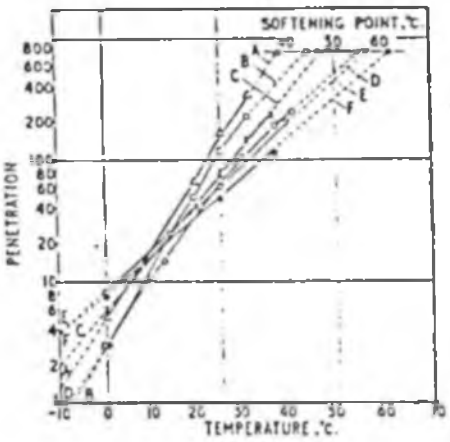


FIG. 12. *Log penetration–temperature relationship of compositions with the 'critical penetration' in the brittleness test at −9°*

- coal tar pitch (untreated) (A)
- coal tar pitch + 4% nitrile rubber (B)
- coal tar pitch + 8% nitrile rubber (D)
- residual bitumen (untreated) (C)
- residual bitumen + 4% smoked sheet (E)
- fluxed 75/30 blown bitumen (untreated; (F)

residual bitumen with the same degree of brittleness. Alternatively, rubberized residual bitumen and blown bitumen are more brittle than untreated residual bitumen of the same penetration at −9°; (c) rubberized coal tar pitch (4 and 8% nitrile rubber) has a lower penetration than untreated coal tar pitch with the same degree of brittleness. Alternatively, rubberized coal tar pitch is less brittle than untreated coal tar pitch of the same penetration at −9°.

It thus follows that the advantages of increasing the penetration index by treatment with rubber or air-blowing are offset somewhat in the case of bitumen, by an increase in brittleness, while the similar modification of coal tar pitch is accompanied by a decrease in brittleness.

Discussion

Significance of brittleness test and comparison with other tests

The most commonly used determinations of brittleness of bituminous materials are the ductility and Fraas brittle point tests. In the former, a briquette with a waist 1 cm. square is extended at a uniform rate of 5 cm. per minute at 25° and the extension occurring before fracture is noted. The test may be carried out at other rates of extension and temperatures. In the Fraas test, a layer of material 0·5 mm. thick is spread on a steel plaque which is repeatedly flexed under standard conditions at a decreasing temperature until brittle fracture occurs, when the temperature is known as the Fraas brittle point. Saal has pointed out[3] that brittle fracture occurs in the ductility test if the stiffness exceeds a certain value and by repeating the test at decreasing temperatures a 'critical temperature' of brittle fracture can be determined. The object of the present test is to determine a 'critical penetration' corresponding to brittle fracture at a standard temperature. In the standard ductility test, the energy of stretching causes a rise in temperature of the specimen and this effect was avoided by using a very low rate of deformation. The possibility of thixotropic breakdown which may occur with both the ductility and Fraas tests was also minimized and the effects of repeated flexing prior to fracture which occur in the latter were avoided. The Fraas test has been criticized on grounds of limited reproducibility and sensitivity to film thickness which is difficult to control with the necessary degree of accuracy. With rubberized materials, the difficulty in preparing satisfactory specimens is increased. The present test cannot be directly compared with all aspects of these two standard tests but it has the merit that it enables the result of a 'pass' or 'fail' brittleness test at a low temperature to be expressed in terms of a parameter which can be determined with precision, the penetration at 25°. It is not considered that materially different results would have emerged if ductility briquettes had been used in these experiments.

Other than by studying its bearing on the behaviour of joint-sealing compounds no attempt has so far been made to correlate the result of this test with road performance.

Use in road construction

At present, the only established outlet for rubberized bituminous materials is for sealing compounds for joints in concrete pavements. The compositions employed are generally based on

(*a*) blown bitumen and rubber or (*b*) rubberized coal tars, where the use of bitumen is precluded, e.g., in areas subject to fuel spillage. The requirements for joint-sealing compounds are well known and will not be considered here.

The use of a rubberized composition as a binder in a flexible pavement would appear to be most advantageous where reduced temperature susceptibility is desirable and untreated road tars and bitumens have been found functionally inadequate. There have been frequent references to the improved flexibility, elasticity, etc. imparted by the presence of rubbers and rubber-like substances dispersed in tars and bitumens. Taking the evidence at present available, the effects described in this paper appear to be the essential ones on which road experiments may at present be based, and two suggestions are made below as to how the principles under consideration may be of value in planning road experiments.

Mastic asphalt

Considerable difficulties have been experienced in recent years with cracking at the joints when asphalt has been laid over a concrete foundation and it has been proposed to use mastic asphalt based on rubber/bitumen compositions to give greater flexibility in the asphalt, and the approach outlined above may prove to be of assistance in developing suitable asphaltic cements. Comparable load-bearing qualities would be expected to result from the use of cements with the same softening point as that of the residual bitumen normally specified, and the incorporation of different proportions of rubber additives would enable the penetration and low-temperature flexibility to be increased to varying degrees. The relatively high mixing temperatures required for mastic asphalt necessitate particular attention being given to the thermal stability of the compositions in question. It may be found, therefore, that the best results can be obtained with blown bitumens or blends of blown and residual bitumens.

Tar carpets

In the immediate future, the most important outlet for rubberized binders may prove to be in tar carpets. There is a demand for improved tar carpets in both road and airfield construction, where oil spillage limits the suitability of asphalt. Hitherto, the use of tar carpets has been restricted by (*a*) the relatively high rate of weathering of the binder, and (*b*) insufficient stability.

Substantial progress has been made in dealing with the former limitation by the use of close-textured surfacings such as Dense Tar Surfacing where the binder does not appear to weather at a significant rate but the stability problem has not yet been solved. The consistency of road tars is usually specified by reference to the equi-viscous temperature (e.v.t.) and this is related to the maximum working temperature of a road surfacing in which it is incorporated. The following figures show the e.v.t. of compositions considered earlier in this paper:

	Softening point, °C	E.v.t., °C	Difference between e.v.t. and softening point, °C
(i) Untreated coal tar pitch (of ' critical penetration ' on brittleness test)	38·5	58	19·5
(ii) Coal tar pitch + 4% nitrile rubber (of ' critical penetration ' on brittleness test)	44·5	73	28·5
(iii) Coal tar pitch — 5% polyvinyl chloride	56	90	34

Compositions (i) and (ii) had the same degree of brittleness at −9° and the latter had a softening point 6° higher but its e.v.t. was 15° higher, thus confirming the previous observation that the reduction in temperature susceptibility is most marked at higher temperatures. For standard road tars, the difference between the e.v.t. and softening point is usually 18–20°, while with the composition containing 4% nitrile rubber it is 28·5° and with composition (iii) containing 5% of polyvinyl chloride, the difference was as great as 34°. The reduced temperature susceptibility of such modified road tars should enable high-stability tar carpets to be produced without detriment to their other properties.

Acknowledgments

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THE DETERMINATION OF 7-OXOCHOLESTEROL IN WOOL WAX

By A. H. MILBURN and E. VERNON TRUTER

A method for quantitative determination of 7-oxocholesterol is described, and used for examining a number of wool waxes from different sources. The amount of free 7-oxocholesterol varies between 0·7 and 2·8%, and in addition 0·2—3·9% occurs in the form of esters. Cholestenone is present only in traces. It is shown that at least part of the 7-oxocholesterol arises by autoxidation.

Introduction

The identification of 7-oxocholesterol in wool wax has been reported by Panizo & Bilbao[1] and by Milburn & Truter.[2] The present paper sets forth a quantitative method, of fairly general applicability, for the determination of 7-oxocholesterol in naturally occurring mixtures of sterols. The method is based on two observations: (1) that 7-oxocholesterol forms an insoluble complex with digitonin and (2) that it has a chromophore which absorbs in the region of 240 mμ. The principle of the method is as follows. After precipitation and weighing the digitonide from a known weight of the sample, a small amount is made into a standard solution and the optical density over the range 230—250 mμ measured. If 7-oxocholesterol provides the only chromophore in the digitonide there will be an absorption maximum at about 240 mμ.

If A is the maximum optical density of the digitonide solution, E the specific extinction coefficient of 7-oxocholesterol, and d the thickness of the optical cell, then the concentration (c, g./l.) of 7-oxocholesterol in the digitonide solution is given by:

$$c = \frac{A}{E.d} \qquad \ldots\ldots(1)$$

If Qg. of sample gives Dg. of digitonide and mg. of the latter is made into a standard solution of 50 ml., the fraction (f) of 7-oxocholesterol in the original sample is given by the expression:

$$f = \frac{c}{20} \times \frac{D}{m} \times \frac{1}{Q} \qquad \ldots\ldots 2)$$

Combining equations (1) and (2), and inserting the numerical values: $E = 32{\cdot}3$ and $d = 1$, we obtain:

$$\% \text{ of 7-oxocholesterol} = \frac{0{\cdot}155\,A.D}{m.Q} \qquad \ldots\ldots(3)$$

Formation of digitonides

The amount of material that forms a complex with digitonin may be determined by the original method of Windaus[3] or by the method of Gardner *et al.*[4] In Windaus' method, a solution

Rubberized roads in Queensland

Difficult conditions of climate and terrain have made Australian road engineers particularly interested in the high performance of rubberized bitumen. This report describes recent work in Queensland

To supervise the laying of 12 test sections of road in four areas spread over 1,300 miles of coastline, all in a period of eight days, calls for rapid travelling and first-class organization on the working sites by the engineers and staff concerned. This whirlwind tour was recently made in Queensland, that vast state occupying the north-east corner of the Australian continent, by Mr. Douglas, the Board's Australian manager.

Queensland is one of those fortunate countries with more than its fair share of natural gifts. Twenty-three million sheep and six million head of cattle graze on its plains; sugar cane grows on 7,000 farms along the northern coast. Soil and climate are suitable for rice, coconuts, rubber and jute. Add that it has great mineral wealth, including coal, uranium and bauxite, and it is not difficult to understand why the population is increasing and why roads figure prominently in the development projects.

Rubber for all-weather roads

Providing adequate all-weather roads at economic costs is not easy in a lightly populated country, and along the northern coastal belt of Queensland the problem is complicated by the near-tropical conditions with extreme temperatures, high humidity and an extremely heavy rainfall. It was with these problems in mind that the Queensland engineers turned to rubberized bitumen, a material with something extra in the way of performance as shown by the favourable results obtained with it in the southern states of



Fig. 1. *Rubberized bitumen being laid by the Ayr Shire Council*

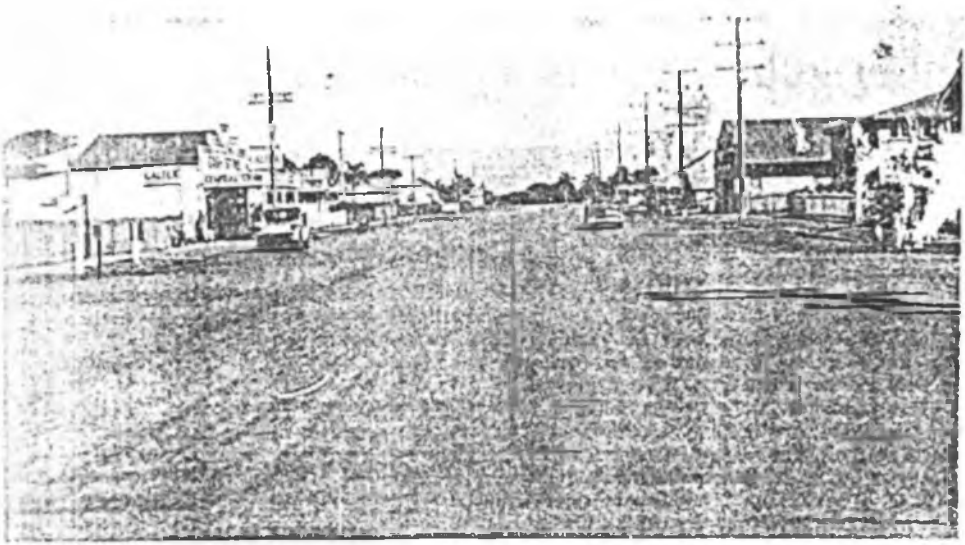


Fig. 2. *The finished road surface at Mackay*

Tasmania, Victoria, South Australia and Western Australia.

The four centres decided upon for trials were Brisbane, Mackay, Ayr and Cairns, all on the east and northern coasts of the state. In each case surface dressings were laid, that is, rubberized bitumen was sprayed on to the existing road surface or prepared pavement, coated with grit and then rolled. This provides a good wearing and watertight surface and, in addition, possesses marked elasticity enabling it to conform to minor movements of the road base without cracking.

The engineers in the four areas concerned had different, though related, road problems. At Brisbane the interest was in finding a binder which would seal road surfaces affected by structural failure. The Mackay City Council wanted to reseal cracked and badly pitted surfaces and therefore required a binder with exceptional adhesive qualities. At Townsville, in Ayr Shire, the coating of a cracked concrete surface was the problem, while at Cairns interest was centred on long wearing life and ability to stand up to shear stresses.

The blending of rubber into bitumen by heat agitation is a straightforward job, but, all the same, when trying out a new process for the first time, it is no bad thing to have someone available who knows the ropes and can give a few hints and tips. The Queensland engineers, therefore, welcomed the presence of the Board's manager, [illegible] experienced in the preparation of rubberized bitumen and has seen large quantities of it laid on Australian roads and airports.

Laying experimental sections

Work started at Mackay on September 12, under the control of the City Engineer, Mr. J. Abbiss. Two road sections were laid with rubberized bitumen and one with ordinary bitumen to act as a control for comparison of behaviour. The cracking in the surfaces treated was noted as "severe" but, all the same, the indications were that the rubberized bitumen would provide a good seal. The temperatures of the three road surfaces were given as 100 to 108 F., which by English standards is definitely hot.

The next job was further up the coast at Townsville, in Ayr, and here three rubberized and two non-rubberized sections were laid under the direction of Mr. D. Haigh, the Shire Engineer. When work was in progress the Chairman of the Shire Council, E. W. Ford, visited the site, an indication of the importance attached to communications in this area. Of the cracked concrete surfaces which were sealed certain areas were too far gone for even rubberized bitumen to cure the trouble, and it was clear that the effectiveness of the treatments could only be judged where conditions could be described as "poor," but not where breaking-up was in evidence. As the Board's literature emphasizes, rubberized bitumen will do a good job, but it won't work miracles.

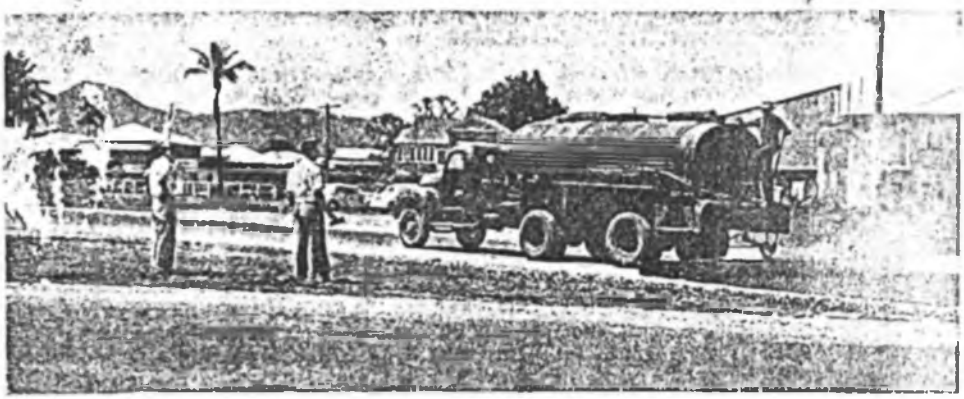


Fig. 3. *Rubberized bitumen being laid down at Cairns*

Cairns was next on the list, and the most northerly of the cities visited. One stretch of rubberized bitumen and one of ordinary bitumen were put down by Mr. Haussmann, the Deputy City Engineer, and the only criticism of the work was that, using a spray bar 24 ft. wide, a somewhat uneven coverage resulted owing to the camber of the road affecting the distance of the jets from the road surface. In the U.K. our heavily trafficked roads seldom allow for the use of these very wide bars.

The round of road layings ended at Brisbane on September 19, when two lengths of street were each given a double rubberized surface dressing. The Brisbane authorities were, as previously mentioned, anxious to find a binder which would seal surfaces affected by structural failure, but in one of the streets selected the construction had failed so badly along part of its length that sections of it could be seen moving under load. It was pointed out that no re-sealing —even with rubberized bitumen—could deal effectively with such conditions, and an alternative section was found where the failure was rather less pronounced.

In each rubberized section laid in the four areas the bitumen used was 80/100 Penetration supplied by Queensland Oil Refineries. To this was added 2½% by weight of Pulvatex (unvulcanized rubber powder). To secure a satisfactory spraying viscosity the rubberized bitumen was then cut back, generally with about 10% of power kerosene or with about the same quantity of mixed power kerosene and road oil or fuel oil. Spraying in all cases was with the slotted Copley jet commonly used in Australian road work.

The intense interest in the experiments and the conviction that they would be successful are typified by the statements of the engineers concerned, as published in their local newspapers.

In the Cairns *Post*, Mr. G. Haussmann, the Deputy Engineer, said: "50% longer life might be obtained for only 15% cost." He added that the most important feature of the new process was that the binder would retain its ductility for a longer period than ordinary bitumen. As a result the new surface was likely to remain sound for much longer.

Mr. J. Abbiss, Mackay City Engineer, remarked on the low "wipe off" of aggregate on the rubberized section as compared with the control sections of normal bitumen, and has ordered further quantities of rubber powder.



Fig. 4. *Mr. Stocker of the Brisbane City Council examines the "rubbery" qualities of rubberized bitumen*

Chemists of Brisbane City Council laboratories state that their field tests on sub-standard pavements appear to be already showing the superiority of rubberized bitumen.

The Ayr *Advocate* quoted Mr. D. Haigh, the Shire Engineer, as saying he was "most impressed with the unusual quality of the rubberized bitumen, notably its elasticity and its strong power of adhesion." The areas chosen for the test work were designed to obtain a quick result and, he stated, if this should be available, he visualized a considerable extension of road work with this material. His staff experienced no difficulty in the preparation of the rubberized bitumen.

This article is based on information supplied by our Australian manager, Mr. Neil Douglas.

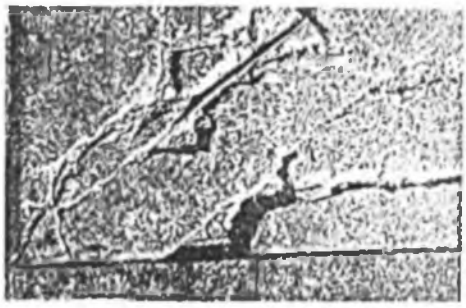


Fig. 5. *Even rubberized bitumen can do nothing for this surface. It is a case for complete reconstruction*

ANOTHER RUBBER LIFERAFT SAVES 17 SCOTS SAILORS

A DRAMATIC incident, which involved the loss of the 274-ton *Freya*, occurred soon after 4 o'clock in the morning on Friday, January 9.

In complete darkness under gale force 10 (60-mile an hour) conditions a freak wave struck



Fig. 1. *Survivors from the "Freya" coming ashore at Invergordon. They sang rock 'n' roll during their five hours adrift in the liferaft* (*Courtesy*—Daily Express)

her on the port quarter and she heeled to a 45-degree angle. Two further waves followed in rapid succession, sending the *Freya* right over on to her side and in 15 minutes the vessel disappeared beneath the waves. Meantime, with the ship lying almost horizontal and all lights out, the bosun, who was on the upper deck, scrambled aft and, assisted by several of the seamen, freed the 12-man liferaft and launched it overboard. The chief officer attempted to get out the lifeboats but this was found to be impossible. Seventeen members of the 20-man crew leapt on to the canopy of the raft. The captain, who was not seen after the first wave struck, and two seamen, however, went down with the ship.

The survivors manoeuvred beneath the canopy into the raft and, despite the fact that some of the men were naked and others were only clad in underwear and pyjamas, the chief engineer stated that once they were under the canopy they were reasonably warm.

So rapid was the incident that no radio distress signal could be sent out. Fortunately, some five hours later a Belgian trawler, *St. Jan Berchmans*, was in the vicinity and the distress signals carried on the liferaft were let off and sighted despite the raging blizzard. The trawler hove to alongside the liferaft and took off the 17 survivors and was also able to recover the raft.

One hundred and seven lives have now been saved by this type of liferaft, say the manufacturers, Elliot Equipment, Ltd., Slough.



Fig. 2. *The raft, an Elliot 12-man "Skipper," aboard the "St. Jan Berchmans"* (*Courtesy—Associated Newspapers, Ltd.*)

(66)

(87)

Some Viscous And Elastic Properties of Rubberised Bitumens.

Smith, L.M

Journal of Applied Chemistry
10, July 1960.

Catalysts of the Fischer–Tropsch type (Expt. 4–6) show a higher selectivity than that of nickel-on-kieselguhr; the selectivity is, however, not improved by addition of calcium hydroxide (Expt. 9). The presence of small amounts of water promotes considerably the formation of glycerol at the expense of propanediol (Expts. 7 and 8), which might be due to a primary hydrolytic splitting of sucrose into monose molecules; the total conversion is little affected by the presence of water.

It is noteworthy that the results of hydrogenation experiments in which both the temperature and the reaction time were varied are represented by a single hyperbola in the triangular diagrams in Figs. 3 and 4. This applies to experiments with nickel-on-kieselguhr in the presence of 3·5% of $Ca(OH)_2$ (Expts. 2 and 3) and those with nickel–thoria on kieselguhr (Expts. 4–6).

(2) *Experiments with metal oxide catalysts* (Figs. 5 and 6)

Promising results were obtained in the hydrogenation of sucrose with copper chromite catalysts, activated with 10 mol.-% of magnesium oxide (Expts. 10 and 11) and particularly with 10 mol.-% of beryllium oxide (Expts. 12–14). Nearly 80% yields of distillable polyalcohols were obtained and the proportion of glycerol in the reaction products was high (cf. Figs. 5 and 6). In Expt. 14 considerable amounts of sorbitol appeared as a crystalline mass in the reaction product, which demonstrates the mild character of the copper–beryllium chromite catalyst applied.

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SOME VISCOUS AND ELASTIC PROPERTIES OF RUBBERISED BITUMENS

By L. M. SMITH

The simultaneous changes in the viscous, elastic, and brittle properties that result from the addition of rubber to bitumen have been investigated for several different types of rubber and bitumens ranging in hardness from 170 penetration to 55 penetration. The results show that the changes in viscosity and low-temperature extensibility are due, in the main, to the molecular (or near molecular) dispersion of rubber in the bitumen. For a given bitumen these changes are linearly related both to each other and also to changes in softening point, thus giving a simple method of assessing the relative merits of different types of rubber. It is shown that sulphur, added to latex or present in a vulcanised rubber, causes a rapid breakdown of the rubber when it is heated with bitumen. An equi-viscous basis is suggested for the characterisation of rubberised bitumens.

Introduction

The major changes in physical properties, brought about by blending small quantities of natural rubber with bitumen, are in viscous and brittle properties although claims have been made of improvements in adhesion, resistance to weathering, etc.[1] The addition of rubber usually increases the viscosity of the binder and decreases its brittleness.[2–8] These effects can be achieved separately by the choice of harder or softer grades of bitumen, respectively, but the addition of rubber produces them both simultaneously. That these improved properties of the binder are conveyed to the road surfacing material as a whole has been shown by Mason *et al.*[6] working with sand asphalts and by the Road Research Laboratory with mastic asphalts[9, 10] and it is this combination of properties resulting from the use of rubberised binders which would appear to be important in providing increased durability of road surfacings.

The work described here has been designed to provide data of the changes in viscosity resulting from the addition of rubber to bitumen and to examine these changes in relation to simultaneous changes in brittleness and elastic properties. One of the objects of this investigation was to examine possible methods of assessing the relative merits of various types of rubber for use in preparing rubberised bitumens and of characterising the products obtained.

It is recognised, however, that the real value of any road binder can only be obtained from full-scale road experiments such as those which have been laid as part of a programme of co-operative research between the Natural Rubber Development Board and the Road Research Laboratory.[11]

Experimental

Materials

(a) *Bitumens.*—Three bitumens ranging from 170 penetration to 55 penetration were used. They were all from Middle East crude oils.

(b) *Rubber.*—Three forms of natural rubber were extensively studied. These were rubber latex, an unvulcanised powder (Pulvatex) and a vulcanised powder (Harcrumb). Other types investigated were a lightly vulcanised powder (Rodorub), ground tyre scrap, natural rubber latex to which had been added dispersed sulphur, and an unvulcanised synthetic rubber powder (Rubarite). Details of the sieve gradings, non-rubber constituents, etc., for each type of rubber are given in Table I.

Table I

Composition of rubber samples used

Rubber	Sieve analysis % by wt. retained on passing						Combined S, %	Non-rubber content, %	Notes
	10 mesh	20 mesh	40 mesh	60 mesh	100 mesh	100 mesh			
Latex	—	—	—	—	—	—	—	~40	Normal 60% rhc ammonia stabilised.
Pulvatex	—	—	14	11	75	—	—	48	Filler: diatomaceous earth
Harcrumb	—	45	38	5	2	—	2·23	3·67	
Latex–sulphur	—	—	—	—	—	—	—	49	15% of S by weight of rubber added as a dispersion in water.
Rodorub	—	15	53	29	3	—	0·29	24	
Ground tyre scrap	—	4	58	23	15	—	1·5	35	Carbon black 29%; ash 4%
Rubarite	—	—	9	9	72	10	—	76	Synthetic rubber, GR-S

Preparation of rubberised bitumens

Samples with rubber in powder form were prepared as follows. Five hundred g. of bitumen were weighed into an 800-ml. beaker and heated to 170° in an oil bath. The appropriate quantity of rubber powder was stirred into the bitumen, with agitation of the mix such that there was complete mixing of the components without drawing air into the sample. Heating and agitation were continued for a specified time and then portions of the mixture were placed in tins of sizes to contain the appropriate amounts for the various tests, so avoiding undue extra heating of the material for the preparation of test samples.

When the rubber was in latex form the above procedure was adapted as follows. The bitumen (500 g.) was placed in a 1-litre beaker to allow for any foaming that might occur due to the water in the latex. A silicone anti-foaming agent (2% solution of Silicone Antifoam A in carbon tetrachloride) was also added (20 p.p.m. of bitumen) and the required quantity of latex was added in five separate portions with agitation between each addition.

With all types of rubber except the latex–sulphur mixtures the periods of heating employed in the preparation of samples were 1 and 4 h. With latex–sulphur the rubberised bitumen was so highly gelled after 1-h. heating that agitation with a normal laboratory paddle stirrer was impossible and sampling was impracticable. The first sample was therefore taken after 2 h., when the gel had broken.

Samples of each of the bitumens were also heated for 1 and 4h. at 170° for direct comparison with the rubberised materials.

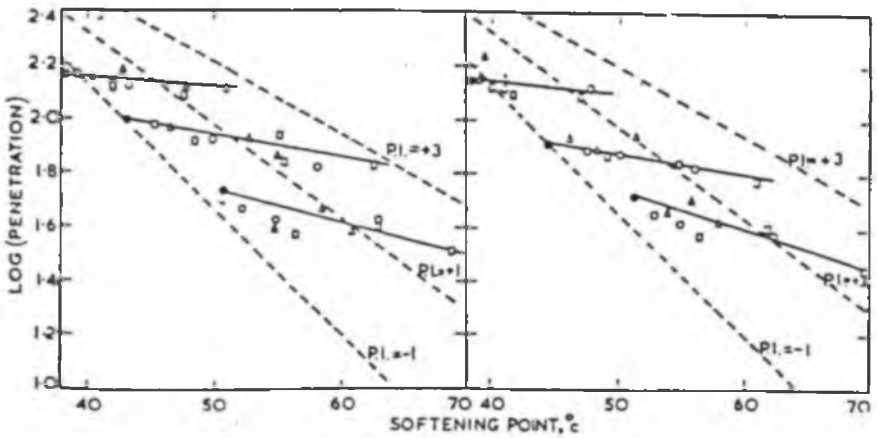
With latex, Pulvatex and Harcrumb, rubberised blends were prepared with three bitumens, soft (170 pen), medium (120 pen) and hard (55 pen), each at three concentrations of rubber—2%, 4% and 6% by weight of the final mix in the case of Pulvatex and Harcrumb mixes, and 1%, 2% and 4% for the latex mixes. With the other types of rubber, rubberised samples were prepared only with the medium bitumen and at a single rubber concentration, 4% for Rodorub, tyre scrap and Rubarite mixes, and 2% for latex–sulphur mixes.

Test methods

(1) *Penetration and softening point*

Needle penetration and softening point tests were made on all materials. The tests were carried out according to the standard procedures of I.P. 49/46 and I.P. 58/46. Many of the materials tested were heterogeneous and contained visible particles of rubber; such materials sometimes gave considerable scatter of individual results in the penetration test and, in these cases, more than three penetrations were made and a mean value obtained. With most materials, however, the scatter of penetration values was inside the limits specified in the standard. Some difficulties were experienced in the preparation of softening point samples from the more heterogeneous mixes since they did not flow evenly and could not be cut cleanly with a hot knife when removing the excess binder. However, the repeatability of results in the softening point test were all within the specification limits of $\pm 0{\cdot}5$°c.

The penetration and softening point data for latex, Pulvatex and Harcrumb mixes are plotted in Figs. 1 and 2. The outstanding feature is the linear relationships which hold between decrease in log(penetration) and increase in softening point; these depend only on the base bitumen and are independent of the type and concentration of rubber. A direct comparison of the effects of the different types of rubber can therefore be made by plotting either decrease in log(penetration), or increase in softening point, against rubber content for each base bitumen. Fig. 3 shows such a plot of increase in softening point versus rubber content for the three base binders at each period of heating.



Penetration–softening point relationships for samples heated for (Fig. 1 left) 1 *h.*, (Fig. 2 right) 4 *h., at* 170°

● bitumen ○ bitumen + latex
□ bitumen + Pulvatex △ bitumen + Harcrumb

To a first degree of approximation the results for latex and Pulvatex mixes are the same and there is a roughly linear relationship between increase in softening point and rubber content. At the 4% rubber level the increase in softening point for both latex and Pulvatex mixes, with all bitumens, is 11±2°, only one point, latex–medium bitumen after 1-h. heating, being outside this range. This similarity is to be expected since Pulvatex is prepared directly from latex with only the addition of a filler, and independent tests have shown that the maximum increase in softening point, due to 4% by weight of filler, is less than 1°c.

The Harcrumb mixes show markedly different behaviour: the increase in softening point at a given rubber concentration varies both with the base bitumen and the time of heating. Qualitatively, the variation with the hardness of the base bitumen is the same for both heating periods, and indicates real differences in the initial rates of dissolution of the rubber in the various bitumens. This is possibly due to the greater swelling of the rubber particles in the softest bitumen. An experiment was made in which 4% by weight of Harcrumb was stirred into a bitumen at the lowest practicable temperature, agitation being kept to a minimum consistent with dispersion of the rubber throughout the bitumen; the subsequent rise in softening point was found to be 1°c. It thus appears that the increase in softening point is primarily dependent on the breakdown and the resultant dissolution of the rubber and is not greatly affected by the presence of undissolved rubber. Thus Harcrumb shows a much more rapid breakdown than either latex or Pulvatex: a possible reason for this is that the sulphur in the vulcanised Harcrumb increases the rate of breakdown of the rubber. Support for this last hypothesis is given by the results for the Rodorub and latex–sulphur mixes. Fig. 3 (d) shows clearly the intermediate position of Rodorub (0·3% of combined sulphur), between latex (0% sulphur) and Harcrumb (2·2% of sulphur). The latex–sulphur mixes are still more striking; after 2 h. heating the increase in softening point is the same as for latex alone [Fig. 3 (c)], but after a further 2 h. heating the increase in softening point is identical with that obtained with Harcrumb [Fig. 3 (d)]. This is consistent with a relatively high rate of breakdown of the rubber in latex–sulphur mixes which results initially in rapid dissolution and subsequently in rapid degradation. This type of behaviour is also apparent in the results obtained by Welborn & Babashek.[12]

(2) *Viscosity and elastic strain recovery*

Neither the penetration nor softening point test measures single physical properties of a material. The penetration of a standard needle under specified conditions depends not only on the viscosity but also on other factors such as the elastic properties, the surface tension and, in the case of rubberised bitumens particularly, the degree of heterogeneity of the mix. Similarly the softening point is a measure of a combination of viscosity, elastic properties, density, thermal conductivity and heat capacity, all of which can vary with the temperature.[13] Since the addition of rubber to a bitumen greatly alters both the viscous and elastic properties it is desirable to know to what extent each of these properties is altered separately.

The instrument used to measure the visco-elastic properties of the bitumens and rubberised bitumens was a simple concentric-cylinder viscometer, the length of the cylinders being 5 cm., their diameters 1·0 cm. and 3·0 cm., the annulus being 2 cm. wide. A wide annulus was employed because of the heterogeneity of some of the materials tested. Preliminary tests showed that, over the stress range existing across the annulus, all the test materials could be considered as being Newtonian fluids.

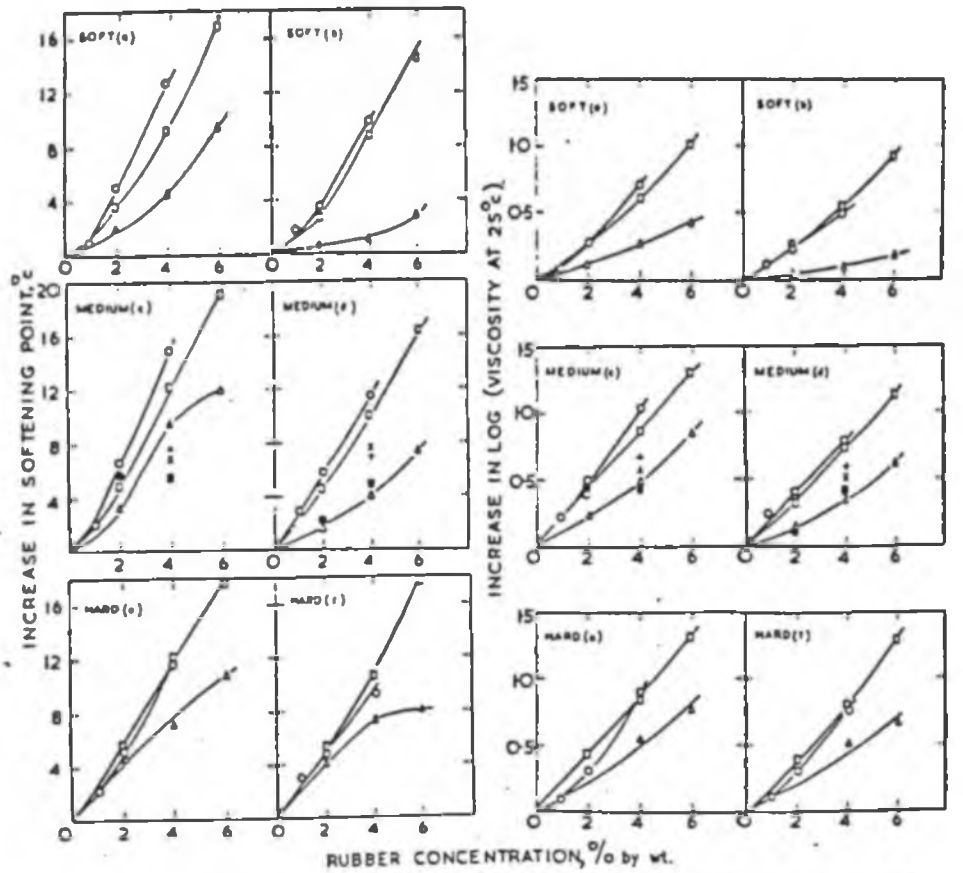
Tests were made at two temperatures, 25° and the softening point of the material under test and, to keep testing times at reasonable values, two values of torque were employed, namely, 10×10^4 and $1{\cdot}4\times10^4$ dyne cm., respectively. The annulus was blanked off at one end by a cover plate which also served to clamp the inner and outer cylinders in their correct positions and to prevent any rotation of the cylinders. The cover plate was smeared with silicone grease to ensure its easy removal before testing. The annulus was filled with hot binder, at approximately 140°–150°, and subsequently allowed to cool in air for at least 1h. The assembly was then transferred to a constant-temperature bath maintained at 25·0°, and kept for a further 1 h. before testing. During the test, the outer cylinder was clamped in a framework which also carried the bearings in which the inner cylinder rotated. The cover plate was removed, a torque of 10×10^4 dyne cm. applied to the inner cylinder and its resultant rotation followed by means of a lamp, mirror and scale. Usually the test was allowed to proceed until

the strain in the material at the surface of the inner cylinder was about 0·9, although with a few of the hardest materials the maximum deformation was only half this, because of the very slow rates of deformation obtained. When the strain reached the desired value, the torque was suddenly removed from the inner cylinder and the subsequent elastic strain recovery observed for a further 15 min. With some materials the rate of elastic recovery, after 15 min., was negligible or zero, but with others it was still appreciable.

After the 15-min. recovery period, the cover plate was replaced, the assembly removed from the testing frame and transferred to a water-bath maintained at the softening point of the material being tested. After 1h. the procedure was repeated but with a lower torque of $1{\cdot}4 \times 10^6$ dyne cm.

Fig. 4 shows the change in the logarithm of viscosity at 25° plotted against rubber content. The curves thus obtained closely parallel those of Fig. 3. Fig. 5 shows the increase in log-(viscosity at 25°) plotted against increase in softening point. A straight line is obtained which passes through the origin and which is independent of the three base bitumens, type of rubber, rubber concentration and time of heating, an increase in softening point of 10° corresponding to an increase in log(viscosity at 25°) of 0·7. Thus changes in softening point reflect changes in viscosity at 25° and the same is generally true of changes in log(penetration), but the scatter of results is much greater.

A bitumen and a rubberised bitumen of the same penetration or softening point will not, in general, have the same viscosity at 25°, but results obtained (see Fig. 6) show that for all materials the viscosity at the softening point temperature is approximately constant. Materials used in the present work covered a range of softening points from 38° to 69° and the log(viscosity)



Effect of rubber concentration on (Fig. 3) *softening point*, (Fig. 4) *viscosity at* 25°

(a), (c), (e), samples heated for 1 h. at 170°
(b), (d), (f) " " " 4 h. " "
○ bitumen + latex ❍ bitumen + Pulvatex
△ bitumen + Heverumb ● bitumen + latex + sulphur
– bitumen + Rodorub
■ bitumen + ground tyre scrap ✕ bitumen + Rubarite

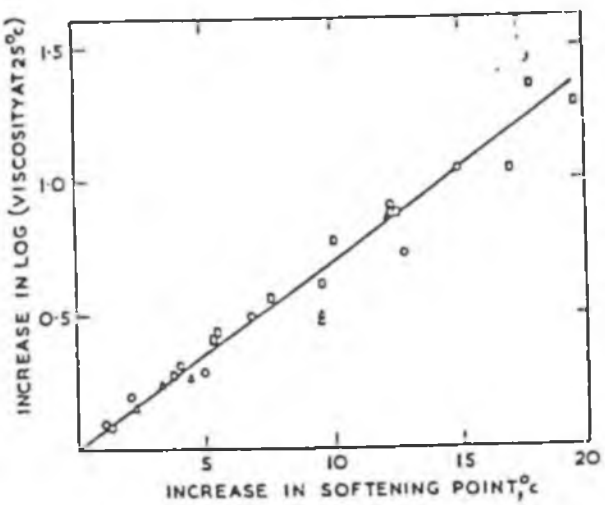


FIG. 5. *Relationship between increases in viscosity and softening point*
Samples heated for 1 h. at 170°
○ Latex □ Pulvatex △ Harcrumb

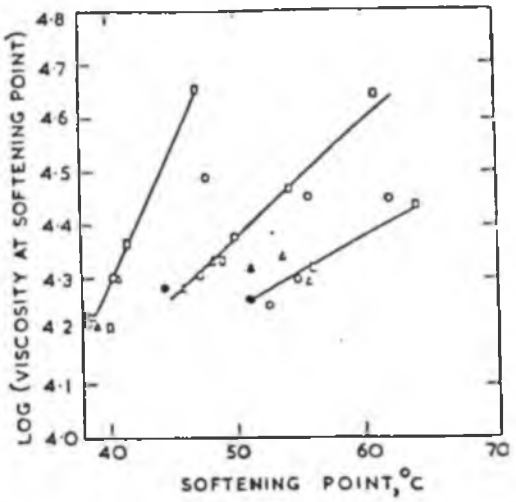


FIG. 6. *Relation between change in log viscosity at softening point and the softening point on the addition of rubber to the three base bitumens*
Samples heated for 1 h. at 170°
● bitumen
○ bitumen + latex
□ bitumen + Pulvatex
△ bitumen + Harcrumb

at the softening point temperature varied from 4·2 to 4·7, i.e. the viscosity varied from $1{\cdot}6 \times 10^4$ poises to $5{\cdot}0 \times 10^4$ poises. In general there is an increase in viscosity at the softening point with increasing softening point and also with increasing rubber concentration.

The temperature susceptibility of the viscosity of road binders is an important factor in the durability of road surfacings and the measurement of viscosity made at 25° and the softening point can be used to calculate the logarithmic temperature coefficient, n, described by Lee *et al.*[14] where

$$n = \frac{\log \eta_1 - \log \eta_2}{\log T_2 - \log T_1}$$

η_1 and η_2 are the viscosities measured at temperatures T_1° and T_2°F.

The viscosities of a bitumen and a rubberised bitumen were measured over a range of temperatures from 20° up to their respective softening points to confirm that the above method of expressing the temperature susceptibility could be used with rubberised binders. The results are shown in Fig. 7. The value of n obtained from the slope of the rubberised bitumen curve was 9·4, while that calculated from the viscosities at 25° and the softening point was 9·7, which is in satisfactorily close accord. Fig. 8 is a plot of n against log(viscosity at 25°) for Pulvatex mixes and clearly shows the reduction in temperature susceptibility, at equi-viscosity at 25°, obtained with various rubber concentrations. The latex mixes show similar results and the Harcrumb mixes rather smaller reductions.

Figs. 9 and 10 show the values of elastic strain recovery at 25°, expressed as a percentage of the total deformation, and plotted against log(viscosity at 25°) for the base bitumens and for rubberised bitumens. The improvements in elastic properties obtained by the addition of rubber are obvious and the qualitative picture obtained of the relative merits of the various rubbers is similar to that obtained from a study of the softening point or viscosity data. There are certain differences, however; for instance, in Fig. 9 the values for the Pulvatex mixes are similar to those for the Harcrumb mixes rather than those for the latex mixes, while a comparison of the two diagrams shows that the latex mixes as well as the Harcrumb mixes suffer losses in elastic quality as time of heating is increased. The high elastic recovery of the Harcrumb mixes at the shorter periods of heating is at least partly due to the large number of swollen rubber particles still present. Visible agglomerations of these particles were large compared with the annulus width. Similarly the differences between the Pulvatex and latex mixes may be traced to the more highly gelled nature of the latter. After the gel is broken the Pulvatex and latex mixes give similar results (Fig. 10).

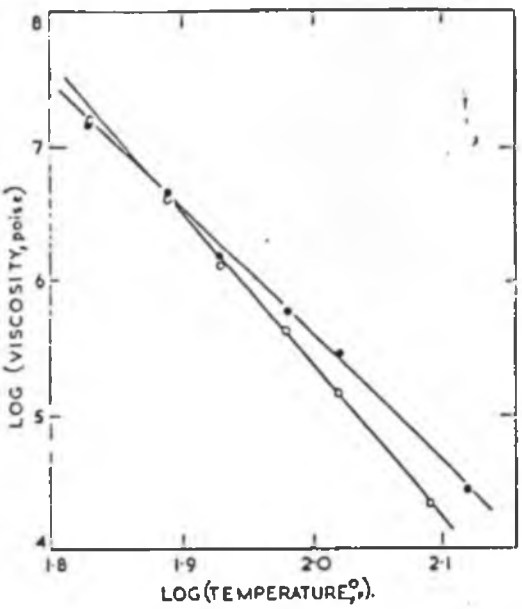


FIG. 7. *Viscosity–temperature relationships for a bitumen and a rubberised bitumen*
Rubberised bitumen with 4% of rubber (by wt.) as Pulvatex, heated for 2 h. at 170°
○ bitumen ● rubberised bitumen

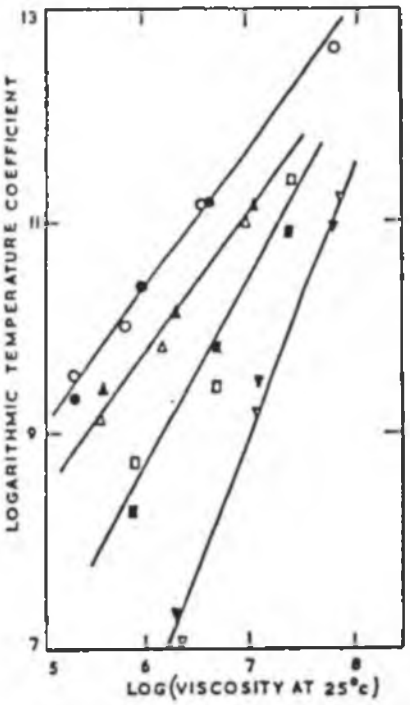


FIG. 8. *Relationships between logarithmic temperature coefficient and viscosity at 25° for a range of bitumens and rubberised bitumens prepared with Pulvatex*

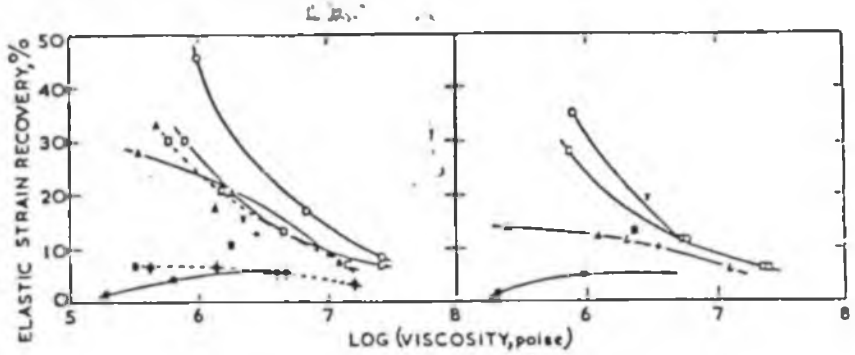
Samples heated for 1 h. at 170°	Samples heated for 4 h. at 170°
○ bitumen	● bitumen
▽ bitumen + 2% rubber	▼ bitumen + 2% rubber
□ bitumen + 4% rubber	■ bitumen + 4% rubber
△ bitumen + 6% rubber	▲ bitumen + 6% rubber

The Rodorub and latex–sulphur mixes show slight and marked losses of elastic quality with longer heating, respectively, in accordance with the hypothesis involving the peptising action of sulphur suggested above.

Also included in Fig. 9 are some values of elastic recovery obtained from measurements made at various temperatures on a single 4% Pulvatex mix (medium bitumen) and plotted against the viscosity at these temperatures (line A). It appears that, to a first approximation, with this particular type of rubber the elastic quality is not dependent on the base bitumen used to prepare the rubberised bitumen, but only on the viscosity at the temperature at which the elastic recovery is measured. Similar data were obtained with the hard bitumen (Fig. 9, line B).

(3) *Low-temperature extensibility*

The elastic strain recovery measurements detailed in the previous section gave a possible means of determining the improvement of elastic qualities caused by the addition of rubber. However, the data are restricted to a fairly narrow range of viscosity and to low rates of strain and it would be unwise to use these results to predict the behaviour of rubberised bitumens under brittle conditions, i.e. at low temperatures (high viscosity) and for high rates of strain. Measurements were therefore made of the extensibility at a low temperature (—10°) of a number of bitumens and rubberised bitumens, the applied rate of strain being approximately 0·1 sec.$^{-1}$ It was originally planned to carry out these tests at 0°, but preliminary tests showed that only the hardest bitumens and rubberised bitumens gave brittle failures under these conditions, the softer materials extending to the limits of the apparatus (about 350% elongation). At —10° it was found that the bitumens were very sensitive to shock and frequently broke during the removal of the specimens from the moulds. The procedure finally adopted was to remove the specimens at 0°, and set them up ready for testing in the constant-temperature bath, and then to reduce the temperature from 0° to —10° over a period of about 10–15 min., the specimens being left for 1 h. at —10° before being tested. The rubberised bitumen specimens could be successfully removed from the moulds at —10°.



Relationships between elastic strain recovery and viscosity at 25°

FIG. 9. All samples heated for 1 h. at 170°, excepting the latex–sulphur mix which was heated for 2 h. at 170°

FIG. 10. All samples heated for 4 h. at 170°

- ● bitumen
- ○ bitumen + 4% rubber as latex
- □ bitumen + 4% rubber as Pulvatex
- △ bitumen + 4% rubber as Harcrumb
- ▲ bitumen + 2% rubber as latex–sulphur
- ⊥ bitumen + 4% rubber as Rodorub
- ■ bitumen + 4% rubber as ground tyre scrap
- × bitumen + 4% rubber as Rubarite

The test specimens were prepared by heating a sample of the binder to 140°–150° and pouring it into suitably shaped brass moulds (Fig. 11) which rested on brass plates, the whole being smeared with silicone grease to prevent adhesion of the binder to the moulds or to the base plates. Three specimens of each binder were prepared at a time. The moulds were overfilled initially and were later cooled down to −10° and the excess binder removed with a hot knife. This process usually left an uneven top surface on the specimen and this roughness was removed by gently warming the mould in an oven for a few minutes. The specimens were normally stored overnight in a refrigerator at approximately 0°.

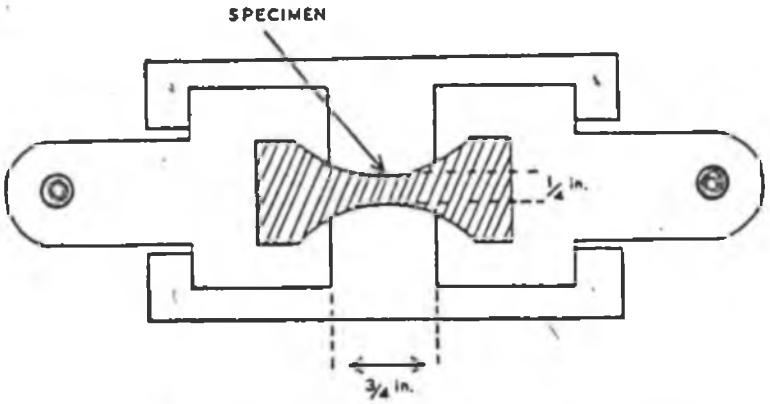


FIG. 11. *Plan view of mould used for preparing extensibility test specimens*

A Hounsfield tensometer was used to extend the specimens which were mounted in a constant-temperature bath between two grips, which were cranked to pass over the sides of the bath and to permit the specimen to be completely immersed as it lay along the axis of the tensometer and not to be subjected to bending forces. One grip was attached to the moving crosshead, which was motor-driven at a constant speed of 0·26 cm. sec.$^{-1}$, and the other to a spring beam. The deflection of the spring beam was indicated by the normal Hounsfield lever–mercury-piston system which displaces a mercury column along a glass tube, the load on the spring beam being read off on a calibrated scale mounted alongside the tube. The movement of the crosshead was recorded by the normal recording drum which gave a magnification of linear movement of 16 : 1. Since the time of test was approximately 0·1—0·4 sec. the load–extension data for each specimen were obtained by photographing simultaneously the movement of the mercury column and the rotation of the recording drum at a film speed of 64 frames/sec. Fig. 12 shows typical curves obtained in this way of load versus film frame number, and crosshead movement versus frame number. From each record the breaking extension of the specimen was obtained by subtracting the deflection of the spring beam from the crosshead movement.

Figs. 13 and 14 give the extensibility at, −10° plotted against log(viscosity at 25°) and show diagrammatically the simultaneous change in these properties due to the addition of rubber. Qualitatively the relative increases in low-temperature extensibility shown by the various rubberised bitumens are very similar to the relative changes obtained in other properties such as viscosity at 25°, penetration at 25° and softening point. The broken lines in the diagrams provide linear relationships between increase in extensibility and increase in log(viscosity at 25°), which depend only on the base bitumen and are independent of the type of rubber used.

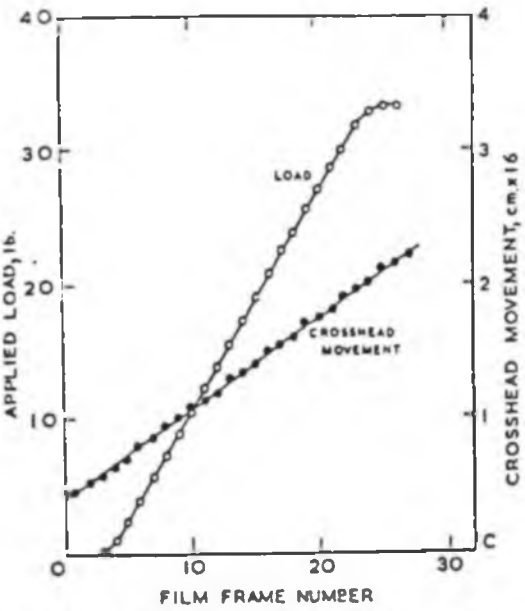
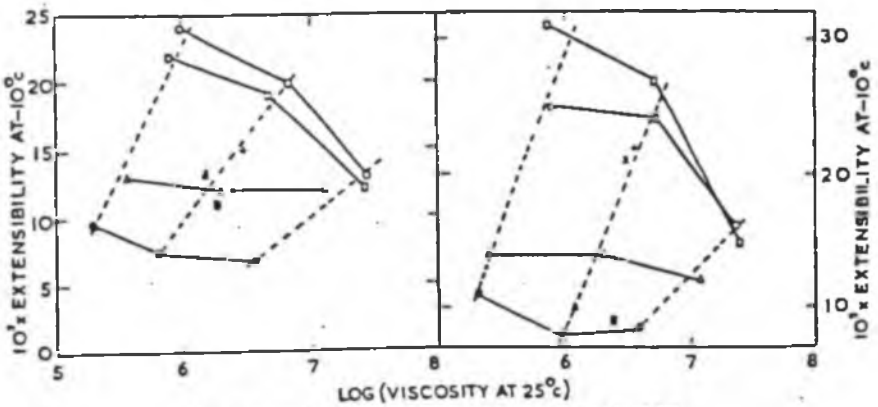


FIG. 12. *Typical curves derived from the photographic record of an extensibility test made on a sample of 146 pen. bitumen + 4% by wt. of rubber (Pulvatex) heated for ¼ h. at 170°*

The extensibility measurements show one trend which is absent from all the previous test data. In general there is an increase in extensibility with increase in time of heating, which occurs even with the base bitumens, and only the latex–sulphur and ground tyre scrap mixes show the reverse effect. This improvement in extensibility is most marked with the Pulvatex, Rodorub and Rubarite blends and is probably due to a reduction in the number and size of rubber particles with longer heating, and the consequent increase in the proportion of rubber in a state of molecular dispersion in the bitumen. At the shorter periods of heating many of the materials tested, and particularly the Harcrumb mixes, contained swollen rubber particles or agglomerations of such particles, many of which were of the order of 1 mm. diameter, compared with the cross-section of the specimen which was approximately 6 mm. × 6 mm. at its narrowest point, and could thus set up stress concentrations giving premature failure of the specimen and low extensibility. It appears probable that, with the Harcrumb mixes, any improvement obtained from a reduction in the number and size of the rubber particles is largely offset by the rapid molecular breakdown of the rubber by the sulphur present. The latex–sulphur mixes show a decrease in extensibility with longer heating because of this. There is



Relationships between low temperature (−10°) extensibility and viscosity at 25°

FIG. 13. All samples heated for 1 h. at 170° excepting the latex–sulphur mix which was heated for 2 h. at 170°

FIG. 14. All samples heated for 4 h. at 170°

● bitumen
○ bitumen + 4% rubber as latex
□ bitumen + 4% rubber as Pulvatex
▷ bitumen + 4% rubber as Harcrumb
▲ bitumen + 2% rubber as latex–sulphur
— bitumen + 4% rubber as Rodorub
■ bitumen + 4% rubber as ground tyre scrap
× bitumen + 4% rubber as Rubarite

poor correlation between extensibility and elastic recovery. These measurements may be affected in different ways by the presence of rubber particles, which usually reduce the extensibility but can, under certain conditions, increase the elastic recovery.

Discussion

It is apparent from the viscosity and extensibility data that the various effects observed are due, in the main, to a similar mechanism which involves the molecular (or near molecular) dispersion of rubber in the bitumen. Any rubber particles which may be present appear to make little contribution to the increase in viscosity, but reduce the extensibility due to the setting up of stress concentrations. However, because of the linear relationships that hold between increases in extensibility and increases in log(viscosity), the relative merits of different types of rubber can be assessed by measuring the changes that occur in either of these properties when each rubber is blended with a given bitumen under standard conditions. Furthermore, as there is a linear relationship between change in log(viscosity at 25°) and change in softening point which is independent of the type of rubber, rubber concentration, period of heating and base bitumen, it is permissible to use this simple standard test to obtain an assessment of the relative viscous and elastic properties of rubberised bitumens prepared with the various rubbers, and bitumens examined using standard blending conditions. These conditions must be chosen with the practical use of the materials in mind, since, as is apparent with the latex–sulphur mixes, rapid changes in the relative ratings of different types of rubber can occur with quite small changes in the heating conditions. For the production of heat-stable rubberised bitumens it appears advisable to avoid the inclusion of sulphur, or other peptising agents, in the mix.

The problem of the characterisation of different rubberised bitumens is obviously much more difficult than of different types of rubber, since the elastic properties vary considerably with the viscosity of the blend. Thus any relative assessment should be made on an equi-viscosity basis. This can be achieved by using curves such as those shown in Figs. 9, 10, 13 and 14, and relating a given rubberised bitumen to a standard rubberised bitumen in terms of equivalent rubber content at equi-viscosity.

Acknowledgments

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(82)

Specialily Polymers In Road Applications - Some Noval Technological Advances.

by

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SPECIALITY POLYMERS IN ROAD APPLICATIONS-SOME NOVAL TECHNOLOGICAL ADVANCES

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ABSTRACT

Laboratory and field studies conducted at Central Road Research Institute confirm that ethylene vinyl acetate copolymer with vinyl acetate content ranging 18 to 28%, when added to bituminous binders to the extent of 2.5% to 5.0%, improve flexibility at low temperature, prevent permanent deformation of road surfacings at high temperature and improve fatigue life leading to safer, durable, longer lasting pavement with low maintenance cost. Performance of road surfacings modified with ethylene vinyl acetate copolymer as an ingredient have been recorded superior under heavy loading.

INTRODUCTION

Increased number of traffic loads with overloading of axles in excess of permissible limits and higher tyre pressure have caused widespread problems with bituminous roads on National Highways and available 60/70 grade bitumen is not suitable for heavy duty roads in industrial complex, ports and airfield pavement. The accelerated deterioration of bituminous surfacings prematurely burdens the maintenance budget and pose funds constraints on new developments. It is a global view that the quality and longevity of pavement must, therefore be restored in order to reduce maintenance budget and to save road user's cost. Polymer modified binders are premium binders, which allows an engineer to design and build a stronger and durable pavement. Jain and Coworkers (1-2) have conducted extensive laboratory and field studies in recent years using a variety of polymeric additives for their use in heavy duty road and airfield surfacings. Ethylene vinyl acetate copolymer having wide range of properties, which depending upon the vinyl acetate content, extends from plastic to rubber like products. At a very low vinyl acetate content, the copolymer behave like LDPE and with increasing vinyl acetate content amorphous character become predominent resulting in a flexible rubbery material. Hence, such wide range properties of EVA make it, a polymer with diverse applications. Flexibility, polarity, low temperature tonghness, shock resistance

and good weathering has made it a material suitable for some potential applications in highway and transportation engineering. viz. bitumen modification, bitumen packing, traffic cones and traffic lane dividers. The paper give details of findings related to laboratory scale development, field trials on heavy duty roads and cost-benefit analysis.

EXPERIMENTAL

The studies were carried out in three phases viz. (I) identification of suitable polymeric ingredients and blending conditions (ii) study of properties of binders and mixes for field trials and (iii) field trials. Results of creep characteristics of ethylene vinyl acetate and low density polyethylene ethylene-vinyl acetate are given in Table 1(2). The properties of modified binders used for various test locations are given in Table 2. The properties of modified mixes are given in Table 3. The comparative performance as recorded during June-July, 1997 is given in Table 4.

RESULTS AND DISCUSSION

For the study of creep and creep recovery properties, a stress of 1.5x10 Pa was applied for 3 minutes at 30°C and 1 minute at 60°C. It can be seen from the data given in Table-1 that creep recovery of EVA and EVA+LDPE blends is faster than LDPE, however, ultimate creep recovery characteristics of neat polymers and blends are same at 30°C, while at 60°C creep recovery of EVA and EVA+LDPE blends are more than neat LDPE. Hence quantity of LDPE in a blend of bitumen EVA-LDPE may be kept towards lower side for better creep properties. Resistance to creep deformation of EVA as well as EVA+LDPE (2:1) blends is better than LDPE at 30°C and 60°C. Values of creep resistance are comparatively better for 1:2 blend of LDPE:EVA then 1:1 blend of EVA:LDPE. Findings related to development of products have also been reported earlier (1). The following formulations were selected for laboratory and full scale field studies.

- For hot climate : 60/70 grade bitumen modified with 3.5% EVA (VA=18%) and 1.5% LDPE (16 MFI) Cold 80/100 grade.
- For snow bound climate: Bitumen modified with 5% EVA (VA = 28%)
- For hot and humid climate : 60/70 grade Bitumen modified with 3.5% EVA (VA=28%) and 1.5% LDPE (16 MFI)

It can be seen from the test results given in Table 2 that physical and engineering properties of modified bitumen are better than conventional 80/100 or 60/70 bitumen. Higher value of penetration ratio indicates improved temperature susceptibility of modified bitumen. Improved value of low temperature ductility further indicate resistance of modified binders to abrasion and thermal cracking. Higher values of softening point for modified binders indicate reduced chance of bleeding and fatting up at higher temperature besides resistance to deformation. Data given in Table 3 related to engineering properties of EVA modified mixes as reported earlier also (1,2) and confirm improved strength and stability characteristics of mixes. The fatigue life of bitumen with 2% EVA + 2% LDPE and 5% EVA + 2% LDPE are 2.5 and 3.5 times higher than conventional bitumen mixes(1). However, the values of fatigue life are 10 to 15 times higher for increased loading (42.5 to 85 kg).

Moisture damage susceptibility test was conducted by measuring tensile strength (ASTM D-4123) before and after moisture conditioning. The tensile strength ratio represents remaining strength factor. Higher value of tensile strength ratio (2) suggest the resistance of modified bitumen to moisture damage.

The performance data of various trial sites covering different traffic and climatic conditions are given in Table 4. It can be seen from the data that overall performance of EVA modified bitumen is much better than conventional bitumen besides their improved resistance to cracking, ravelling and formation of potholes. The performance of EVA modified bituminous concrete within NOCIL factory premises subjected to loading and damaging action of 500 mt crane is very encouraging as the conventional bitumen surface is highly susceptible to wear and tear during movement of crane. The findings of full scale field trials are conforming to laboratory findings. Hence, it can be predicted that life of surfacings having EVA modified bitumen as binder would be 1.5 to 2 times higher than conventional bitumen and offset higher initial cost of overlays. Asuming 1.5 times increase in life of overlay, the frequent overlaying can be minimised. It can be seen from the data initial cost of PMB overlay is about 30% higher, while the life cycle cost is 15-20% less besides 33 % saving in bitumen requirement and 35% saving in aggregate requirement.

ACKNOWLEDGEMENTS

Author is thankful to Prof. (Dr.) A.K. Gupta, Director, Central Road Research Institute for granting permission to publish this paper. Thanks are also due to Shri V.K. Sood and Shri I.R. Arya for encouragements. Author is also thankful to staff of flexible pavement division for assistance in carrying out testing work and M/s. NOCIL for financial inputs. Thanks are also due to Shri Rakesh Bedi, postgraduate student, Delhi College of Engineering for assistance in testing work related to creep studies.

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Table 1. Creep Characteristics of Polymer and Polymer Blends

Polymer/Polymer Blends	Time (Seconds)	Creep (%)		Creep Recovery, (%)	
		30°C	60°C	30°C	60°C
LDPE	300/60	39.1	12.0	91.0/75	90.4
EVA (18)	300/60	14.5	12.3	96.0/90	93.0
EVA (28)	300/60	16.6	7.4	96.0/89	97.0
EVA+LDPE (18)	300/60	31.7	11.5	92.0/83	92.0
EVA+LDPE (28)	300/60	34.7	12.4	91.0/79	93.0

Table 2. Properties of EVA Modified Binders Used for Various Locations

Property	Unit	Method	Modified	Unmodified
Penetration, 25°C	0.1mm	IS:1203	44-49	68-86
Penetration, 4°C	0.1mm	IS:1203	23-25	23-25
Penetration Ratio	%	IS:1203	50-57	33-34
Softening point,	°C	IS:1205	60-69	45-46
Ductility at 15°C	cm	IS:1208	26-38	34-38
Ductility at 4°C	cm	IS:1208	7-9	6-9
Elastic Recovery	%	DIN:52013	42-52	4-5
After TFOT at 163°C				
Weight loss	%	IS:9382	0.3-0.4	0.3-0.5
Pen at 25°C	0.1mm	IS.1203	32-38	38-60
Elastic Recovery	%	DIN 52013	32-49	2-3

Table 3. Properties of EVA Moidified Mixes

Property	Unit	Method	Modified	Unmodified
Marshall stability,	Kg	ASTM:D-1559	1050-1250	855-960
Marshall flow	mm	ASTM:D-1559	3.1-3.2	3.1-3.2
Marshall stiffness	kg/mm	Stability/flow	338-391	276-300
Retained tensile strength	%	ASTM:D-4123	98-99	90-93

Table 4. Performance Points of Unmodified and Modified Bitumens

Location	Specification	Date of laying	Performance points	
			Unmodified	Modified
Kanpur-Allahabad	25mm SDBC	Nov 1994	71	80
Kanpur-Allahabad	25mm DBC	Nov 1994	74	85
Bombay-Nasik	25mm DBC	Apr 1995	76	96
Thane-Belapur	40mm DBC	Apr 1995	-	92
NOCIL factory	50mm DBC	Apr 1995	70	92
Manali-Rohtang	20mm OGPC	June 1996	78	93

(86)

Surface Dressing with Rubberized Bitumen In Stornsey.

By.

Pentecost, G.A.

Rubb: Dev: 11:4; 1958. p 119-122.

G. A. PENTECOST, A.M.I.C.E., M.I.Mun.E., A.M.I.P.I.
(Borough Engineer and Surveyor, Hornsey, Middlesex)

Surface dressing with rubberized bitumen in Hornsey

SURFACE dressing with rubberized bitumen was first used to prolong the life of clinker-asphalt surfacing. Many roads in the Borough have been surfaced with asphalt made from clinker produced at the refuse destructor and manufactured at the Central Depot. Some of these surfaces have been down for many years and, in the course of time, have become badly corrugated, and extensive surface crazing had developed. The surfaces possessed excellent non-skid properties and were reasonably light in colour, and, when used on main roads, were laid on substantial base courses. Apart from wear and openings for mains and cables, the deterioration of the surfaces was considered to be due to oxidation of the bitumen and physical breakdown in some of the clinker particles.

Where trenches had been excavated through



Fig. 1. *Rubber bitumen coated with ½ in. chips was laid over the hot-rolled asphalt at Muswell Hill Roundabout*

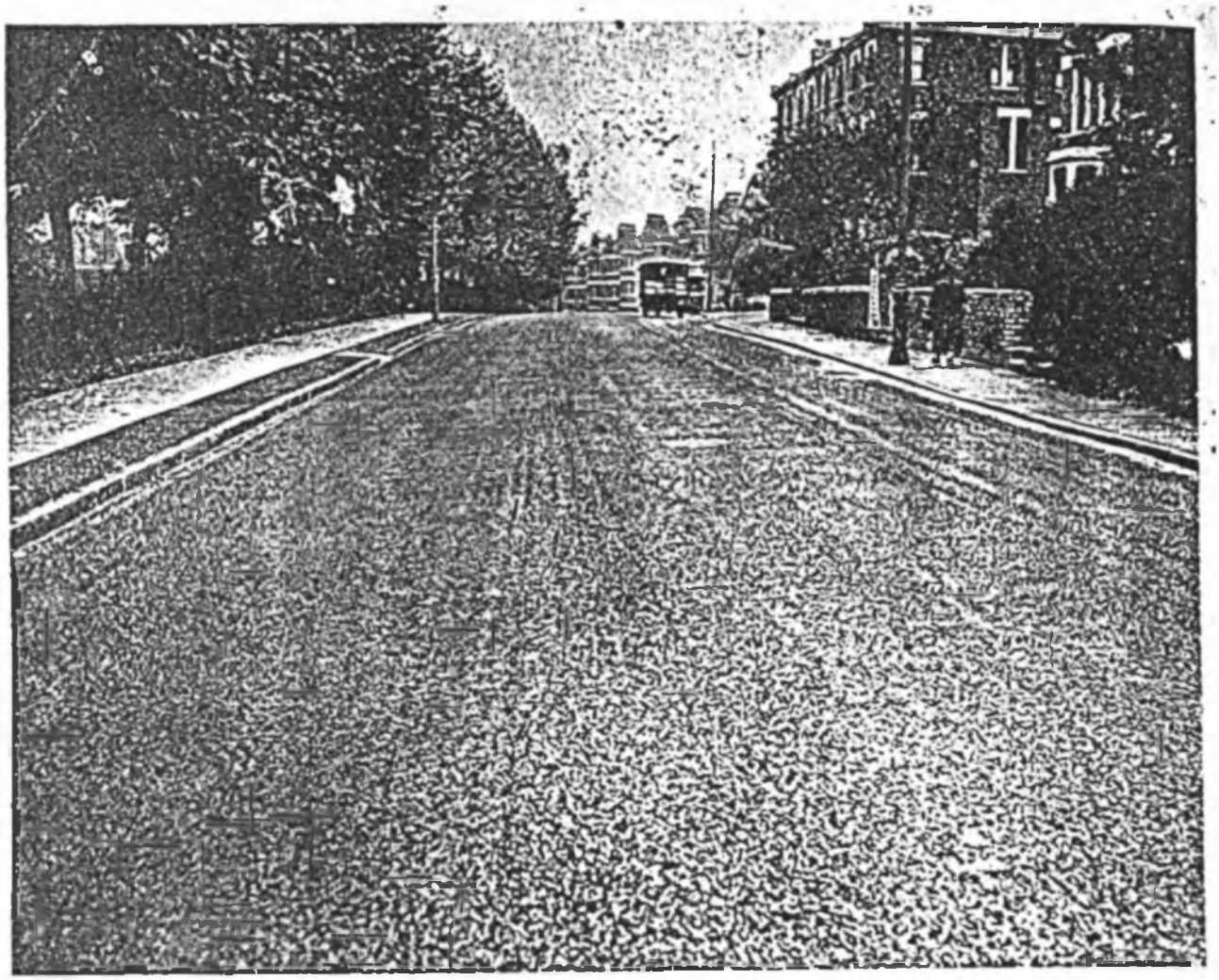


Fig. 2. *On Middle Lane, second section, the existing clinker heated and planed and surface dressed with rubberized bitumen and ¼ in. chips*

clinker asphalt laid on a substantial base course, it has been found impracticable to separate the surfacing from the base course, so that the cost of taking up and replacing the two-coat clinker asphalt would have been a considerable expense.

With the advent of heating and planing technique it was decided to plane off about 1 in. of the asphalt topping and lay, by machine, a thin coat of bituminous surfacing. When the surface of the asphalt was examined after the removal of up to 1 in. of material it was found that a good deal of crazing had disappeared and heating the material had resulted in a form of annealing. At the same time it was considered that the material should be sealed and protected by a more substantial film than was provided by the normal tack coat.

The improved ductility and increased adhesion of rubberized bitumen appeared to be the ideal material for this purpose. The operation then became one of heating, planing and surface dressing, instead of breaking out and replacing surfacing and base coat.

Experiments begin

The first experimental length of surface dressing was carried out in October 1952, a time of year rather late for surface dressing by the usual technique. The stone used was a diabase hornfels of ⅜ in. nominal maximum size. The rubberized bitumen was supplied by the Anglo American Asphalt Co., from Bristol, and consisted of 2% natural-rubber powder digested in residual bitumen and fluxed to a spraying viscosity with about 20% of flux oils. The rubber powder for this trial was kindly supplied by the Rubber Development Board. It subsequently became obvious that the ⅜ in. nominal maximum size stone was too small for the thickness of bitumen film required to effectively seal the clinker asphalt.

The trial run of 1,000 gal. on October 15, 1952, proved that traffic could run on the dressed surface immediately without removing chippings, and buses were able to turn into the road without affecting the work done. A further 3,000 gal. was laid commencing on November 22, and operations were interrupted by a very heavy rain storm,

as a result of which a small area of carriageway had to be scraped and resprayed.

When the work had settled down it appeared that a minimum life of five years could be expected, and the following year a further 3,000 gal. was laid on planed clinker-asphalt surfaces. On these trials ½ in. and ⅜ in. nominal maximum size aggregates were used (diabase hornfels). As a result of these tests it was decided to heat and plane and surface-dress with rubberized bitumen all existing clinker-asphalt surfaces as they became due for treatment. During subsequent work, partial stripping occurred on three or four roads, and this was attributed to too light a rate of spread using the ½ in. aggregate, possibly combined with insufficient material removed from the clinker-asphalt surface.

In 1954 a recently laid bituminous-macadam surface on a hill 700 yd. long suffered damage by diesel oil dropped from vehicles, and it became obvious that unless some action was taken all the surfacing would have to be taken up and renewed: 2,200 gal. of rubberized bitumen were applied liberally and dressed with ½-in. igneous rock chippings. The bituminous surfacing was saved from further damage. At the same time action was taken by the operators to prevent the vehicles concerned from dropping fuel oil. The skidding resistance of the dressed surface, even though on a gradient of 1 in 10, was considered satisfactory.

In August 1955 a test was made using rubberized bitumen, rubberized tar and a high-viscosity tar, on sections of the same road. While this experiment was rather limited in scope and not necessarily conclusive, the rubberized bitumen proved the more satisfactory; some stripping occurred on the other two sections.

Resistance to skid

During 1956 complaints were received that bituminous-macadam surfacings at bus stops had become slippery and that there had been a number of skids. Fifty bus stopping places were

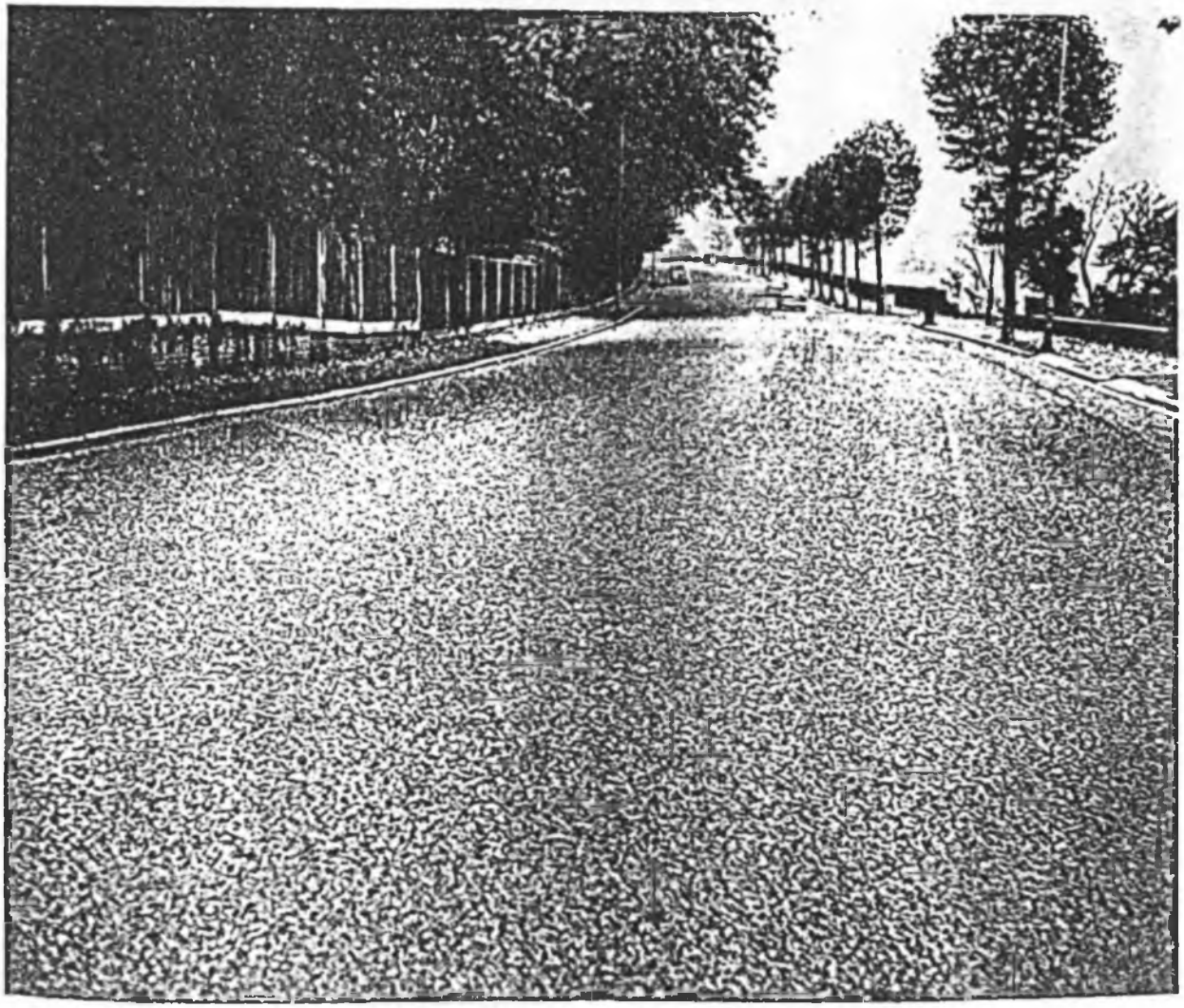


Fig. 3. *On Hampstead Lane the machine-laid bitumen-macadam was treated with rubberized bitumen and ½ in. chips*

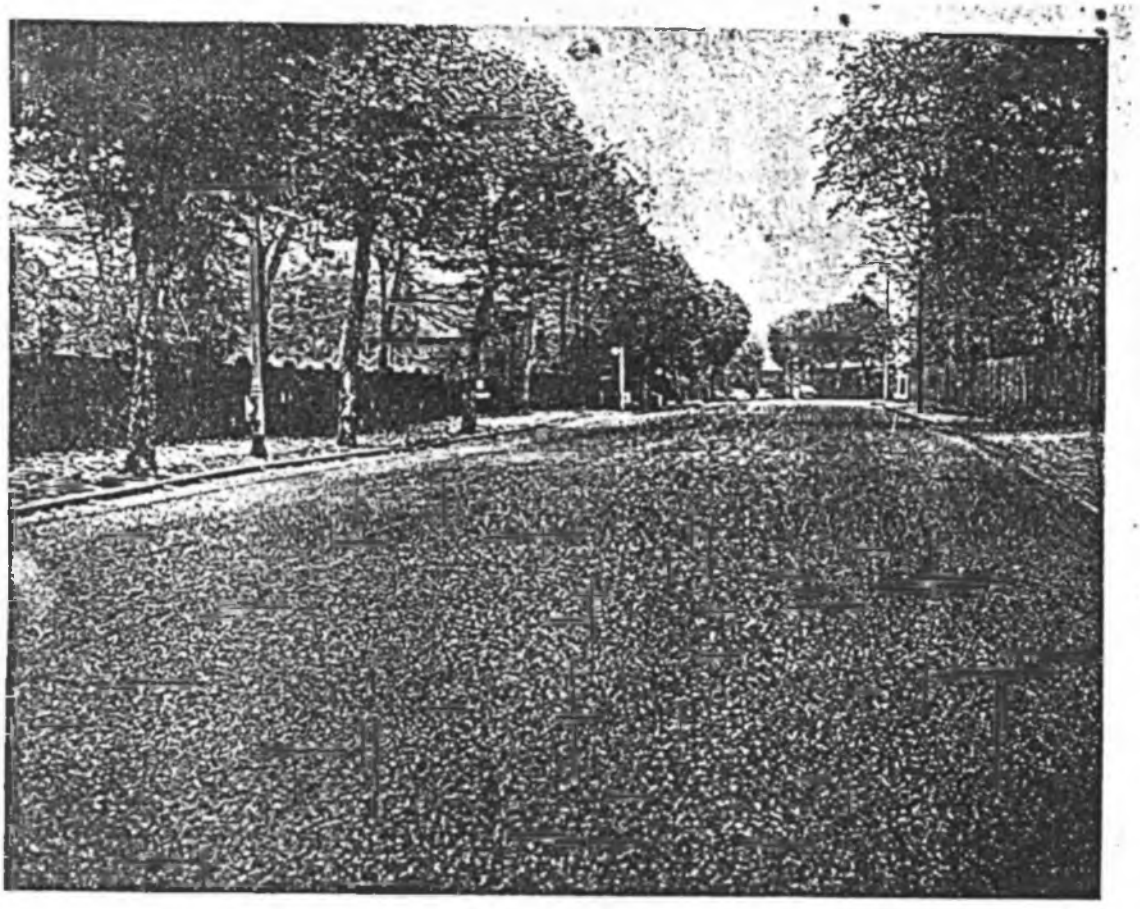


Fig. 4. *On Hampstead Lane near Kenwood the treatment was the same as for the section shown in Fig.* 3

dressed with rubberized bitumen and ¼-in. igneous chippings, and the skidding resistance of the area was apparently greatly improved.

Skidding complaints developed in relation to a roundabout which had recently been surfaced with hot-rolled asphalt. There was a small bus terminus on the centre island and some carry-over of oil droppings on to the adjoining carriageway, necessitating frequent sanding. Skidding was found to be particularly troublesome at one corner with adverse camber, and it was eventually decided to dress the roundabout with rubberized bitumen and ½-in. igneous chippings, since when no further complaints have been received.

A further example of skidding trouble occurred on a restricted Class II road surfaced with machine-laid bituminous macadam. Several test runs at 30 m.p.h. indicated that even under damp conditions the surface was reasonably safe, but this would not necessarily be so with faster driving. After a fatal accident, the section of road was dressed with rubberized bitumen and ½-in. chippings (porphry-syenite). The work, carried out in 1957, has proved satisfactory.

RUBBER TRACKS PROTECT NEW CONCRETE

A METHOD of allowing road-laying machines to move over newly finished concrete is to attach rubber-covered crawler pads to the tracks. The pads are made of steel plates ¼ in. thick, about 8 in. wide and 15 in. long with a covering of tough, pliable rubber on one side. They are available from the M.W. Protective Coatings Division of Metalweld Inc., Philadelphia, Pa., U.S.A.

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A SURVEY ON RUBBERISED ASPHALT FOR ROAD SURFACING



ผลสำรวจการใช้ยางราดผิวถนน

■ **Rubberised road surfacing** is defined as the use of rubber, either natural or synthetic, in the forms of preserved latex, powdered/crumb rubber from scrap tyres, rejected gloves and other rubber-based articles, as one of the components to mix with conventional asphalt/bitumen for road pavement in order to improve road performance in various aspects.

The idea of blending natural rubber (NR) with bitumen was initiated in 1823. Studies with small-scale field trials and actual applications started in the 1930's produced satisfactory results. Rubberised road surfacing has since developed into an advanced set of technologies, with large-scale applications in European countries and in the United States in the 1990's.

The main objective of this survey is to identify the available technologies in rubberised asphalt road surfacing, to document their limitations and advantages, and to analyse their social and economic impacts, both in the NR producing and consuming countries.

■ **ยางราดผิวถนน** หมายถึง ยางธรรมชาติและยางสังเคราะห์ในรูปของน้ำยางคงรูป ยางผง/ก้อนจากผิวยางล้อยานพาหนะ ถุงมือถักทิ้งและวัสดุยางอื่นๆ จากโรงงานอุตสาหกรรมยางที่นำมาใช้ผสมกับยางแอสฟัลท์ สำหรับราดปูผิวถนนเพื่อปรับปรุงการใช้งาน

ความคิดในการผสมยางธรรมชาติกับยางแอสฟัลท์เริ่มขึ้นตั้งแต่ปี 2366 เริ่มศึกษาทดลองและใช้งานได้ผลเป็นที่น่าพอใจอย่างจริงจังในปี 2473 หลังจากนั้นเทคโนโลยีด้านนี้ได้รับการพัฒนาให้ก้าวหน้าไประดับหนึ่งซึ่งนำมาใช้ในยุโรปและอเมริกาในปี 2533

วัตถุประสงค์หลักของการสำรวจข้อมูลครั้งนี้ก็เพื่อต้องการกรานเทคโนโลยีที่มีเอกสารแสดงข้อจำกัดและข้อดี และเพื่อวิเคราะห์ถึงผลกระทบต่อสังคมและเศรษฐกิจของประเทศผู้ผลิตยางและผู้บริโภคยางทั้งหลาย

DEVELOPMENTS ON RUBBERISED ROAD SURFACING

Rubberised road surfacing in fact is not a new idea since the work on this subject began in the early 19th century. According to Zenke, King George IV awarded a patent for the application of natural rubber in road construction to a Mr. Hancock in 1823. Studies on the incorporation of NR and synthetic polymer into asphalt to improve the properties of the binder for road pavement date back to the 1930s.

The Dutch utilised rubber powder with asphalt in road construction in Holland and Indonesia in the early 1940's. The information pertaining to the technology on rubberised road surfacing published by the Rubber Stichting, was distributed in the United States by the Rubber Development Bureau in Washington D.C. to the Public Roads Administration. In Birmingham, U.K. the first trial pertaining to the use of rubber in road surfacing was in a test bus stop in 1951.



Final look of a rubberised asphalt road
(Courtesy of Canadian Technical Asphalt Association)
ภาพแสดงถนนราดผิวด้วยยางผสมแอสฟัลท์

The Australian Office of the Natural Rubber Bureau in 1961 formulated a solution of natural rubber and power kerosene mixed with bitumen in an effort to strengthen road performance. Full-scale installation of rubber modified asphalt for three municipalities were undertaken during the period of October 1994 to July 1995, in Canada's State of British Colombia. The projects digested 4,350 tonnes of modified rubber asphalt with about 9,500 tyres used. In Japan, a number of trials on rubberised road surfacing had been reported at the Annual Conference on Japanese Roads organised by the Japan Road Association in recent years.

A number of field experiments on rubberised surfacing have been conducted since 1974, in India, and most of these trials were carried out by incorporating two percent specially preserved NR latex to the conventional asphalt using conventional paving equipment. In Malaysia, the first trial on 100 yards of rubberised road with 5 percent NR

การพัฒนาการใช้ยาง ราดผิวถนน

การใช้ยางราดผิวถนนไม่ใช่เป็นเรื่องใหม่แต่อย่างใด เพราะได้ปฏิบัติกันมาตั้งแต่ต้นศตวรรษที่ 19 ในปี 2366 ปรากฏว่า Mr.Hancock ได้รับรางวัลจากพระเจ้าจอร์จที่ 4 ให้มีการสงวนลิขสิทธิ์ในการใช้ยางธรรมชาติสร้างถนน ส่วนการใช้ยางสังเคราะห์และยางธรรมชาติผสมกับยางแอสฟัลท์ เพื่อปรับปรุงคุณสมบัติในการเกาะยึดเพื่อราดผิวถนนได้เริ่มมาตั้งแต่ปี 2473

ชาวดัทช์ได้ใช้ยางผงกับยางแอสฟัลท์ในการสร้างถนนในฮอลแลนด์ และอินโดนีเซียมาตั้งแต่ต้นปี 2483 ทางสำนักงานพัฒนายางในกรุงวอชิงตัน ดี.ซี. เคยแจกจ่ายข้อมูลด้านเทคโนโลยี การใช้ยางราดผิวถนนที่พิมพ์โดย Rubber Stichting แก่สำนักงานบริหารการทางในสหรัฐอเมริกา ส่วนในอังกฤษได้ทดลองใช้ยางราดผิวถนนเป็นจุด ๆ มาตั้งแต่ปี 2499

ปี 2504 สำนักงานยางธรรมชาติออสเตรเลีย ได้ใช้ยางเหลวและยางผสมน้ำมันก๊าซผสมกับยางแอสฟัลท์เสริมสร้างความแข็งแกร่งของถนน การใช้ยางที่ปรับปรุงสูตรแล้วในเขตเทศบาล 3 แห่ง ของรัฐบริติสโคลัมเบีย ประเทศแคนาดาได้เริ่มมาตั้งแต่เดือนตุลาคม 2537 ถึงเดือนธรกฎาคม 2538 โดยใช้ยางผสมดังกล่าวในโครงการประมาณ 4,350 ตัน เท่ากับการใช้ยางผลิตยางล้อรถประมาณ 9,500 เส้น ในประเทศญี่ปุ่นได้มีรายงานการใช้ยางราดผิวถนน ต่อที่ประชุมเกี่ยวกับงานทางญี่ปุ่นที่จัดขึ้นโดยสมาคมการทางญี่ปุ่นเมื่อเร็วๆ นี้

การค้นคว้าวิจัยด้านสนามเกี่ยวกับการใช้ยางราดผิวถนน เริ่มมาตั้งแต่ปี 2517ในอินเดีย โดยใช้น้ำยางคงรูป 2 เปอร์เซ็นต์กับยางแอสฟัลท์ราดถนนด้วยเครื่องมือตามปรกติ ในประเทศมาเลเซียได้ทดลองใช้น้ำยาง 5 เปอร์เซ็นต์ราดถนนเมื่อปี 2493 ในประเทศไทยโดยกระทรวงเกษตรและสหกรณ์ได้มอบหมายให้มหาวิทยาลัยสงขลานครินทร์ศึกษาความเป็นไปได้ในการใช้น้ำยางข้นผสมกับสารเคมี เพื่อก่อสร้างถนนในหมู่บ้าน อินโดนีเซียมีศักยภาพสูงในการใช้ยางในงานทาง องค์กรวิจัยและพัฒนางานสร้างถนน (ARCRD) รายงานว่าสามารถลดค่าทุนการใช้ส่วนผสมยางสารเคมียึดในการสร้างถนนลงได้ต่ำกว่าประเทศอื่นๆ ถึง 25 เปอร์เซ็นต์

latex was initiated in 1950's. The Thailand's Agriculture and Cooperatives Ministry had assigned the Prince of Songkla University's Faculty of Rubber Technology to conduct a feasibility study on building roads in villages by using concentrated latex mixed with chemical substances. In Indonesia, there is great potential for using natural rubber in road construction. The Agency for Road Construction Research and Development (ARCRD) of Indonesia indicated that the cost of polymer modified binder in Indonesia is about one quarter of that commonly found in other countries.

Two main sources of polymer are used in the rubberised road surfacing namely **ground compounded and vulcanised rubbers and raw natural rubber.**

THE TECHNOLOGY ON RUBBERISED ASPHALT FOR ROAD SURFACING

There are two types of technology currently employed in rubberised asphalt for road surfacing, the **wet process** and the dry process. In the wet process, the crumb rubber reacts with the bitumen prior to use. The resulting binder is commonly referred to as rubber-bitumen in Europe or asphalt rubber in the USA. There are three elements to the equipment necessary to achieve the wet process, which include blending the crumb rubber and asphalt cement; reacting the two materials, and transferring the modified binder product to the desired project application.

In the **dry process**, crumb rubber is added to the aggregate in a hot-mix plant before adding the bitumen, after which all these components are mixed at the same time (mixture time is of the order of 45-60 seconds). During this short mixing time part of the crumb rubber, the fine particles, more or less dissolve in the bitumen while the coarse particles will remain as inert fillers or elastic mineral aggregate. Unlike the rubber-bitumen, it is, therefore, difficult to know the properties of the binder modified in this process.

This method applies only to hot mix asphalt production and not other asphalt-paving applications such as

วัตถุประสงค์หลักของการสำรวจข้อมูลครั้งนี้ก็เพื่อต้องการทราบเทคโนโลยีที่มีเอกสารแสดงข้อจำกัดและข้อดี และเพื่อวิเคราะห์ถึงผลกระทบต่อสังคมและเศรษฐกิจของประเทศผู้ผลิตยางและผู้บริโภคยางทั้งหลาย

แหล่งวัตถุดิบยางหลักที่ใช้ในการราดผิวถนนมี 2 ประเภท คือ ยางบดผสมและยางคงรูปกับวัตถุดิบของยางธรรมชาติ

เทคโนโลยียางผสมแอสฟัลท์สำหรับราดผิวถนน

กระบวนการผลิตยางผสมแอสฟัลท์มี 2 แบบคือ การผลิตแบบแห้งและแบบเปียก ในกระบวนการแบบเปียกใช้ยางก้อนทำปฏิกิริยากับยางแอสฟัลท์ก่อนใช้ ด้วยยางยึดเกาะเรียกว่า Rubber-bitumen ในยุโรป หรือ asphalt rubber ในอเมริกา มีองค์ประกอบ 3 ส่วนในการปฏิบัติในกระบวนการแบบเปียกได้แก่ การผสมยางก้อนและยางแอสฟัลท์ให้ทำปฏิกริยากัน แล้วนำไปใช้ในโครงการที่เตรียมไว้ ส่วนในกระบวนการแบบแห้งใช้ยางก้อนทำให้แตกฝุ่ยในอุปกรณ์ผสมแบบร้อนก่อนที่จะเติมยางแอสฟัลท์ลงไป หลังจากนั้นนำส่วนผสมดังกล่าวเข้าผสมกันในเวลาเดียวกัน(ใช้เวลาผสม 45-60 วินาที) ระหว่างการผสมระยะสั้นนี้ยางก้อนบางส่วนซึ่งเป็นยางก้อนขนาดเล็กจะละลายในยางแอสฟัลท์ ขณะที่ยางก้อนหยาบหรือขนาดใหญ่จะคงอยู่เป็นตัวเติมหรือสารที่เป็นผงร่วมไม่เหมือนกับ rubber-bitumen ที่ไม่สามารถจะรู้ได้ชัดเจนเกี่ยวกับคุณสมบัติของสารยึดเกาะที่ปรับตัวไประหว่างกระบวนการ

วิธีนี้ใช้กับการผลิตยางแอสฟัลท์แบบร้อนเท่านั้น ไม่รวมถึงวิธีราดถนนด้วยยางแอสฟัลท์อื่น ๆ เช่น วิธีการปูผิวถนน วิธีนี้ปรกติใช้กับยางผงเท่านั้น ไม่ต้องใช้เครื่องมือพิเศษใดๆ ในกระบวนการ เว้นแต่ต้องรู้สัดส่วนของระบบป้อนวัสดุซึ่งใช้กับเครื่องผสมขนาดใหญ่เท่านั้น กระบวนการผลิตแบบแห้งนี้ จะก่อให้เกิดปฏิกริยาระหว่าง CRM และยางแอสฟัลท์ และในกระบวนการ CRM จะแสดงค่าดรรชนีชี้สภาวะการราดปูผิว(PCI) ที่เสื่อมได้เร็วกว่าการราดปูผิวถนนโดยใช้ยางแอสฟัลท์ตามวิธีปรกติ

บทสรุป

ในการค้นเอกสารดังกล่าวชี้ให้เห็นว่า การใช้ยางราดผิวถนนได้มีการศึกษาไว้มาก ซึ่งมีข้อดีมากกว่าการใช้ยางแอสฟัลท์ราดถนนแบบปรกติ การใช้ยางผสมแอสฟัลท์ไม่เพียงแต่จะปรับปรุงคุณภาพและอายุการใช้งานของผิวถนนได้สูงขึ้นเท่านั้น แต่ยังเป็นการแก้ปัญหายางล้อใช้แล้วที่เป็นปัญหาด้านสิ่งแวดล้อมให้หมดไปได้อีกด้วย แต่อย่างไรก็ตามการนำเทคโนโลยีด้านนี้มาใช้ในประเทศผู้ผลิตยางธรรมชาติที่กำลังพัฒนาค่อนข้างจะจำกัด

มีเทคโนโลยีการผลิตยางผสมสำหรับราดผิวถนน 2 แบบคือ แบบแห้งและแบบเปียก กระบวนการผลิตแบบเปียกจะมีประสิทธิภาพและมีอายุการใช้งานนานกว่าการผลิตแบบแห้ง

จึงเป็นที่หวังว่าการวิจัยต่อไปจะเป็นผลทางด้านต้นทุนการใช้

surface treatments. This process is normally used when a rubber aggregate product is desired. No special equipment is needed for this process except a calibrated proportioning feed system is necessary when drum plants are used. The dry process will generate some reaction between the CRM and asphalt cement. In this process, CRM exhibits lower Pavement Condition Index (PCI) values that are deteriorating at a faster rate, than anticipated, for conventional asphalt pavements.

CONCLUSIONS

The literature survey indicates that rubberised road surfacing has been widely studied and is becoming more popular for its merits and advantages over the conventional asphalt road. The use of crumb rubber modified asphalt not only improves the quality and life span of the pavement, it also provides a solution for tyre disposal problem which contributes greatly to the benefit of environment. However, the uptake of the technology, especially in the developing NR producing countries is rather limited.

There are two processes available on rubber modified bitumen technology for road surfacing i.e. the wet process and the dry process. The wet process will result in more efficient and durable road-surfacing pavement as compared to the dry process.

It is hoped that further research will result in cost effective usage of NR, either in the form of scrap rubber or virgin NR, as input in rubberised bitumen binders if price constraint has become less significant. Among the NR producing countries, it is heartening to learn that some of them have carried out successful trials on rubberised bitumen pavement for road surfacing and are progressively expanding its usage. It is expected that this would result in better quality road surfacing as well as a further increase of NR consumption.

Rubberised road surfacing however, has not developed as rapidly as it should. One of the main obstacles for its rapid and wide application is that it costs more than the conventional asphalt road, despite its longer life span and lower maintenance costs. The social and economic impact of the technologies and its applications are quite encouraging. Rubberised road surfacing would also result in more comfortable driving, reduce traffic noise, and absorb light that can protect the driver's eyes.

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Rubberised road surfacing would also result in more comfortable driving, reduce traffic noise, and absorb light that can protect the driver's eyes.

ถนนราดผิวด้วยยางทำให้ขับรถสบายขึ้น ลดเสียงดังจากการจราจร และยังดูดแสงที่เป็นการป้องกันสายตาของผู้ขับรถได้ดีอีกด้วย

ยางธรรมชาติ ไม่ว่าจะเป็นขี้ยางหรือยางสดเป็นตัวยึดเกาะในการราดผิวถนนมากราคาอางตกต่ำ เป็นที่ทราบดีว่าระหว่างประเทศผู้ผลิตยางธรรมชาติบางประเทศได้มีการวิจัยการใช้ยางราดผิวถนนด้วยความก้าวหน้าและสัมฤทธิผลเพื่อขยายการใช้ออกไป จึงหวังว่าจะมีถนนที่มีคุณภาพสูงขึ้นและยังเป็นการเพิ่มการใช้ยางธรรมชาติขึ้นด้วย

การใช้ยางราดผิวถนนยังไม่ได้รับการพัฒนารวดเร็วอย่างที่คิด อุปสรรคสำคัญคือ การนำมาใช้ให้รวดเร็วและแพร่หลายได้ ต้องคำนึงถึงต้นทุนค่าใช้จ่ายซึ่งสูงกว่าการราดผิวถนนโดยยางแอสฟัลท์ตามวิธีปรกติ ทั้ง ๆ ที่อายุการใช้งานนาน และค่าบำรุงรักษาต่ำกว่าก็ตาม ผลกระทบทางสังคมและเศรษฐกิจนับว่าเป็นที่น่าสนใจ ถนนราดผิวด้วยยางทำให้ขับรถสบาย ลดเสียงดังจากการจราจร และยังดูดแสงที่เป็นการป้องกันสายตาของผู้ขับรถได้ดีอีกด้วย

(Courtesy of INRO)

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A Survey On The Use Of Rubber In Bituminous Pavements: 1945-1961.

Betty Jo Clinebell

&

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A Survey on the Use of Rubber In Bituminous Pavements: 1945-1951

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DURING the last fifteen years, considerable investigation has been devoted to the study of the incorporation of rubber in pavements. This subject of current technical interest can be traced to conceptions which occurred as early as 1844 *(1)*. An asphalt-rubber paving company was established in France in 1901 *(2)*. In 1902, records show that a rubber-based hydrocarboned road surfacing was made in Cannes *(3)*. Between 1922 and 1924, liquid rubber, a mixture of ground rubber and fillers, and latex were tested for roads *(1)*. In 1925, the pioneering developments were begun in the United States *(4)*. For the next twenty years, several programs were conducted by the Dutch *(5, 6)* and the British *(1, 7)* in this field.

Detailed information concerning the conclusions of these early experiments is widely scattered and difficult to obtain. Since 1945, more concentrated effort has been placed on the subject by contemporary scientists and engineers throughout the world.

Numerous Test Strips Laid

In the United States, test roads have been laid in Ohio, Virginia, Texas, Minnesota, New York, Maryland, Connecticut, Massachusetts, Georgia, Arkansas, and Washington, D. C. *(4, 8-20)*. A number of constructions have been made by the Dutch in various sections of the Netherlands *(5, 9, 21-24)*. Since 1948, l'Institut Francais du Caoutchouc has been conducting researches on the use of rubber in road-making *(21, 22, 24-27)*. Rubberized asphalt road surfaces are also being investigated in England, Canada, Java, Malaya, Penang, Indonesia, Singapore, Belgium, Newfoundland, Finland, Sweden, Denmark, and South America *(1, 5, 9, 22-24, 28-37)*.

The forms in which rubber has been used in pavement constructions includes natural and synthetic latex and natural, synthetic and reclaimed powdered rubber *(3, 9)*. Latex has been incorporated with emulsions of tar and asphalt, which mixture was spread on the macadam *(38)*. This type of construction has been used in France *(39)*. The mix used on one experimental stretch comprised the addition of 28.8 liters of 38% latex to 400 liters of bitumen emulsion, resulting in a rubberized emulsion containing 50% bitumen of which the bitumen contained 5% rubber *(40)*. Mixtures of this type have been spread at the rate of 1.5 kilograms per square meter and mixed with gravel at the rate of 10 liters per square meter *(41)*.

A number of investigations have been conducted to study the action of rubber on asphaltic bitumen *(1, 9, 20, 42-48)*. It is generally concluded that the rubber powder absorbs the volatile constituents of the bitumen and swells to several times its original volume. This results in a system in which swollen rubber is dispersed in bitumen having a higher softening point and lower penetration than the original bitumen.

Since natural latex stabilized with ammonia has a pH similar to that of bitumen emulsions, latex may be mixed directly with bitumen without flocculation. Latex mixed with bitumen at the time of heating the bituminous concrete gives a finer dispersion than powdered rubber. Latex has been mixed with anthracenic oil emulsions for use in regenerating the surface binder *(9)*. Buna N type latex added to asphaltic material has been employed as a protective sealing coat on asphaltic surfaces *(49)*.

In 1949, the Virginia Department of Highways conducted field experiments incorporating natural and reclaimed powdered rubber in the bituminous concrete-sand asphalt wearing surface; also, a third section used natural rubber added to cut-back asphalt for a seal treatment *(50)*.

In a study of the effect of butadiene-based synthetic rubber powders on the properties of road-type petroleum asphalts, the rubber powder was prepared by standard methods such as (a) grinding pretreated bulk rubber, (b) spray-drying a latex, and (c) coagulating latex to a fine crumb *(48, 128)*.

The improved properties of bitumen obtained by the use of 5% of a special synthetic rubber powder are an indication that synthetic rubber may be better than natural rubber for road surfaces *(51)*. Studies of the effect of the chemical composition of the rubber powder (kind of rubber, natural or synthetic, and the rubber and carbon black content) indicate that a high carbon black, tread-type compound is best for asphalt road surfaces; that about 10% of the powder should be added to the asphalt; and that powder made from a blend of natural

An Invitation . . . . .

This survey on the use of rubber in bituminous pavements was prepared in the Rubber Library maintained at the University of Akron in Akron, Ohio, by the Division of Rubber Chemistry, American Chemical Society. It is the first of a number of contemplated surveys, the plan being to make each one available to the rubber industry in some form or another. It is the intention of the Rubber Division's Library Committee to select those subjects which may have the greatest interest to the industry. Accordingly, readers are invited to suggest subjects for future surveys. Suggestions should be sent to Miss Betty Jo Clinebell, Librarian, Rubber Library, University of Akron, Akron, Ohio.

and synthetic rubber has advantages over both the pure natural and the pure synthetic rubbers *(52)*.

When an asphalt mixture containing evenly distributed ground reclaim is used, the resulting surface has a mat finish with numerous projecting rubber particles; it is claimed that this gives improved non-skid properties *(31)*. Tire scrap has been utilized in this manner *(48, 53)*.

A "meltable rubber compound" has been blended with asphalt for use in pavements *(54)*. The "meltable rubber compound" is added to the hot bituminous oil used in preparing the resurfacing mixture, whereas powdered rubber is added to the dry aggregate *(55)*.

Rubber powder may be added to asphalt in two ways: (a) by mixing the rubber powder with the asphalt, and (b) by adding the rubber powder to the aggregate and then mixing with the asphalt *(20, 56)*. The latter method has been used in most of the United States experimental tests *(57)*. From the plant operator's point of view, the addition of the powder to the aggregate is simpler; the rubber powder is simply handled as a filler and added as such to the aggregate. However, experience has shown that engineers prefer a pre-blend of the rubber and the asphalt. When rubber powder is mixed directly into asphalt, the temperature should not exceed 300° F. (149° C.), and the period of heating must not be prolonged *(1)*.

The effect of heating time and temperature when powders from vulcanized rubber are used is less marked than that found with latex powder; Van Rooijen described a kind of "phase reversion" which occurred when asphalt containing 10% latex powder was heated for long periods at high temperatures, wherein asphalt instead of rubber becomes the disperse phase *(52, 58, 59)*. For tests carried out by the Indonesisch Instituut voor Rubberonderzoek in Kuala Lumpur, the rubber was mixed with either cold or warmed asphalt *(60)*.

It has been claimed that the rubber powder should be as fine as possible, it should be sifted, and should be produced in a toothed-rim or similar mill, rather than a grinding mill *(52)*.

Proportions of Rubber Used

Different proportions of rubber have been added to paving mixtures to make rubberized surfaces. The quantity of rubber powder by weight of asphalt used in most cases ranges from 5 to 10% *(51, 61)*; however, the specifications for one asphalt paving material called for 5 to 30% rubber by weight of the asphalt *(62)*. Since the rubber and asphalt mixture comprises only a small percentage of the paving mixture, the actual amount of rubber powder in the road-building material is only a fraction of 1% *(63)*. When "meltable rubber" is used, the basic mixture contains about 1.25% of this material *(64)*.

It has been stated that as little as 400 pounds of rubber would be needed per mile of highway *(65)*. However, in an actual test in Virginia, it was found that about 3200 pounds of rubber was used per mile of 2-lane, 20-foot pavement; it is assumed that the smaller figure is based on experience in Holland, where a thin top dressing, which is applied by hand placing, is preferred, whereas in the Virginia test a paver was used to place the thicker wearing course *(66)*.

Rubber-asphalt paving mixtures can be mixed and rolled in the same manner and with the same equipment as with ordinary asphalt paving *(67-69)*. Test sections in the United States have been conducted where conditions, such as sand and other materials and methods of application, were different *(8)*. Near Akron, Ohio, a resurfacing material containing finely ground sand slag, replacing a higher-priced material, and rubber was spread in a thin layer on a notoriously slippery surface *(70)*. The United States test sections range from one thousand feet to one mile in length, and, depending upon the type of construction, the thickness varies from one-eighth to one and one-half inches *(20, 63, 69)*.

Two general types of road constructions utilizing rubber have been made: (a) bituminous-concrete, sand-asphalt rubber mixtures in courses of varying thicknesses, and (b) surface treatments or seal coats *(61, 71)*. In Holland, the chief application of bitumen-rubber mixtures has been as a surface dressing on top of coarse asphalt roads *(72)*. Ohio has used a slag-sand-asphalt-rubber mix as a deslicking agent *(73)*. Test surfaces in England were made partly with, partly without precoated granite chips *(74)*. Rubber-asphalt pavements have been laid in New York over cobblestones *(15)* and over granite blocks *(18)*. An asphalt mixture containing rubber must be laid while hot; such a mixture has a tendency to stiffen and therefore it must be used immediately and should not be stored overnight *(61, 75)*. The appearance of roads containing rubber is not visibly different from those without rubber *(50)*. It has been stated that a rubberized mix is more homogeneous than a normal mix, and that there is never any evidence of free oil coming to the surface. Traffic can be resumed sooner on a surface containing rubber than on an ordinary surface *(55)*.

Another use of rubber in roads includes rubber blocks, which are expensive, but which are useful where sound absorption is important *(76-80)*. According to a British patent of 1948, a road surface is claimed, made by preparing a rubber mat or sheet containing large inclusions of flint, stone, or granite. Such inclusions are first coated with metal, such as brass, as by spraying, to increase adhesion to the rubber. In order to prevent damage to rolls or platens used to prepare the sheet, both surfaces are coated with a layer of low grade rubber composition. This presents a smooth surface to the rolls and platens, but quickly wears away with traffic to expose the inclusions, which then provide a non-slip surface *(81)*.

In general, the properties of asphaltic paving materials which are affected by the incorporation of rubber are: thermal susceptibility, aging, and skid resistance *(3, 4, 9, 20, 48, 63, 76, 82, 83, 128)*. Test results to date indicate that when rubber is added to asphalt road compositions the road surface is more durable and has better anti-skid properties, the foundation is better protected, maintenance costs are lower and there are less traffic hold-ups due to repairs, and the road surface is more hygienic because of the absence of dust *(5, 68, 72, 84)*. A layer only a millimeter thick will protect and seal a road surface and give it good anti-skid properties *(76)*. The addition of rubber changes asphalt's susceptibility to shock, and improves the cushioning effect, which persists at 0° F. *(85, 86)*.

In general, a bitumen-rubber mixture furnishes a road surface which is less soft at high atmospheric temperatures, and also less brittle at lower temperatures than a road surface without rubber *(41, 72, 84, 128)*. According to several reports, the reduction of the sensitivity to heat of the mixture increases with the rubber content *(48, 87)*. After an extremely severe winter, rubber roads in the Akron area suffered less damage than non-rubberized pavement. Engineers claim that the extra elasticity accounted for the fact that the rubber road was able to withstand the expansion and contraction that accompanies severe changes in temperature *(88)*. A reduction of susceptibility to temperature variations has also been noted by the addition of latex to bitumen *(89)*.

Outstanding results of the experiments of the test

area at Tjisalak in Java proved that desirable improvements may be expected from the use of rubber-containing bitumen mixtures in the tropics *(5)*.

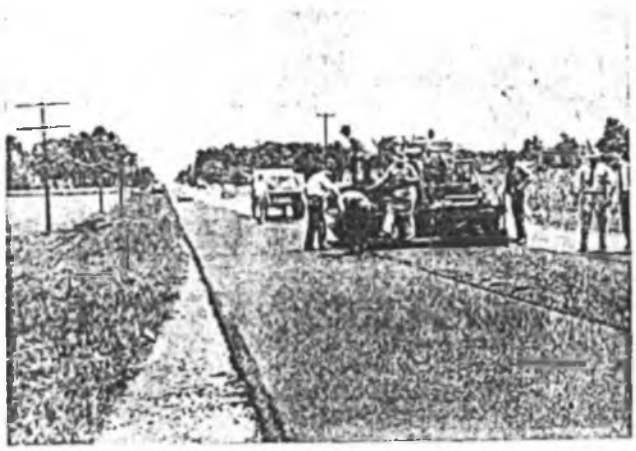
The addition of ground or powdered reclaim to road surfacing compositions has shown that neither winter cold nor summer heat appears to have had any effect on the structure of the surfacing or on its surface characteristics during the past twelve years *(31)*. The use of a special type of butadiene-based synthetic rubber powder in petroleum asphalts gives a wider useful temperature range than either new or unprocessed natural rubber. The addition of the elastomers raises the softening point of the asphalt and reduces susceptibility to temperature changes *(48, 90)*.

Most of the available test results indicate that there is a definite increase in skidding resistance by the use of rubber in pavements *(50, 57, 69, 85, 91-96)*. One investigation has shown that less than 1% of rubber in construction materials for highways provides a safety factor of 15.7% in its favor against regular highways. The use of rubber allows a car traveling 40 miles per hour to stop within 87.5 feet compared to 102.2 feet on ordinary highways. Further tests indicate that asphalt-rubber paving resists the formation of ice. A surface film of ice occurs at a lower temperature where rubber has been added to the asphalt *(57)*.

The shattering of the road surface from heavy impacts is minimized because of the resiliency of the rubber which permits the road to "give" under the weight of heavy vehicles and to spring back into shape after they have passed. It has also been noted that there is less evidence of fatigue when walking on rubber-asphalt roads than on asphalt, concrete, or other road surfaces *(97)*.

Penetration data definitely indicate that the character of the changes in asphalt vary with the type of rubber used when mixing rubber with the asphalt paving material *(20)*. One source indicates that there is a decrease in penetration of 25% by the introduction of rubber into the binder *(3)*. However, the use of 5% of a special synthetic rubber has shown up to 50% decrease in penetration *(48, 51)*. Impact as measured by height of drop for fracture at 35° F. shows that the drop height is tripled with the use of 5% of this special rubber *(51, 128)*.

Rubber-containing asphalt offers equal advantages in many types of asphaltic application, including tennis courts, basements, floors, tile, playgrounds, sidewalks, roofs, shingles, adhesives, waterproofing, and expansion joints *(5, 39, 76, 83, 90, 98-122)*.



Typical resurfacing operation for rubber-asphalt roadways.

In 1949, the use of rubber in road constructions was receiving considerable attention, but as a result of the outbreak of hostilities in Korea, this type of construction has slowed considerably because of the shortages of rubber *(123, 124)*.

Estimates of the added cost due to the use of rubber in road constructions covers a very wide range *(13, 14, 33, 61, 90, 97, 123, 125-127)*. The rubber consumption in such road surfaces is anywhere from one-third ton to a whole ton of rubber per mile of highway, the amount depending partly on the breadth and thickness of the road surface. One source indicates that the initial cost of the rubber is estimated at $400 per mile *(127)*. Another authority claims that a 5% mixture of rubber with the conventional asphalt mixture applied at an average thickness of one and one-half inches on a 24-foot highway would add about $1,000 per mile to the installation costs *(125)*. Still another source estimates that $2,500 is added to the cost of every mile of highway to which some form of rubber is added to the surfacing material *(123)*. A possible explanation for this wide range of cost estimates is the variation in price, source, and type of rubber which is used. However, the general opinion seems to be that the added initial cost would be more than offset by the reduction in maintenance costs.

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The Technical Merits Of Rubber As An Additive To Road Binders : The Present Position.

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The Technical Merits of Rubber as an Additive to Road Binders: the Present Position

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Small quantities of rubber produce large changes in the physical properties of bitumen and these in turn are reflected in the behaviour of road mixtures. The effects are influenced considerably by the kind of rubber and the method of adding it to the road materials.

The results of a systematic examination into the relative effectiveness of different kinds of rubber are described. In addition, the organisation and execution of large scale road experiments carried out during recent years in Great Britain are discussed. It is emphasised that for such experiments careful design is essential, involving the inclusion of adequate control sections, the close control of variables such as the state of the rubberised binder, the temperature and time of mixing, and spreading technique. The results obtained from these trials and their implications are described.

Although the use of rubber in bituminous road surfacings has been a subject of continuous interest and widespread activity over a long period of years, its value and acceptance has yet to be generally established. Reasons for this are not hard to find. Firstly a number of attendant disadvantages such as extra cost of raw materials, extra cost of preparation of materials, and extra care in handling and laying have to be reckoned with. Secondly, although numerous road surfacings have been laid in many countries by both natural and synthetic rubber interests, little reliable evidence has been produced to show comparisons between the performance of rubberised and non-rubberised materials. As yet, there are hardly any well-founded data showing the relative advantage of the use of rubberised materials in relation to the increase in cost. This lack of conclusive evidence, after prolonged activity, has created scepticism in some quarters and it appears unlikely that a much wider use of rubber in road surfacings will ensue until the advantages can be more definitely specified.

Only well-designed road experiments can provide the necessary data. This was recognised some years ago in the drawing up of a cooperative programme of research to be carried out in the United Kingdom by the Natural Rubber Producers' Research Association, the Natural Rubber Development Board and the Road Research Laboratory of the Department of Scientific and Industrial Research. The programme was started in 1951, and involved carrying out a sufficient number of full scale road experiments designed on the basis of associated laboratory studies.

LABORATORY STUDIES OF THE PROPERTIES OF RUBBERISED ROAD MATERIALS

The phenomenon of road wear is so complex and ill understood that no laboratory tests can be applied which reproduce and generally correlate with road performance. Laboratory investigations can, however, reveal:

1. Changes in the properties of bitumen and bituminous road surfacing materials which result from the addition of rubber and may be expected to influence their service performance.

2. How these changes can best be realised in respect of the type, amount, and method of incorporation of rubber.

3. The preferred modifications which merit practical testing, and hence offer a basis for the design of road experiments.

4. How industrial procedures for the manufacture and laying of road binders and surfacings can be adapted to give properly modified materials.

All of these aspects have been examined in some detail and in each case certain general conclusions are now available.

Effect of Rubber on Physical and Mechanical Properties of Bitumen and Road Surfacing Mixtures

It is now clearly established that the main consequences of the addition of rubber to bitumen follow from changes in the viscosity, strength and elasticity characteristics (VAN ROOIJEN, 1938; DE DECKER AND NIJVELD, 1951; MULLINS AND SMEE, 1951; LEWIS, PECK, REX AND WELBORN, 1954; NATURAL RUBBER DEVELOPMENT BOARD, 1956). Quite small quantities of rubber produce very large changes in these properties. The apparent viscosity is increased many times by the addition of a few per cent by weight of rubber. This in itself is not important as bitumens with widely different viscosities are readily available, but associated with this change the susceptibility of the bitumen to changes in temperature is greatly reduced. Typical results of the changes in penetration, softening point and penetration index are given in *Table 1*. These clearly show that in all cases the effect of rubber is to decrease the penetration and at the same time to increase the softening point. Figures of the penetration index which are included in the last column show a pronounced reduction in the susceptibility of the binder to changes in temperature.

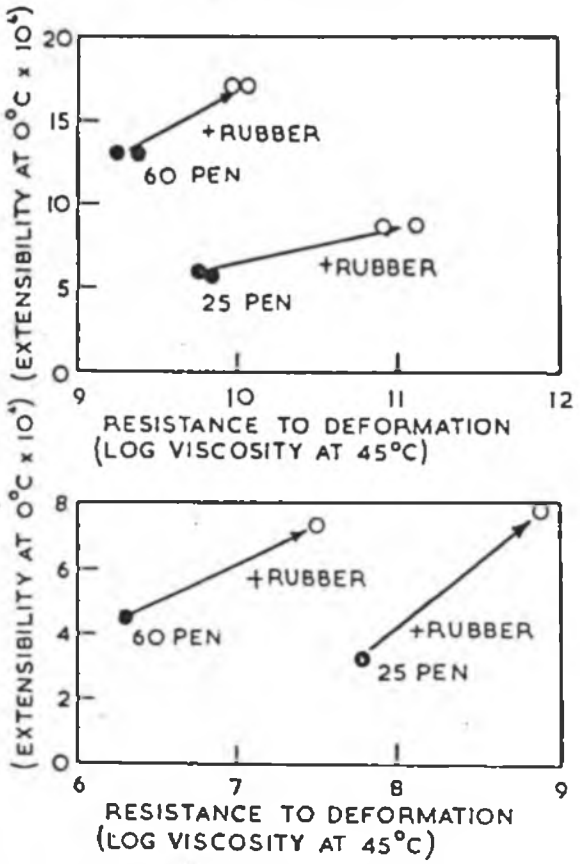


Figure 1. The increased resistance to brittle fracture and to deformation at high temperatures which results from the addition of rubber road asphalt (top) and road binders (bottom).

A more striking demonstration of the important changes of the properties of the binder which results from reduced temperature susceptibility is shown by a comparison of the softness or deformability of both rubberised and non-rubberised binders at high temperatures and their brittleness at low temperatures (MASON, SMITH AND THROWER, 1957). The effect of rubber is to increase the resistance to deformation at high temperatures and yet at the same time reduce its tendency to brittle fracture at low temperatures. Since brittle fracture when cold and flow when hot are major factors contributing to failure of road sur-

TABLE 1. EFFECT OF RUBBER ON PROPERTIES OF BITUMEN

Bitumen	Rubber	Period of heating	Penetration (77°F)	Softening point	Penetration index
AC/1	None	—	87	118	— 0.2
"	5% Vulcanised crumb (Mealorub)	2 hrs at 300°F	66	142.5	+ 1.7
Bitumen 50/60	None	—	57	129	0
"	5% Unvulcanised crumb (Pulvatex)	2 mins at 320°F	41	140	+ 0.5
Mexphalte 60/70	None	—	57	120	— 1.5
"	5% Vulcanised crumb (Mealorub)	2 hrs at 300°F	41	136	+ 0.1

TABLE 2. EFFECT OF RUBBER ON PROPERTIES OF ROAD MIXTURES

% Rubber	% Voids	Marshall stability	Hveem stability	Cohesion strength
0	5.21	1638	44	146
5% (Mealorub)	5.23	1695	46.3	214

facing in countries such as Great Britain, which have temperate climates, these improvements in behaviour would appear to be potentially of considerable advantage. *Figure 1* demonstrates the results of laboratory studies on this role of rubber in both bitumen and sand-asphalt.

Another important and obvious change in quality which results from the addition of rubber is the development of extreme 'rubberiness'. It is shown by the pronounced resiliency, toughness, tenacity and highly elastic nature of rubberised bitumens. Such a quality is difficult to measure in an objective way but it is reflected in part by the improved temperature susceptibility already discussed, by improved strength and toughness particularly when subject to suddenly applied stresses or exposed to low temperatures, and by improved resistance to cold flow.

Extensive laboratory investigations have confirmed that changes in the mechanical properties of road surfacing mixtures containing aggregate and fillers are parallel to those which occur in the binder alone. For example a mixture made with rubberised bitumen shows increased strength and toughness in conventional stability tests (*Table 2*).

Other properties of bituminous binders which may be expected to affect road performance are the adhesion between binder and aggregate, volatility and susceptibility to atmospheric oxidation. The results of laboratory tests on both of these properties show that the addition of rubber does not adversely affect them; indeed, a slight improvement appears to result (LEWIS, PECK, REX AND WELBORN, 1954).

Effect of Method of Incorporation and Type of Rubber

The extent to which the physical properties of a binder are altered by the addition of rubber depends upon both the amount and type of rubber and the temperature and period of heating.

If rubber in a powder or crumb form is added to hot bitumen it exists in the bitumen firstly as a dispersion of fine particles of rubber. In this state, the physical effect on the bitumen is relatively small. On further heating, these particles of rubber swell and ultimately dissolve to give a tough rubbery material. There is no generally recognised test which indicates when the blending of rubber in bitumen has been completed and when the resulting rubberised material is at its most effective for the type of surfacing on which it is to be used, but it has been clearly shown that the improvement in physical properties of the binder produced by the rubber are most marked when the rubber is thoroughly dispersed or dissolved in the bitumen rather than existing as discrete particles. Experience during road laying experiments, suggests that the optimum blending of rubber powder in bitumen has been reached when traces of the powder are still observable in the bitumen but when most of the material has been transformed into a soft gelatinous state. Conditions governing the addition of rubber powders have therefore been laid down on this basis; these involve close control of the temperatures and periods of heating during road laying. Recommendations for the minimum heating for the three commercially available natural rubber powders are as follows (NATURAL RUBBER DEVELOPMENT BOARD, 1958).

Harcrumb		*Pulvatex*		*Rodorub*	
180°C	½ hour	165°C and higher	10 mins.	170°C	½ hour
170°C	1 hour	150°C	¼ hour	160°C	1 hour
160°C	2 hours	135°C	½ hour	150°C	1½ to 2 hours
150°C	3–4 hours	125°C	¾ hour		
140°C	6–8 hours				

When latex is employed, care must be exercised against excessive and dangerous foaming, and the procedure recommended is that the latex should be added slowly to the surface of the bitumen held at as high a temperature as possible; the use of an antifoaming agent is advantageous. Here again a period of heating (½ hour at 150°C) should be allowed after addition of the latex.

Prolonged heating of rubberised bitumen or road materials at high temperatures results in a progressive fall off in the "rubberiness" of the materials and is to be avoided.

A comprehensive series of measurements comparing the relative effectiveness of different kinds of rubber added in varying amounts and heated for different periods has shown that the simultaneous changes in viscous, elastic and brittle properties which result from the addition of rubber are linearly related to each other and also to the changes in softening point (SMITH, 1960). Measurement of the increase in softening point thus gives a simple method of assessing the relative merits of different types of rubber. It is confirmed that this increase is greatest when the rubber is dissolved in the bitumen and that natural rubber in latex form is the most effective, weight for weight. Unvulcanised natural rubber powder, unvulcanised SBR rubber powder and vulcanised natural rubber powder follow in this order (*Figure 2*).

Basis for Road Experiments

The results of these laboratory studies provide a guide to the best way in which rubber should be used, and to the type of road experiment in which its effect on performance may be shown to maximum advantage.

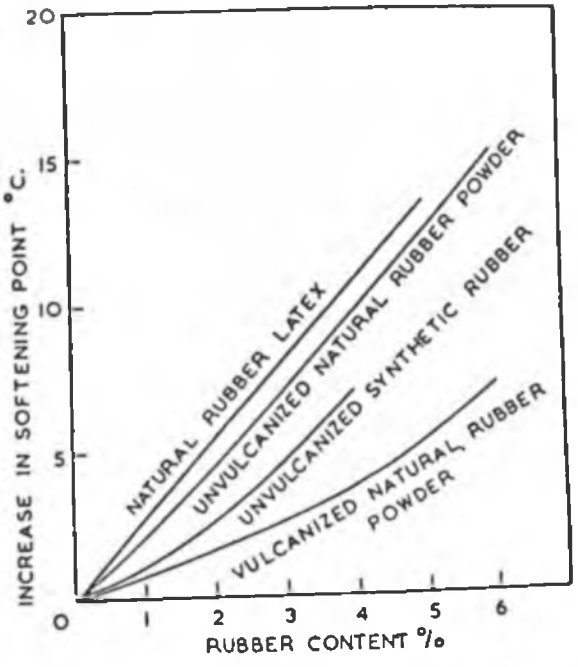


Figure 2. The effect of blending different kinds of rubber on the softening point of a 90/110 bitumen.

The importance of dissolving the rubber in the bitumen has already been discussed, and this has been an essential feature in all road experiments carried out in the United Kingdom since 1952. It is believed that a contributory reason for the lack of success of road trials conducted prior to 1952 is that the dissolution of the vulcanised powder (Mealorub) used was inadequate. It is therefore disturbing to find that reports are still being received of the laying of rubberised roads where no effort has been made to achieve dissolution, or even to define the conditions actually prevailing in this respect.

The ability of rubber to produce mixtures which are less brittle at low temperatures and at the same time less liable to flow at high temperatures would be expected to be its main potential advantage in countries with temperate climates where roads fail either because they bleed and deform in the summer or because they become brittle and crack in the winter. In countries where the seasonal variation of temperature is small, such as in Malaya, this advantage will not be of great value. The increased strength and greater extensibility of rubberised

materials should, however, result in improved performance of any road surfacing subjected to relatively large movements of the base or to heavy duty, especially in low-cost roads where larger local deformations have to be accommodated.

Manufacture of Rubberised Road Binders

The addition of rubber to bituminous road materials presents no real problem if rubber powder is used, although if this is added to the aggregate in the mixer during the preparation of pre-mixed materials, steps must be taken to ensure that the mix is held at a high temperature for a sufficiently long period for the rubber to be adequately blended with the bitumen.

The addition of latex is more difficult and the recent development by BENSON (1960), in which latex is added direct to bitumen at the refinery, is of importance.

DESIGN OF ROAD EXPERIMENTS

It has already been emphasised that conclusive evidence as to the merit of the addition of rubber can only come from road experiments. The organisation, execution, and interpretation of a road experiment is extremely complicated, and an important reason contributing to the present lack of conclusive evidence is that insufficient attention has been given to this difficulty. An examination of the numerous rubberised roads laid in a large number of countries underlines this problem. Most trials contain many factors over which little or no control can be exercised and whose contribution to the observed behaviour cannot be assessed; in cases where no adequate control sections have been laid the so-called trials are without value. For example, surface dressings are very susceptible to weather and traffic during the first few days of their lives—a feature which can only be taken into account by carrying out trials at different times of the year, in different localities, and with sufficient control sections.

It is clear that road trials should be planned and carried out, and the results analysed, with the same critical approach as is employed in laboratory research. There appear to be two possible approaches. The first is essentially a statistical one. In this, the behaviour of a very large number of rubberised and non-rubberised road surfacings constructed in normal practice is observed. The basic difficulties lie in the maintenance of adequate records and in the extreme care needed in interpreting the data. The second approach involves carefully designed and well controlled full-scale road experiments. A pattern for such experiments has been described by LEE (1950) and followed in road trials carried out in the United Kingdom in conjunction with the Road Research Laboratory. It requires the laying of a sufficiently large number of sections of road in each experiment, to permit the introduction of important variables, including compositions leading to premature failure. The variables have usually been rubber content of the bitumen, rubberised bitumen content of the surfacing, and hardness of the rubberised bitumen. It also demands adequate technical control to permit the study of the variables within the limits specified. Lastly, facilities are required for assessing the performance of the experimental road surfacings, including the analysis of multiple records.

This technique has an added advantage in that by arranging for some sections to fail prematurely it may provide a short cut to results which otherwise would take many years to obtain.

ROAD EXPERIMENTS

Figure 3 shows the sites of the full scale road experiments designed to compare rubberised and non-rubberised surfacings in the United Kingdom (NATURAL RUBBER DEVELOPMENT BOARD, 1958). The main effort has been concentrated on short-lived road surfacings or on surfacings subjected to heavy duty or large deformations. These are surfacings in which the improved properties resulting from the addition of rubber may be expected to show up to maximum advantage and from which reliable conclusions should be possible in a reasonably short time. Up to the end of 1959, ten surface dressing experiments were carried out on roads carrying widely different traffic densities, four experiments on the repair of cracked rolled asphalt with mastic, two experiments on timber decked bridges, three experiments with rolled asphalt over concrete (for the prevention of reflective cracking under heavy traffic) and one rolled asphalt and one bitumen-macadam experiment on roads subject to heavy traffic. In no case is a final assessment yet available. The results so far indicate that in surface dressings the addition of rubber to bitumen enables it to resist the onset of hot weather without fatting up, this advantage being especially apparent at the heavier rates of spread of the bitumen on roads carrying heavy traffic. Further, a small initial advantage in wetting and chip retention has been observed. With mastic asphalt, rubber in high concentrations (up to 15% vulcanised powder) prevents reflective cracking from road foundations, although no satisfactory material has yet been produced for timber decked bridges. With rolled asphalt, however, up to 5% of vulcanised powder does not prevent reflective cracking. In due course, these experiments should provide reliable information on the relative durability of the rubberised materials and any increase in tolerance of binder content which may result. Further road experiments are envisaged involving rolled asphalt surfacings.

Reports have been received of two full-scale road experiments in Malaya. These have been conducted on similar lines and involve a series of bitumen macadam carpets on the Seremban-Port Dickson Road laid in 1954 and a series of wet sand mixes on the Kuantan-Kemaman road in Pahang.

It is considered that road experiments of this type provide the quickest and the most reliable method of comparing the behaviour of rubberised and non-rubberised road surfacings. Those already laid in the United Kingdom may well be sufficient to provide reliable information as to the advantage of the use of rubber in surface dressings and of its use in mastic asphalt to prevent reflective cracking. Further experiments are still necessary to amplify those examining rolled asphalts and bitumen macadam. However, conclusions from these experiments may not necessarily be directly applicable to other parts of the world, and experiments should also be carried out in other countries to take into account differences in climate and in local conditions.

COMMERCIAL ROAD INSTALLATIONS

Apart from the full scale road experiments there is a continued and progressive use of rubberised materials by road authorities in many parts of the world. It has not been possible to keep track of all the road sections which have been laid in Africa, Australia, Canada, Europe, Malaya, New Zealand, the United Kingdom, the U.S.A. and elsewhere, but *Table 3* gives an analysis of recorded installations of roads incorporating natural rubber. This table only gives commercial road layings in which the Natural Rubber Development Board was consulted; there have undoubtedly been numerous other layings.



Figure 3. Sites of full-scale road experiments with rubberised materials in the United Kingdom.

TABLE 3. RECORDED ROAD LAYINGS INCORPORATING NATURAL RUBBER, TOTAL TO 31.12.59

Country	No. of layings	Equivalent mileage
Africa	33	41.3
Australia, Tasmania, New Zealand	193	107.3
Canada	8	4.0
Malaya	166	75.8
Great Britain	204	200.4
United States	132	97.6
Miscellaneous	5	1.3
Total	741	528 (approx)

It is not anticipated that any conclusive evidence as to the merit of the use of rubber will result from these commercial road layings, but they clearly reflect widespread interest; in many instances, where repeat and regular orders have resulted after an initial trial, they have apparently given convincing evidence of the advantages accruing from the use of rubber.

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TECHNO-ECONOMIC FEASIBILITY OF USING NATURAL RUBBER MODIFIED BITUMENS FOR MAINTENANCE OF FLEXIBLE PAVEMENTS

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By

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1 INTRODUCTION

1.1 Flexible pavements constitute over 95% of total road network and airfields in our country. The growth of economy of a country depends largely upon efficient transport system with minimal possible hindrance to road user due to periodic and routine maintenance. The increased volume of traffic, overloading of axles in excess of permissible limits (Table-1) and very high vehicle damage factor have caused widespread problems for performance of flexible pavements. The various performance reports indicate that useful life of bituminous overlays has declined from average value of 6-8 years in past to about 2-4 years in recent years. The volume of traffic and subsequent congestion (bumper to bumper traffic) is often there, if one is overlaying one lane of the highways. Because only one lane is available, within hour traffic gets piled on both the sides to the extent of 10-12 kilometers on some of the highways. To see, that this should not happen, it is essential to produce surfaces, which do not require frequent overlaying as the economic loss caused due to obstruction and frequent repairs is very high.

Table-1: Traffic, VDF and MSA on some typical National Highways (Source; MOST R-2 Report, 1992)

Name of the road	Location	VDF 1992	CVD 1992	Traffic (MSA)	
				1997	2002
NH-4	Poona-Bangalore (Km. 188;Chitradurga)	7.08	2964	44	108
NH-7	Madurai-Kanyakumari (Km. 48; Virudunagar)	3.85	4218	34	84
NH-45	Madras-Tirchi (Km. 197; Ulundurpet)	3.64	2017	16	30
NH-3	Dhule-Nasik (Km. 356; Chandwad)	5.16	2385	26	64

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1.2 It is well known that under the prevailing heavy traffic and extreme environmental conditions, the conventional bituminous overlays, in general, are not meeting the durability requirement. Some field engineer's opine that bitumen they receive these days is not of the same quality, as it used to be earlier. The accelerated deterioration of flexible pavements overlay burden the periodic and routine maintenance budget, which in turn affects the availability of funds for new developments. It is a global view that quality and longevity of pavement must, therefore be ensured in order to reduce maintenance budget and also to save road user's cost. These requirements can be met if:

i) Quality control is efficiently imposed

ii) Performance related specification are implemented during selection of materials and design of mixes

iii) Use of improved materials viz., modified binders and new techniques is encouraged

1.3 Recently, Sharma (1) reported that existing pavement structure of National Highways and State Highways are generally 35-45 cm thick with modest bituminous surfacing representing a structure of MSN-3. The pavement deterioration curve for pavement with MSN 3 shows that a newly strengthened pavement undergoes a gradual deterioration in initial life and after 5th year, when the roughness is around 4000 mm/km, the rate of deterioration increases rapidly. A timely implementation of renewal treatment may bring down the roughness to around 1800 mm/km. A renewed pavement surface again start deterioration to reach critical value (4000 mm/km.). If the renewal is deferred to one more year, the roughness may approach near to 6000 mm/km. The economic loss by way of increase in vehicle operating cost amounts to Rs. 7-9 lakhs per km as against the renewal cost of Rs. 5 to 6 lakhs/km as reported by Sharma (1). The other way of saving is by way of extending time to reach critical roughness with the use of natural rubber modified binders.

1.4 It has been trial tested in developed countries that natural rubber modified binders are premium binders, which allow the engineer to design and build a more strong, maintenance free and durable pavements. These binders have better field performance and are proved economical, when life cycle cost is taken into consideration. Extensive laboratory studies at CRRI and elsewhere (2-6), confirm superior fatigue resistance and performance of mixes developed using natural rubber modified binders. This paper deals with review of laboratory and field trials under different traffic and climatic conditions using natural rubber modified road binders and techno-

economic feasibility and social aspect of using NR modified binders in India for maintenance of pavements and resurfacings.

2 NATURAL RUBBER AS A BITUMEN MODIFIER

2.1 The 1940, 50 and 60s saw a whole series of innovations with natural rubber in terms of new uses and commercial developments (3). The prime example is the use of natural rubber in roads. The early use of natural rubber in roads was in the Rue Fessier in Geneva in 1947 followed quite rapidly with investigations of its benefits in other parts of the World from Europe to Malaysia and Australia to cape Town. Seventy miles of road corridors, were laid in U.K. in 1955 by Road Research laboratory and following benefits were reported by the use of NR modified binders:

- **One third Improvement in life**
- **Provision of Non Skid Surface**
- **Prevention of distress caused due to low temperature**

The large scale use of NR in developed countries could not be promoted due to higher price of natural rubber as compared to cheaper bitumen. In US, rubberised roads were laid on experimental basis in places such as Ohio, Virginia, Texas, Minnesota, New York, Georgia, connectiant and Washington D.C. A large number of trials were conducted by Dutch in various parts of the Netherlands. Extensive investigations on rubberised roads were made in England, Indonesia, Malaysia, Australia and New Zealand. The French Scientist and Road engineers should be given credit for installing the first road with rubberised bitumens as reported by Jain (2), and Gopalkrishnan (7)

2.2 Thompson (4) has discussed the merits of adding natural rubber to bituminous road surfacings. The addition of rubber improve the brittleness properties, temperature susceptibility, softening point and elasticity of bitumen. A series of full scale road experiment were undertaken to show how rubberised surfacings behave under traffic in comparison with conventional bituminous materials. In surface dressing or seal coats, rubber reduces fatting up considerably and give improved retention of chippings in open textured premix carpet and increased life of overlay was recorded. The rolled asphalt and mastic asphalt were more resistant to cracking. Later on, Thompson and Szatkowski (5) reviewed results of full scale road experiment using rubberised bitumen.

2.3 Recently, Fernando and Guirguis (8) reported that physico-chemical properties of road binders are significantly improved by incorporation of a very small amount of natural rubber to produce superior asphaltic concrete, capable of withstanding a wide range of environmental and traffic conditions. The improvements in rubber modified

bitumen were quantified and significance of the results is illustrated with respect to the potential behaviour and performance of road surfacings. It is also reported that the additional cost is more than offset by extra service life, better riding quality, less maintenance and improved safety.

2.4 Recently Bose and Jain (9) reported engineering properties of Natural rubber modified bituminous mixes for construction of road surfacings. Results of flexural fatigue test indicated that fatigue life of natural rubber-bitumen blends with 4% rubber content is about five times higher than neat bitumen mixes. A relationship between strain and fatigue life for various blends is illustrated in Figure-1. Shukla and Coworkers (6) reported results of laboratory study and field trials on use of natural rubber in bituminous road construction. It is reported that incorporation of 2 to 4 per cent natural rubber to bitumen is beneficial for road construction. The improvements reported are as under:

- Improved Softening point
- Lower penetration value
- Improved Penetration Index
- Two fold life of overlay
- Economical periodic maintenance
- Suits to heavy traffic and coastal climate

3 BLENDING OF NATURAL RUBBER WITH BITUMEN

3.1 Road Note No. 36 from TRRL, UK deals with specifications of the manufacture and use of rubberised bituminous materials and binders. The code of practice covers the preblending of penetration grade and cut back rubberised binders and manufacture of rubberised rolled asphalt, mastic asphalt, bitumen macadam and surface dressing.

3.2 For blending of latex of natural rubber with bitumen, the bitumen shall be heated to a temperature of 140-170^{o}C depending upon penetration value of bitumen. The capacity of boiler shall be double than the quantity of materials to be blended. The boiler shall be fitted with propeller type stirrer or any other means of agitation. For blending of latex, antifoaming agent dissolved in Kerosene shall be dispersed in bitumen before latex is added.

3.3 The miscibility of rubber latex is easier with cutback bitumens. Rubber-bitumen blends can be prepared with cutback bitumen containing 4% kerosene oil. Incorporation of 4% natural rubber is found optimum. Incorporation of rubber more than 4% poses viscosity problems in handling of rubber bitumen blends. The blending time for NR with bitumen are as under (Road Note No. 36).

Temperature ^{o}C	Time (Minutes)	
	Unvulcanised NR	Vulcanised NR
140	25	360-480
150	15	180-240
160	10	120

3.4 As reported by Fernando (8), the particle size of rubber (in case of dry rubber powder) also influence the blending of NR with bitumen. Incorporation of NR latex produce better blend than powder. The rubberised bitumen shall not be stored for longer time at elevated temperature. The suggested storage time at different temperatures (Road Note No. 36, TRRL, UK) are as under:

Temperature, ^{o}C	Time (max)
180	3 hours
160	12 hours
140	48 hours
120 or below	7 days

4 PROBLEMS ENCOUNTERED WITH BLENDING AND SUGGESTED REMEDIES

4.1 Blending of Vulcanised rubber powder with bitumen takes longer time as compared to unvulcanised powder and latex (NR). Blending of latex at site poses following difficulties and limitation.

- Vigorous Foaming due to presence of water
- Higher Energy Consumption

4.2 To avoid excessive foaming, and consumption of extra energy, rubber need to be blended with bitumen at refinery. The advantages of blending with NR rubber at refinery are as under:

- Cost effective
- Less energy consumption and safety
- Better quality control
- Consistency in quality of modified bitumen

4.3 The estimated cost of production of NR modified bitumen at refinery is as under:

Item	Quantity (Kg.)	Cost (Rs.)
Bitumen (80/100)	960	6048
Natural Rubber	40	1600
Additive	2	160
Processing	1000	50
Total	1000	7858
Bitumen (60/70)	1000	7300

The exrefinery price of NR modified bitumen at refinery would be Rs. 7850/- per tonne as compared to Rs. 7300/- per tonne for unmodified 60/70 bitumen. The NR modified bitumen processed at refinery have added advantage of premium properties due to antistripping agent and antioxidant as additives.

5. PROPERTIES OF NR MODIFIED BINDERS

5.1 Based upon available literature, the NR modified binders are reported to have following advantage over conventional bitumens.

- Improve softening point
- High Elastic Recovery
- Reduced Fraass brittle point value
- High viscosity at higher pavement temperature
- Resistance to age hardening
- Resistance to stripping

5.2 Stripping and Ageing properties of conventional and NR modified binders are given in Table-2 and Table-3.

Table-2: Durability of Binders (Fernando and Guirguis)

Indicator (TFOT)	Unmodified	NR Modified
Ageing Index (AI)	2.02	1.000
Durability 1/AI	1.00	2.02

Table-3: Loss in Adhesion by Water

Indicator	Unmodified	Modified	Method of Test
Stripping value % with Quartzite	5-10	Nil	IS 6241
Loss in Compressure strength %	10-12	Nil	ASTM D 1075

6. PROPERTIES OF NR MODIFIED BITUMINOUS MIXES

6.1 From the review of literature above and experimental work carried out at CRRI, the NR modified mixes are reported to have following advantages over conventional mixes.

- High stability of mixes
- High Marshall stiffness
- High value of tensile strength
- Higher fatigue life
- Resistance to creep
- Resistance to rutting
- High value of stiffness modulus

6.2 The data of Marshall stability, Marshall stiffness, indirect tensile strength and compressive strength of unmodified and NR modified mixes are plotted in Fig. 2,3,4 and 5. Mix stiffness modulus and rutting data of modified and unmodified systems are given in Table 4 and 5.

Table-4: Stiffness of Mixes (Fernando and Guirguis)

Temperature	Unmodified	Modified with 4% NR	% Change stiffness value
5°C	87 x 108	73 x 10^8	- 16
25°C	8.5 x 108	12 x 10^8	+ 41
45°C	0.55 x 108	1.1x 10^8	+ 100

Table- 5 : Rutting of Mixes by Wheel Tracking Test at 60_oC (Fernando and Guirguis)

Indicator	Unmodified	NR Modified
Rut Depth after 24 hours (mm)	13.3	2.20
Rut Depth Rate (mm/hour)	0.22	0.02

The following conclusions can be drawn from the data.

At low temperature NR reduce, stiffness of mix (Table-4) and at high temperature, the increase in stiffness of mix is around 100%. These results support to rut resistance properties at high temperature and improved flexibility at low temperature. The rut resistance properties of NR modified mixes are further supported by wheel tracking test data given in Table- 5. The measured rut depth after 24 hours at 60$_{o}$C is around 2.2 mm compared to 13.3mm for 60/70 bitumen. Rut depth rate of NR modified mixes is about 0.02 mm/hour as compared to 0.22 mm/hour for unmodified mixes.

7. LIFE CYCLE COST ANALYSIS

7.1 The renewals for periodic maintenance usually provided under different traffic and climatic conditions are as under.

Specifications	Traffic CVD	Rainfall mm	Periodicity years
40mm BC	> 4500	> 1500	4-5
40mm SDBC	> 4500	< 1500	4-5
25mm BC	1500-4500	> 1500	4-5
25mm SDBC	1500-4500	< 1500	4-5
20mm MSS	1500-4500	< 1500	3-4
20mm OGPC	< 1500	< 1500	3-4
20mm OGPC-LS	< 1500	> 1500	3-4

7.2 Shukla and Co-workers (6) reported 2 times higher life with the use of NR modified bitumen for coastal climate of Kerala. The cost analysis of overlays (20mm OGPC) for 1000m$_{2}$ using modified and unmodified bitumen for 15 years designed life are given as under (assuming 50% increase in life of overlay).

Item	Cost Analysis and Specifications	
	Unmodified (60/70)	Modified (NR)
Binder	16,896	17,466
Aggregate	9,450	9,450
Filler/Sand	1,500	1,500
Processing	16,100	16,100
Total:	43,946	44,516

7.3 For a design life of 15 years, three overlays of conventional bitumen mixes are required against two renewals using NR modified bitumen. Incorporating initial cost of construction and 2% escalation for every year the periodic maintenance expenditure would be as under:

Binder	No. of Renewals Required	Total cost of Renewals			
		I	II	III	Total
60/70	3	43,946	48,517	54,635	147098
NR/Modified	2	44,516	50,751	Not Required	95267

It can be seen from above table that the cost of the periodic maintenance of flexible pavements can be curtailed to 35% which would be sufficient for maintenance of 35% additional corritores. The use of NR in road construction will also generate demand for consumption of NR and socio-economic development of NR producing states.

8. ROAD RUBBERISATION UNDER INDIAN CONDITIONS

8.1 Natural rubber is produced in adequate quantity in India and available at reasonable price for bitumen modification. The scenario of cost and availability is different in India, if we compare with developed countries. The consumption of rubber fails to match rise in production says V.S.Malaney (10). The natural rubber production during April to September 1997 has been estimated around 2.64 lakhs tonne against 2.50 lakh tonne produced during the same period in 1997. Consumption is being estimated at 2.86 lakh tonne against 2.85 lakh tonne in preceding year. In the last fiscal, India's rubber production was 5.47 lakhs tonnes. The Kerala government decided to pay subsidy at the rate of 40 paisa per kg for procuring rubber from STC. The current NR price is Rs. 35 per kg. Recently, significant progress has been made by Rubber Board to focus on socio-economic and ecological aspect in the development of rubber plantations in the North-Eastern sector. Consequently, the north-eastern region alone accounts for about 40,000 hectare under rubber. With appropriate agro-technologies evolved by research, it has been possible to obtain yield of 16-19 tonne per hectare in NT region. The Board's survey indicated that about 1.2 million hectare land would be available. Hence, sufficient NR can be made available for bitumen modifications. Eventually road rubberisation has special significance in India.

8.2 The following trials have been conducted successfully in India

1 2 cm Opengraded Premix Carpet on M.C. Road Trivandrum between Km.8 - Km.9

2 13 kms. of Roads on the way to Sabarimalai

3 Experiments conducted by the Rubber Research Institute of India show that additional cost due to rubberisation would be 16 m Kerala.

9 SPECIFICATIONS OF RUBBERISED BINDERS

9.1 A number of international specifications are available for rubber modified Binders. The key requirements of modified binders are given as under (German Specifications).

Properties	Test Method	Grade		
		80 B	65 B	45 B
Penetration, 0.1mm (100g, 5s, 25°C)	DIN 52010	> 120	> 50	> 20
Softening Point, °C	DIN 52011	40-48	48-55	55-63
Fraass Breaking Point °C	DIN 52012	- 20	- 15	- 10
Elastic Recovery, %	DIN 52013	> 50	> 50	> 50

9.2 Recently, an expert group constituted by flexible pavements committee submitted draft specifications to IRC. The key requirements of binder properties are as under;

Properties	Test Method	PMB-70	PB-40
Penetration, 0.1mm	IS: 1203	60 to 9	30 to 50
Softening Point, °C	IS: 1205	48 to 58	58 to 68
Frass breaking Point °C	IS: 9381	< -15	< -15
Elastic Recovery, %	DIN 52013	> 50	> 50

9.3 Specification submitted to IRC is in close agreement with German specifications. The grade PMB-70 and PMB-40 can be made easily by blending 80/100 bitumen or 60/70 bitumen with 2% and 4% natural rubber. Hence, NR modified bitumens are expected to be in compliance to available specifications.

CONCLUSIONS

i) A small quantity of NR viz 2 to 4% brings about dramic improvements in properties of bitumen and mixes besides significant improvements in performance.

ii) NR modified bitumen offers greater resistance to cracking at low temperature, plastic deformation at high temperature and resistance to shoving besides higher stability and Marshall stiffness values to sustain higher tyre pressure and heavier loads. The fatisol life of mixes is 4 times higher

iii) For economica reasons and to achieve better quality blending of NR at refinery is advisable. A 35% saving in periodic maintenance cost is possible with the use of NR modified bitumens.

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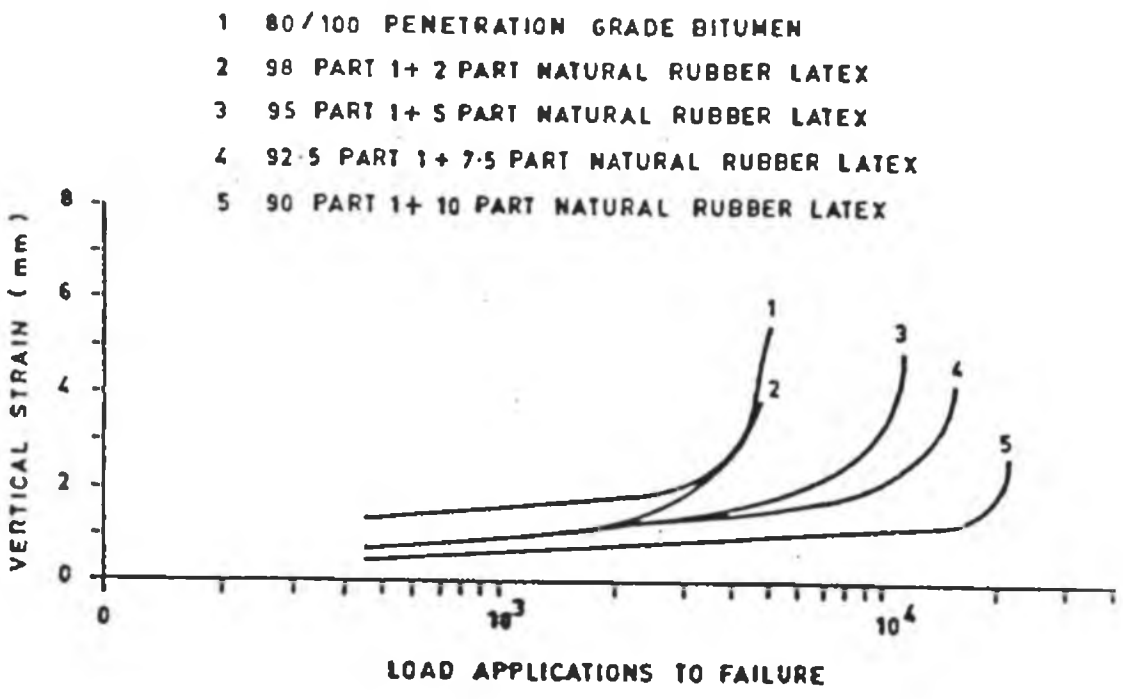


FIG.1. STRAIN- FLEXURAL FATIGUE LIFE RESULTS FOR NATURAL RUBBER LATEX - BITUMEN BLEND MIXES

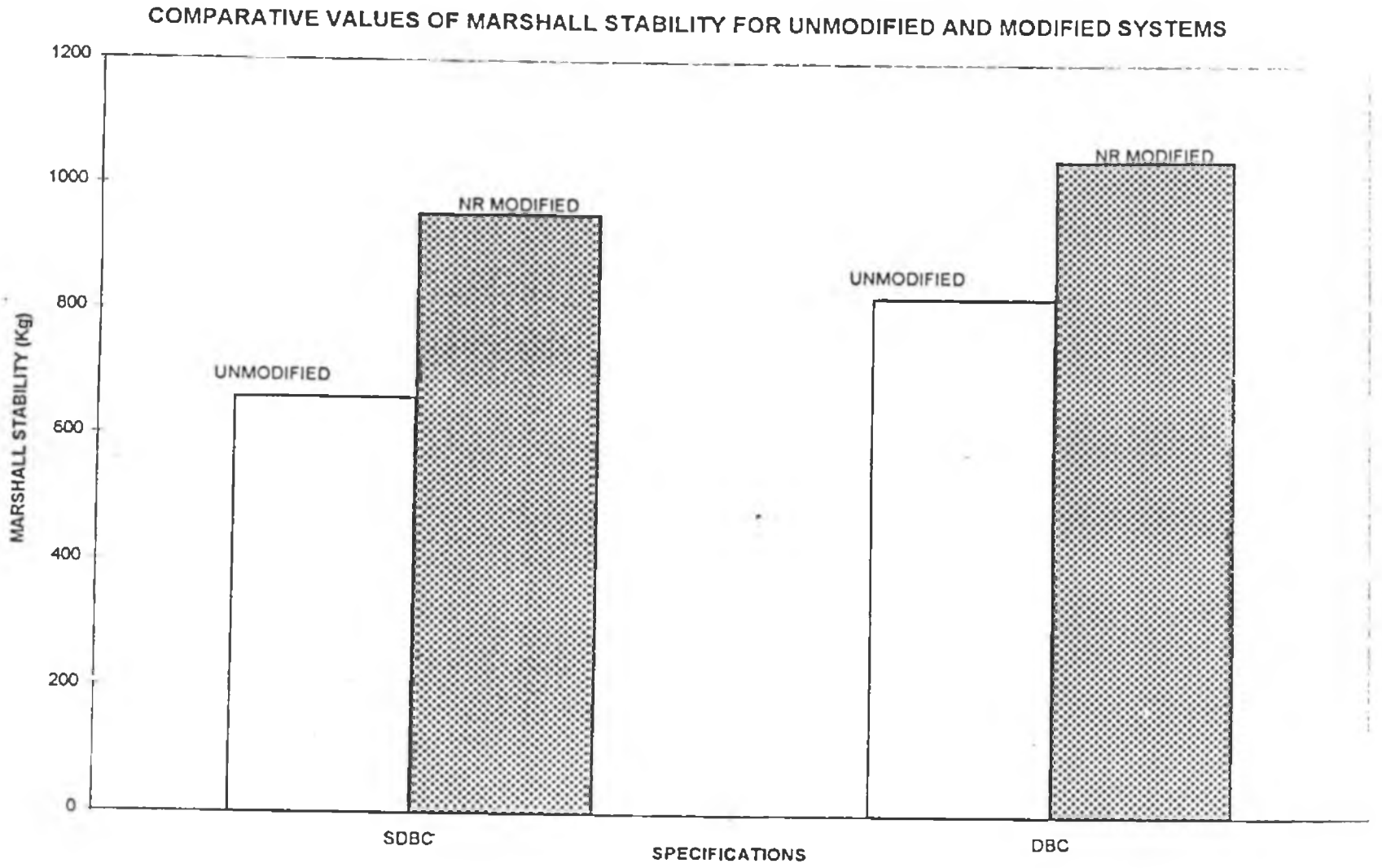

COMPARATIVE VALUES OF MARSHALL STABILITY FOR UNMODIFIED AND MODIFIED SYSTEMS
MARSHALL STABILITY (Kg)
1200
1000
800
600
400
200
0
UNMODIFIED
NR MODIFIED
UNMODIFIED
NR MODIFIED
SDBC
DBC
SPECIFICATIONS

FIG. 2

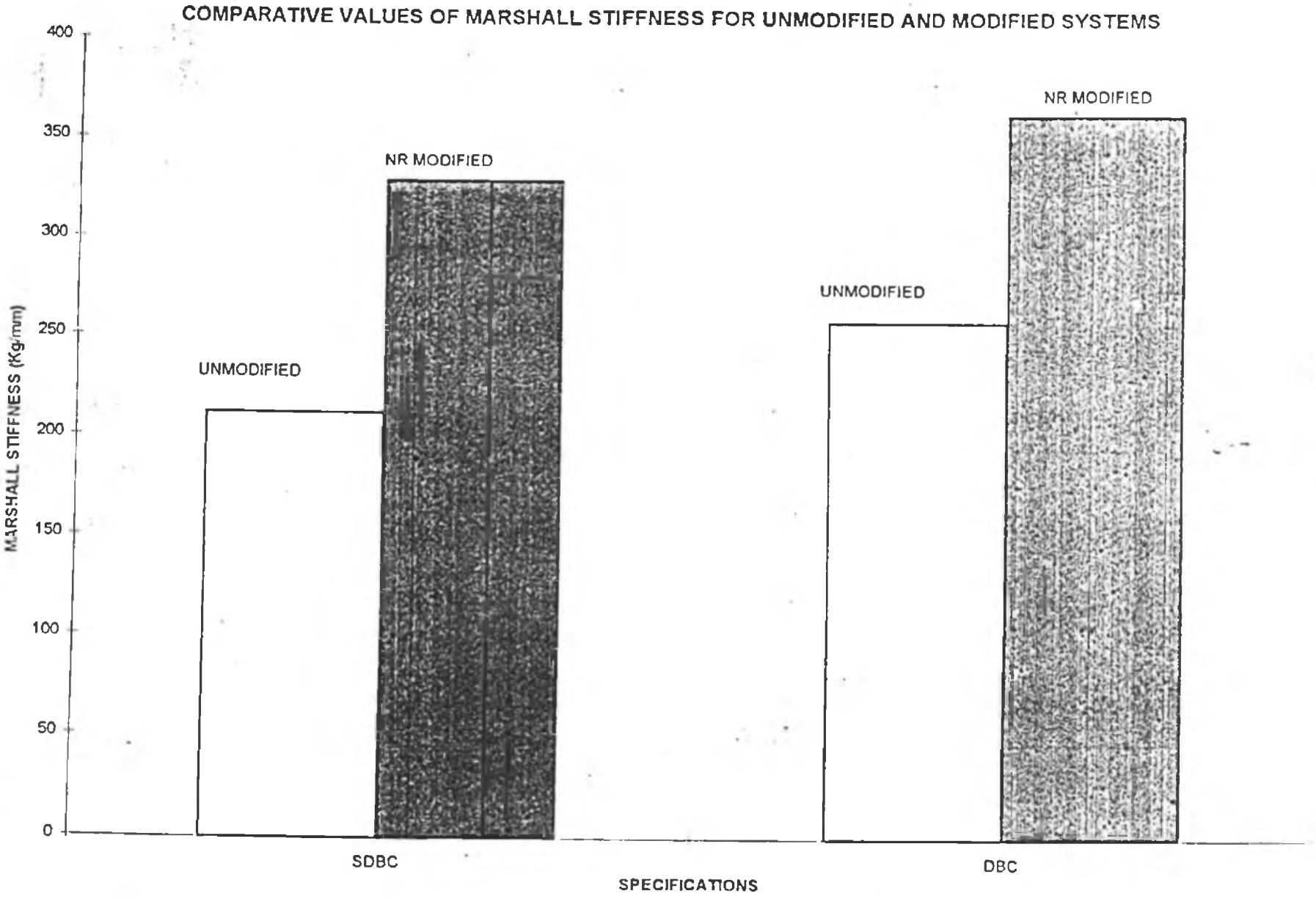

COMPARATIVE VALUES OF MARSHALL STIFFNESS FOR UNMODIFIED AND MODIFIED SYSTEMS
MARSHALL STIFFNESS (Kg/mm)
400
350
300
250
200
150
100
50
0
NR MODIFIED
UNMODIFIED
UNMODIFIED
NR MODIFIED
SDBC
DBC
SPECIFICATIONS

FIG. 3

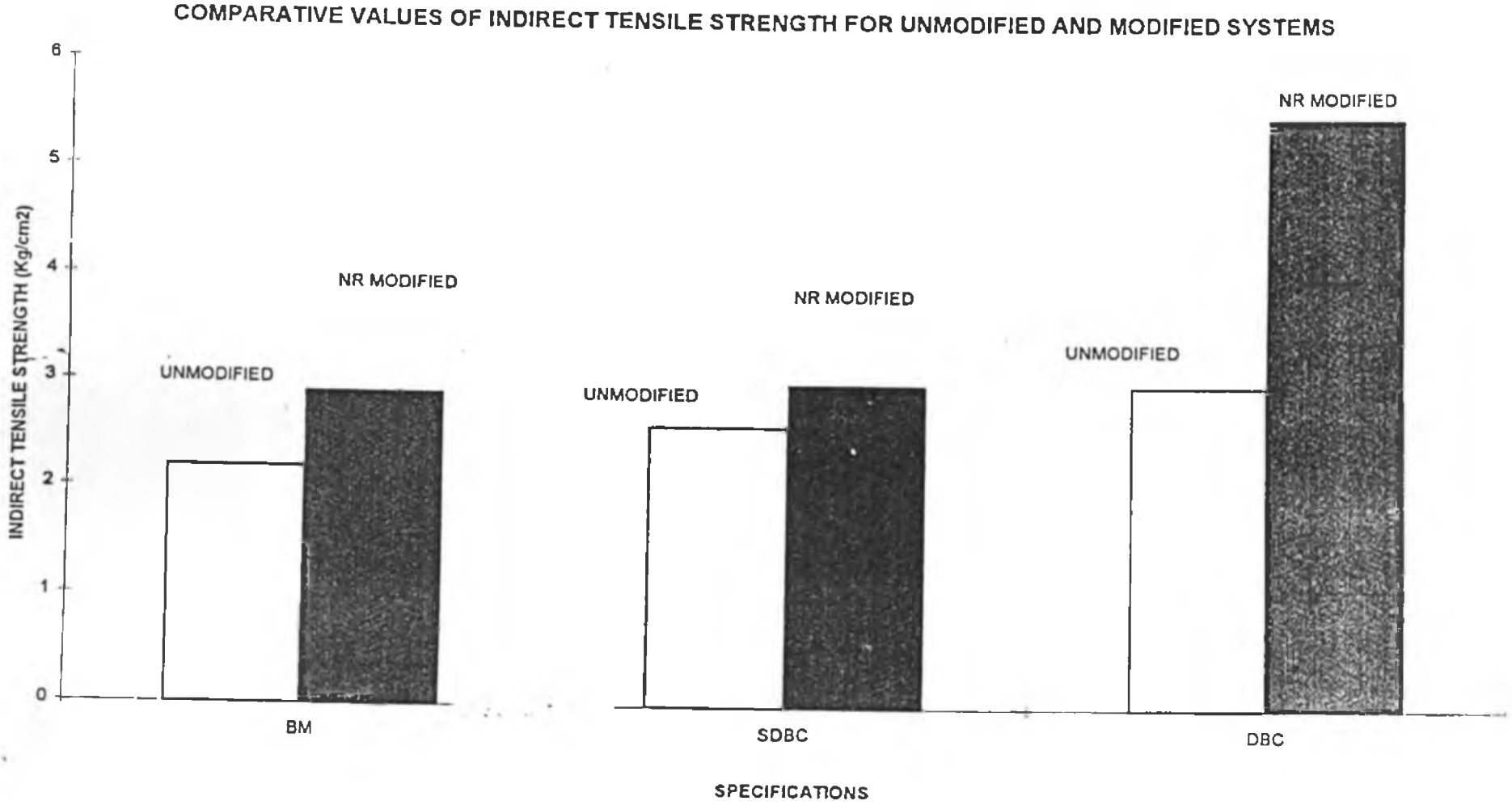

COMPARATIVE VALUES OF INDIRECT TENSILE STRENGTH FOR UNMODIFIED AND MODIFIED SYSTEMS
INDIRECT TENSILE STRENGTH (Kg/cm2)
0
1
2
3
4
5
6
UNMODIFIED
NR MODIFIED
BM
UNMODIFIED
NR MODIFIED
SDBC
UNMODIFIED
NR MODIFIED
DBC
SPECIFICATIONS

FIG. 4

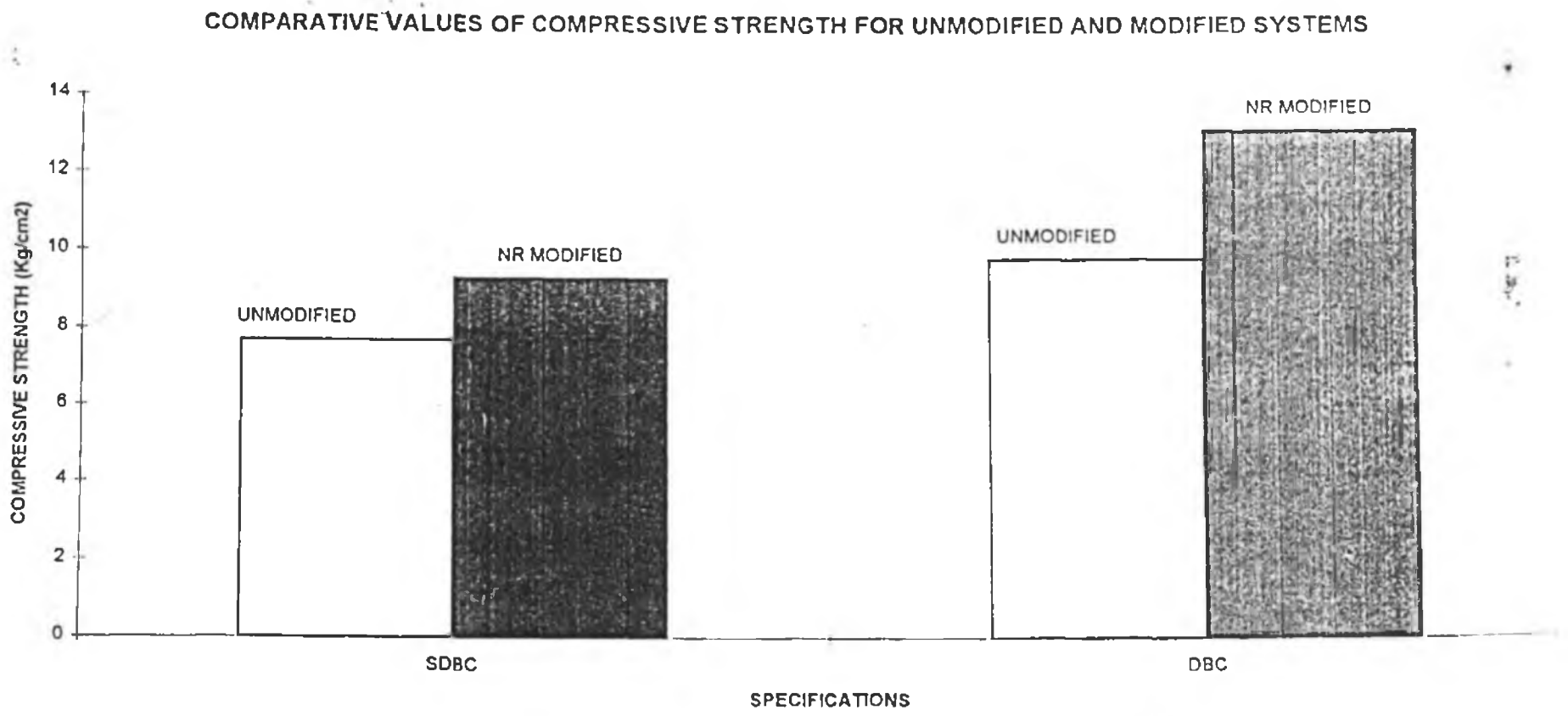

COMPARATIVE VALUES OF COMPRESSIVE STRENGTH FOR UNMODIFIED AND MODIFIED SYSTEMS
COMPRESSIVE STRENGTH (Kg/cm2)
14
12
10
8
6
4
2
0
UNMODIFIED
NR MODIFIED
UNMODIFIED
NR MODIFIED
SDBC
DBC
SPECIFICATIONS

FIG. 5

THERMOPLASTIC ELASTOMERS AS BITUMEN MODIFIERS FOR THE ROADS AND AIRFIELDS SURFACINGS

BY
DR. PARTAP K. MAHAPATRA*

1. INTRODUCTION

Bitumen is used as binder and water proofing material for construction of roads, pavements and airfield surfacings for several years. The demand of bitumen has increased tremendously because of rapid urbanisation in recent years. On account of increased bitumen demand and non availability of good quality bitumen from indigenous sources, it is felt imperative to reduce the bitumen consumption. The objective can be achieved by enhancing the durability of existing road surfacings which will result in reducing maintenance and resurfacing operations. Hence, the modification of bitumen to meet the required performance standards of the pavement appears to be logical and economical approach. Polymer modified binders are the ideal binders and can prove to be economical as compared to conventional and multigrade bitumen.

2. ROLE OF SBS TYPE TPE FOR BITUMEN MODIFICATION

The first commercial application of Thermoplastic Elastomers in modifying bitumen had its beginning in the late 1960s, and since then considered as wll established products in most of the Western countries. Bitumen modification with SBS has been identified as a promising avenue in USA and overseas and have shown that such binder systems can be effective in increasing the service life of pavement and reducing cost[1]. Japan is using over 20 percent of SBS modified bitumens while European countries and USA are about 10-15 percent of their bitumen consumption. The use of such binders is expected to save 20 percent to the road authorities and the user and if accidents are taken into account, the savings becomes quite substantial at the level of about 45 percent[2]. Several field trials using SBS Thermoplastic Elastomers in Europe and Asia showed excellent results and the road maintenance cost is reported to be reduced by 20-25 percent for pavement construction. As overlay with SBS modified bitumen in Netherlands on heavily trafficked roads, intersections and slopes of bridge over canal showed excellent performance for over 10 years compared to 6-8 months with conventional mixes[3].

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This article deals with evaluation of Thermoplastic Elastomer of SBS type as a modifier for bitumen for use in road and airfield surfacings, as a high performance materials.

3. NATURE AND FUNCTION OF SBS TPE

The nature and properties of the two grades of SBS Thermoplastic Elastomers generally used for modifying bitumen are shown in Table-I.

- Loss of adhesion and moisture damage.
- Poor setting characteristics.
- Thermal and fatigue cracking.
- Permanent deformation and rutting.

The prime role of a thermoplastic elastomers in bitumen modification is to increase the resistance of bitumen to permanent deformation at high road temperature without effecting the properties of the bitumen at other temperatures. This is achieved by improving the elasticity of bitumen enormously by the TPE modification, which results in improving the load spreading capacity of the material and increasing the structural strength and expected design life of pavement. Also the unique combination of thermoplastic behaviour above the glass transition temperature of the Polystyrene segments and the rubbery performance below that temperature (i.e. 100^{o}C) makes the bitumen resistance to thermal cracking and widen the service temperature range[4].

4. BLENDING OF SBS AND BITUMEN

The blending of the components is essentially a solution process that of either SBS in the bitumen or bitumen/oil blend. The blending can be carried out by low shear mixing (Paddle or Propeller type) or by high shear mixing. The limiting factor in any type of mixing is the break-up of the Polystyrene domains of the TPE; until this is achieved the Polymer will remain as a dispersed solid. The mixing time is generally 3 to 5 hours which depends on the batch size and stirrer efficiency, temperature and also the type of mixing. The usual temperature of mixing is in the range of 180 - 190^{o}C depending upon the time and type of mixing.

5. EFFECT OF SBS ON PROPERTIES OF BITUMEN

The important effect of SBS Type in a blend with bitumen improves the elasticity of the bitumen significantly; also increase the viscosity. From these improvements the other benefits in the properties like penetration index, softening point, ageing characteristics, stability and stiffness follows.

6. PENETRATION - TEMPERATURE RELATIONSHIP

The improvement of properties of bitumen by incorporation of TPE may be illustrated by penetration index (Table-II), the higher the penetration index, the lower the dependence of rheology on temperature. The results of penetration ratio, penetration index and penetration viscosity number (PVN) indicate that change of their properties with change of temperature and load and loading time is lowered by incorporation of SBS 411 and SBS 475. Penetration index values of SBS modified bitumens are quite higher than that of conventional 80/100 grade bitumen and thus significantly improves resistance to deformations.

The higher values of penetration at 4°C before and after Thin Film Oven Test (TFOT) penetration ratio (Fig: I) indicate improved fatigue resistance of modified mixes in moderate and cold climate. The optimum concentration of SBS TPE is 3-5% for improved fatigue resistance as seen in Fig. 2. The resistance to fatigue cracking is further supported by the higher values of PVN of modified bitumen (Table-II) than that of the conventional 80/100 grade.

The softening point results of SBS modified bitumen as obtained with different TPE concentrations reveal a marked increase in the value at around 5% concentration (Fig: 3), indicating a formation of full network throughout bitumen. The significant increase in the softening point of 80/100 bitumen modified with 5% SBS 411 indicates the suitability of these binders for heavily trafficked roads in coastal areas, airfield surfacings, roads in desert climate areas and also for surfacings used for intersections, bus stops and bridge decks as well. Higher values of softening point indicate reduced chances of blending and fatting up at high pavement temperatures.

7. VISCOSITY - TEMPERATURE RELATION

The viscosity value at 60°C usually is of specific importance as it controls the deformation of bituminous surfacings at high pavement temperature. Fig: 4 and 5 shows the relationship of viscosity and temperature of SBS, the viscosity value of bitumen is increased about 3 fold at 3% level. Hence, SBS modified bitumens are suitable for heavily traficked roads like National highways and express highways and also airfield surfacings where stiffness is required to prevent rutting along wheel path.

8. STABILITY AND STIFFNESS OF MIXES

The stability and stiffness are indicators of deformation resistance at high pavement temperature. Results indicated (Fig 6 & 7) that the stability and stiffness (Stability/

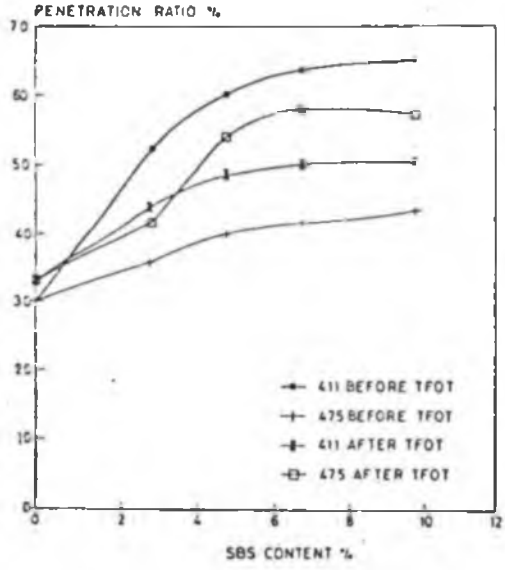


FIG. 1 PENETRATION RATIO OF SBS MODIFIED BITUMENS BEFORE AND AFTER THIN FILM OVEN TEST

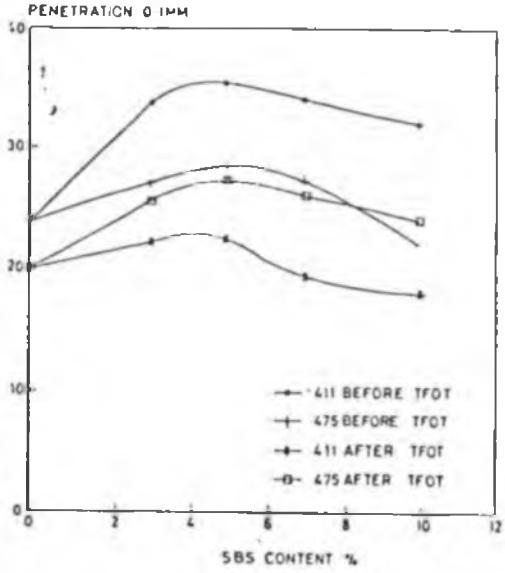


FIG. 2 LOW TEMPERATURE PENETRATION BEFORE AND AFTER THIN FILM OVEN TEST FOR SBS MODIFIED BITUMENS

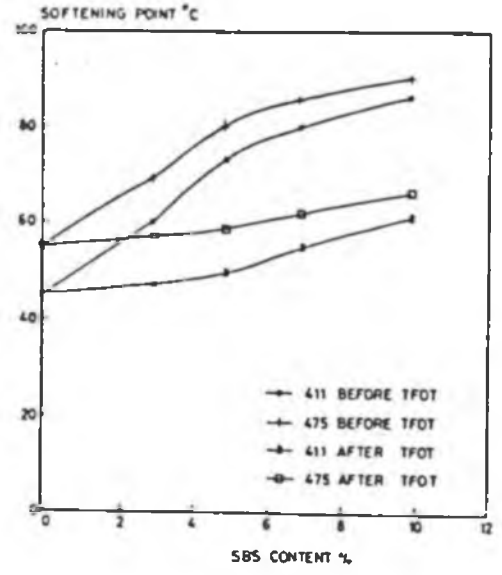


FIG. 3 EFFECT OF SBS CONTENT ON RING AND BALL SOFTENING POINT VALVE OF BITUMEN

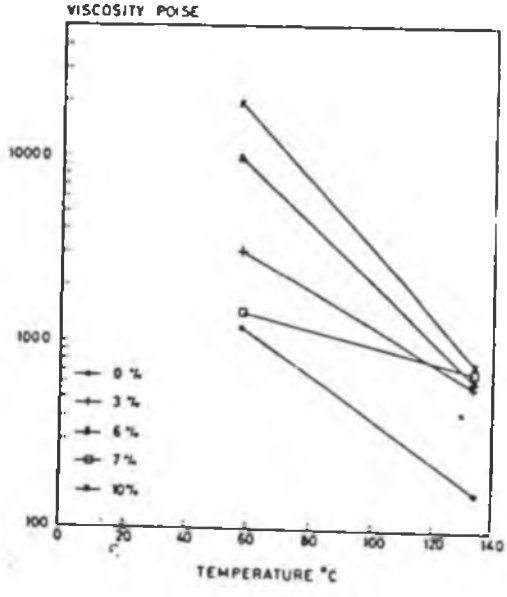


FIG. 4 VISCOSITY AS FUNCTION OF TEMP FOR SBS 475 MODIFIED BITUMENS

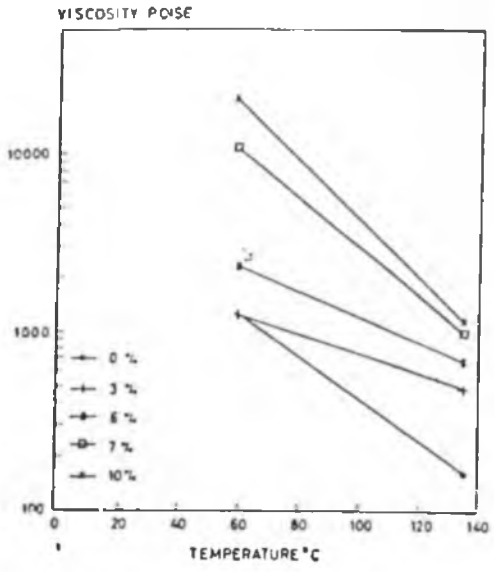


FIG: 5 VISCOSITY AS FUNCTION OF TEMP. FOR SBS 475 MODIFIED BITUMENS

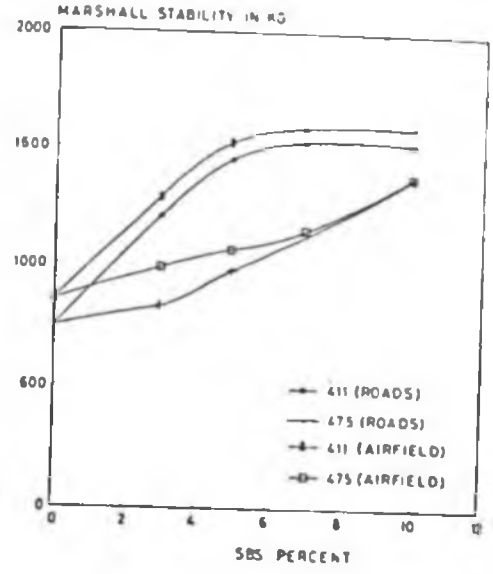


FIG: 6 RELATIONSHIP BETWEEN MARSHALL STABILITY AND SBS CONTENT IN BITUMEN FOR ROADS AND AIRFIELDS

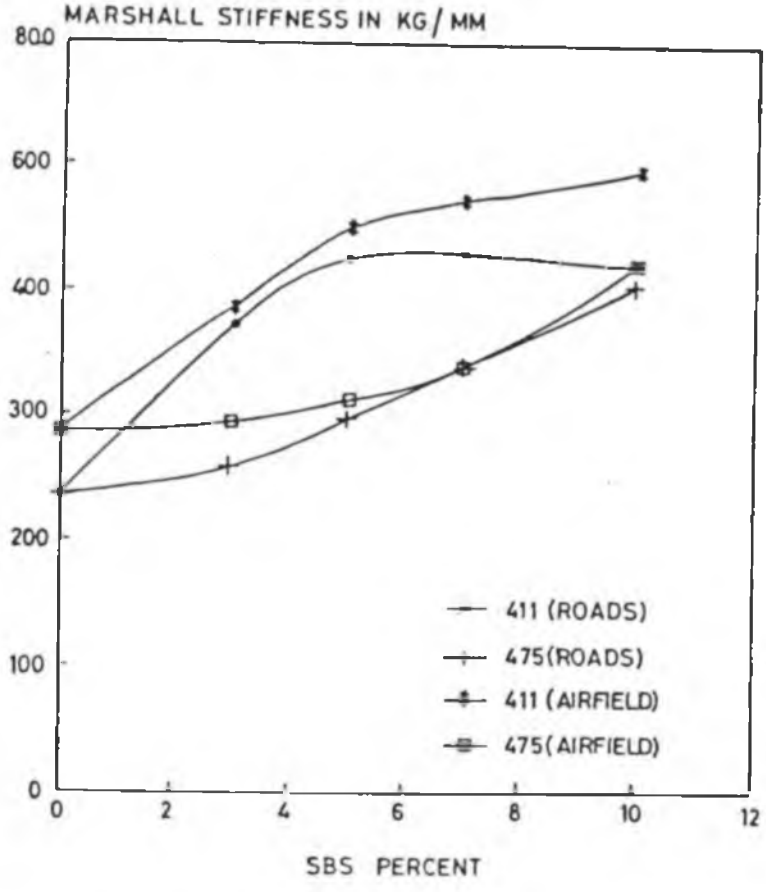


FIG 7 RELATIONSHIP BETWEEN MARSHALL STIFFNES (STABILITY/FLOW) AND SBS CONTENT FOR ROADS AND AIRFIELDS

Flow) of modified bituminous mix has 2 fold higher stability and stiffness for roads and airfield surfacings as compared to conventional mixes 80/100 bitumen. So surfacings would be suitable for heavy traffic at high pavement temperature and for bridge decks, where reduced surfacings thickness is required to cut down on dead load coming on structures.

9. EXAMPLES OF FIELD TRIALS IN THE WORLD

- Bitumen modified with Styrene butadiene copolymer (SBC) has been applied in a section on the new Mexico City in a express highway on 1991 for evaluation[5].

- In France the use of SBC for bitumen modification has been very successful and playing a leading role in the development technology. In 1988 about 50% of all modified bitumens used in road application which represents 4-6% of the French roadway system[5].

- oad and Waterways Authority of Finland reports that 500 Km of SBC modified pavement shown an increase on the life of surfacings by two to three years[5].

- SBS modified bitumen showed excellent performance on A-452 Stonebridge round-about in England and also given 12 years maintenance free service at St. Quentin bridge[2].

10. CONCLUSIONS

1) SBS is compatible with conventional bitumen 80/100 grade and can be incorporated upto 10 percent concentration.

2) The improvement in properties like penetration ratio penetration index and penetration viscosity number indicated that resistance to deformation at higher temperature and resistance to brittle cracking at low temperature can be achieved by modification of bitumen with SBS thermoplastic elastomers.

3) Higher values of softening point values of SBS modified bitumens indicate that blending and fatting up of surfaces can be checked.

4) Overlay thickness can be reduced substantially, upto 40% depending upon the requirement, if SBS modified bituminous mixes are to be used, which is evident from the higher value of stability and stiffness results of modified bitumen mixes.

5) Modification of bitumen by SBS thermoplastic elastomers increases the durability of the pavements and decreases the overall maintenance cost significantly on heavily trafficked roads viz. National Highways, expressway and airfield surfacings.

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2) Rutting Resistance of Asphalt mixes containing non conventional and Polymer modified Asphalt Binders. A report by SHell International Co.

3) Srivastava, A., Hopman, P.C. and Mulenaar A.A., SBS Polymer modified Asphalt binder and its implication on overlay design" ASIM SIP 1108.

4) Cariflex TPEs in bituminous roofing, Technical Bulletin, Shell Elastomers; Nov 1989.

5) Martinex N.E. and Klip Abraham, "Elastomers for a new environment" IISRP Annual General Meeting, Washington, 1991.

TABLE - I
SBS THERMOPLASTIC ELASTOMERS

SBS GRADE PROPERTIES	TEST METHOD	UNIT	A-411	A-475
BUTADIENE/STYRENE RATIO	-	-	70/30	60/40
BLOCK POLYSTRENE	-	-	30	40
MELT FLOW 200^{o}C AT 5 KG.	D-1238	g/10min	Nil	2.2
TENSILE STRENGTH	D-638	MPa	14.0	18.6
ELONGATION	D-638	%	400	1000
300% MODULUS	D-638	MPa	2.9	2.1
HARDNESS	D-2240	Shore A	80	62

TABLE - II

PHYSICAL PROPERTIES OF SBS MODIFIED BITUMENS*

Typical Properties	SBS 411 0%	3%	5%	7%	10%	SBS 475 3%	5%	7%	10%
Penetration, 0.1 mm (25°C/ 5 Sec/100g)	81	66	59	53	49	78	71	68	63
Penetration, 0.1 mm (4°C/ 60 Sec/200g)	24	35	36	34	32	27	29	29	27
Penetration, 0.1 mm (35°C/ 5 Sec/100g)	216	160	122	102	82	200	175	165	158
Penetration, Ratio, % (Pen 4°C/Pen 25 C) x 100	30	53	61	64	65	35	41	41	43
Penetration, Ratio, % (Pen 25°C/Pen 35 C) x 100	38	43	48	52	60	39	41	41	40
Penetration Temp. Suscep (PTS)	.06	.036	.036	.032	.030	.036	.035	.036	.036
Penetration Index (PI)	-2.5	+0.3	+0.7	+1.5	+1.5	+0.7	+0.7	+0.7	+1.7
Softening Point °C (R & B)	45	56	76	80	86	45	47	50	55
Pen-Visc-Number	-11	-0.1	+0.2	+0.4	+0.4	-0.2	+0.1	+0.2	+0.2

* Results obtained at CRRI Delhi.

(90)

Those Amazing Rubber Roads. 1.

By

Kenneth Allison.

Rubber World 156 ; 6 ; 1967. p47-52

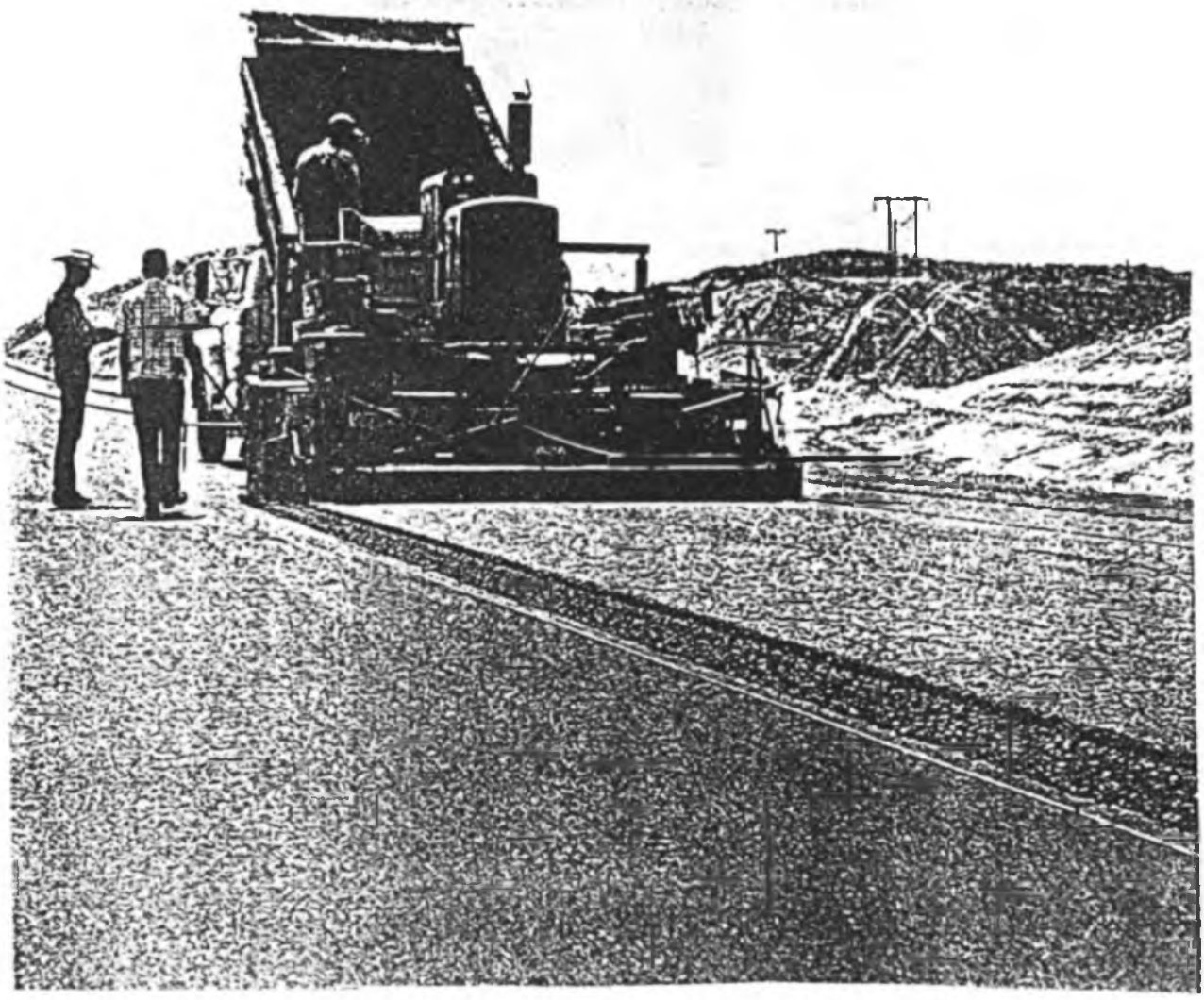
Those Amazing Rubber Roads

Kenneth Allison
Engineering Editor

Few rubber industry developments in recent memory have come in for as much discussion and enthusiasm as the intriguing subject of rubber roads, claimed by many to be the next big-volume market for elastomers. Evidence of the topic's high-interest rating can be seen in the numerous technical papers that are being presented before industry associations and professional groups; another indicator is the fact that business and technical magazines have picked up the story. And, of course, there is the inevitable flood of promotional messages—all singing the praises of rubberized streets and highways.[1]

By almost any yardstick, the story is both impressive and significant. The advantages claimed for rubber roads range all the way from chemical protection against road-salt deterioration of pavements to remarkable achievements in highway safety

[1] For those wishing to pursue the subject at length, a selected bibliography of 86 (at last count) English-language references (1950-66) is available from the National Academy of Sciences, through its Washington, D.C.-based Highway Research Board of the Division of Engineering, National Research Council.



(including demonstrated reductions in accident rates).

Commerically, the development appears to hold great—if not unlimited—opportunities for rubber polymer producers and reclaimers. Its market potential, viewed in terms of existing and planned new roads, is indeed formidable. Some industry forecasters say the new application could boost U.S. rubber consumption by more than 40%.

Despite the seemingly bright outlook for rubber roads, the path to market is strewn with some king-size obstacles. Skeptics, detractors and (possibly the thorniest problem of all) politicians have served notice that the new roads will have to overcome more than the usual resistance to sweeping new product changes. The political trappings are tied to the fact that city, state and federal agencies control what's "in" or "out" in the highway developments and technology.

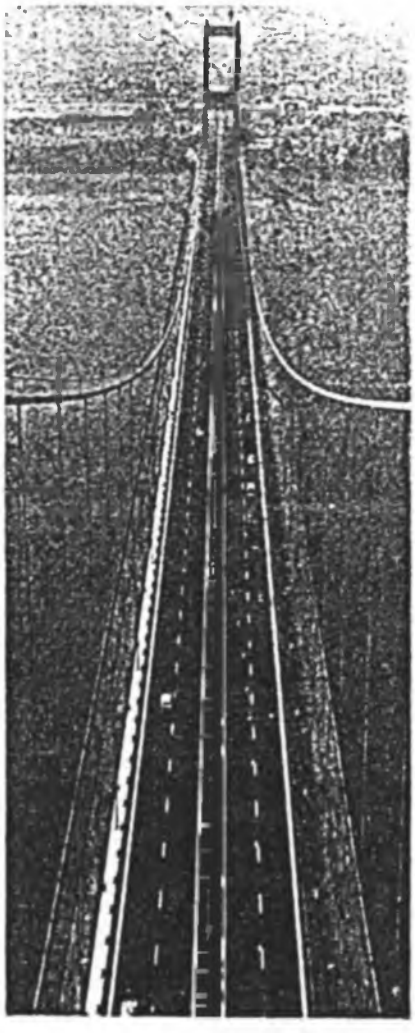
While most observers feel that the rubber roads movement is just beginning to gather some momentum, even a cursory reading of events to date indicates that the subject raises a number of important questions. Not the least important of these is, "Just how amazing are they?"

Early Developments

The concept of rubberized roads is hardly a new one. Research in this area has been carried out for at least the past 40 years—and not just in the U.S. During this period many thousands of people have worked on the program around the world . . . from England and South Africa to Japan and Java.

In Europe in the early 1920s, for example, an unsuccessful attempt was made to attach vulcanized rubber sheets to a concrete base. In the U.S., Goodyear's efforts date back to 1925. The company laid a road of solid (and expensive) rubber paving blocks that lasted more than 25 years under heavy traffic. In Southeast Asia, British and Dutch producers, faced with an excess supply of natural rubber, also became interested. They tried solid-block NR roads (1929) with the thought of reducing noise and vibration around hospitals and other buildings.

RUBBER ROADS AROUND THE WORLD



England—Severn Bridge has 5% unvulcanized NR powder in insulating layer.



Japan—road crew lays rubberized asphalt in Hakone (NRPRA).

Perhaps the most dramatic example of all occurred in Holland. In 1936 the Dutch paved a road near Rotterdam with rubberized asphalt that later proved to be a boon to the invading Germans. It held up with excellent results even under the wartime traffic of Nazi tanks and panzer vehicles.[2]

These early tests using solid rubber were, of course, the industry's first venture into the road business. Although current technology is oriented to a more practical approach—i.e., improving the properties of common asphaltic pavements and coatings with the addition of a few percent of crumb, powdered, or liquid elastomers—part of the basic know-how developed before World War II is still being used today, plus much that was published a decade ago.

More recent technological advances, however, have given rise to an escalation in the number of rubber road projects around the world. According to one estimate, about 10,000 highway miles of rubberized roads (and a substantially greater number if measured in lane miles) have been laid and tested.

One immutable aspect of the roads business is its very political nature. It is hardly news that control of the earthly paths designated for transporting people, horses and horseless carriages (along with legally posted cross-paths for cattle, deer, elephants, etc.) has customarily resided in the sometimes unearthly provinces of national, state and local governments and departments. Politics has, in fact, played a key role in road building throughout history. Even the Romans' Appian Way was blocked out as a government project. In those days, civil servants and senators on the Capitoline Hill probably had their say in much the same way as do our present law-makers. And when it came to construction methods and materials, it's a safe bet that Rome's stone cutters, masons and other counterparts of our

[2] The Hollanders liked to show off this section of rubberized asphalt highway to visitors after the war, pointing out how well it had withstood the ravages of time and violence. Sometimes, however, they compared it with sections that had not been paved with any asphalt.

modern asphalt/concrete producers and road contractors also made themselves heard.

Current Trends

In the forefront of tomorrow's news may be an as-yet-unreleased research study that the International Institute of Synthetic Rubber Producers submitted to the U.S. Commerce Department's Bureau of Public Roads. The 50-page report details laboratory results and adds more weight to technical arguments that a small amount of rubber in asphalt improves properties such as viscosity, low-temperature ductility and impact resistance, adhesion, elasticity, flexibility, tenacity and toughness.

IISRP's report also shows that rubber-asphalt paving mixtures incorporating the aggregate have greater compressive strength (wet or dry); slightly less flow in a Marshall test; and a capacity to use more asphalt effectively to reduce voids while maintaining stability or compressive strength.

Also in the category of hard news is the release (in February) of final test results at the conclusion of a 15-year British investigation—both in the laboratory and on full-scale road experiments.

This cooperative program of research on rubberized road materials began in 1951 and was carried out jointly by the Natural Rubber Producers Research Assn. and the Road Research Laboratory of the U.K. Ministry of Transport. Objectives were to examine the properties of rubberized binders; to discover how best these properties could be used to improve road surfacings; to show by full-scale road work the advantages obtained in practice; and to establish the best methods of manufacturing rubberized materials.

NRPRA states that these test results clearly establish the advantages of rubberized materials for certain applications. The following benefits were cited:

- In surface dressing: improved resistance to fatting up (flushing, bleeding) and greater chip retention.
- In bitumen macadam: increased life, and improved resistance to stripping.
- In rolled and mastic asphalt: improved resistance to cracking, and increased stability.



Germany—insulating layer on Emmerich Rhine Bridge (Rubber Latex Powder Co.).



Australia—rubberized bitumen seals all streets in busy Yallourn (NRPRA).



Canada—Toronto's Lawrence Ave. bridge gets latex mix (Firestone).

Despite NRPRA's optimism, conservative elements in the rubber roads picture are inclined to take a wait-and-see stand. Skeptics, of course, place little stock in such reports. The "additive peddlers," they say, have for years been touting impressive data, studies and claims, complete with bullish statements and pie-in-the-sky promises.

Yet the new British report may be significantly different and influential (even in other countries) since it carries government-commerical sponsorship. And it may have the effect of stimulating more research tests throughout the world. This is important since variables of climate, terrain, soil conditions, traffic loads and other factors often change radically even within short distances.

Another beneficial by-product of the British study is that it adds something to credibility and impartiality if only because it is not oriented to a single company. This carries more than passing significance, for in talking with people in the highway business, the believability issue inevitably crops up. By way of dramatic illustration, one firm had its comparative test cores of actual highway pavements handed back over a potential customer's desk with the indication there was no assurance the cores were not faked. Reports are that such credibility gaps are the rule rather than the exception—and apparently pose quite a problem when it comes to doing business.

The Problems

Most observers agree that the rubber road development is proceeding at less than a breakneck pace. Although costly research and field testing is going ahead, the actual market penetration has been very limited to date. Some sources, discouraged and disappointed at the lack of progress, are beginning to wonder whether rubber will ever be truly "go" in this application. (In point of fact, though, optimism rather than pessimism rules the rubber supplier's thinking.)

Clearly one of the chief stumbling blocks here is the ingrained attitudes of government legislators and civil highway administrators who hold the all-important purse strings. An-

other negative is similar thinking on the part of their old-line contractors and material suppliers. It is also obvious that the latter have their problems too.

Many contractors and asphalt suppliers say they are faced with a new and unfamiliar material (rubber), fewer well-educated personnel on work crews, no background of experience to draw upon, and a disinclination to study research reports written by and for chemists, physicists and engineers.

In more practical terms, they note that the purchasing, mixing and separate handling of relatively small quantities of special materials that are not regular day-to-day output in order to lay short road test strips will automatically increase their costs by a big factor. And who pays the bill, they ask, if the contractor's equipment gets "gunked up" or if the material takes four times as long to compact or spray?

And, of course, the contractors and asphalt people feel that they already have a very satisfactory product which they have been supplying for years with complete confidence and no guesswork. So, they reason, why add unkown and unproven elements to a winning formula?

The Asphalt Institute, which represents the producers, says that it is open to the idea of improving asphalts with additives such as rubber and asbestos. Although asbestos has been accorded a limited blessing (based on lab tests), rubber is not even included in the organization's current research plans. Further evidence of the asphalt interests' coolness toward rubber is found in these excerpts from a recent Institute report:

- "To date, where *hot-mix, hot-laid pavements* or *hot penetration macadams* are concerned, there have been no field performance data published or otherwise brought forth showing that commercially available additives are economically desirable or yield longer pavement life. AI therefore recommends that the use of additives be confined solely to experimental projects until such data are produced that indicate the benefits, if any, of additives."
- "There is some evidence, based on field observations, to indicate that the use of additive-treated liquid asphalts under adverse conditions may sometimes be beneficial in the early stages of pavement life. How long these benefits continue or whether these additives contribute to longer service life of the pavement remains to be determined."
- "Empirical laboratory tests and arbitrary specification limits do not provide a sound engineering basis for justifying the use of "anti-strip" additives [such as rubber to bind in aggregate stones, anti-skid abrasive particles, etc.]. In most instances there is no correlation of these tests and specification limits with field performance. Even where some degree of correlation does exist, there are definite limits to the applicability of currently used laboratory 'stripping' tests."
- There is mounting evidence that different rubbers affect different asphaltic materials in different ways. Apparently, special studies and precise controls are needed to guide the treating of a particular asphalt with a particular rubber to achieve an improvement in quality of the rubberized asphalt over the untreated asphalt. Special handling techniques are also involved in using rubberized asphalts. These problems must be solved reliably before the benefits and limitations of rubberized asphalts may be adequately appraised."

Despite the AI's negative attitude on researching rubber additives, several refiners are doing independent work in this area at their own expense. Sohio, for example, has been working with Goodyear since 1962. And a five-mile stretch of road outside Cleveland has one-mile sections of Goodyear Pliopave, Firestone Rub-R-Road and Sohio Ductron—each separated by a mile interval of conventional untreated asphalt.

This test road was laid in 1964 and is too recent for comparative results to show, Sohio says.

(The major differences between Ductron and Pliopave is reported to be in the production step at which the rubber is mixed—Ductron being blended into the asphalt in the refinery while Pliopave is added in the pug mill. A pug mill is a mixer for asphalt and mineral aggregate road materials.)

The National Asphalt Pavement Assn., which represents the manufacturers of in-plant mixed asphalt and aggregate and the contractors who lay these materials, takes a very neutral stand on the rubber additives question. Spokesmen do, however, note a lack of coordination in the efforts of rubber (and other) additive suppliers. This, they feel, has led to much confusion about products, methods, benefits, etc.

NAPA stresses the need for proving benefits that justify the costs, admitting in the process that while rubber additives do appear to have some benefits the products are not generally accepted in the industry. Pricing appears to be another problem. Some member firms, the association says, have reported high supplier costs and poor delivery of additives. Others say their contract bids are acceptable and competitive by government-customer standards. Still others note the high cost of some of the systems suggested to blend rubber with asphalt.

Also burdened with a heavy load are those government highway engineers who admit (and some don't) to improved physical properties of asphalt-rubber mixes. It falls to these men to prove to their budget-minded bosses—not to mention tax-paying motorists—that the extra cost is justified by resultant benefit. This of course, is not a quick and easy matter when field observations require the proof of time, weather, traffic, etc. Sometimes, however, over-caution gets the upper hand.

Massachusetts highway officials, for instance, have been testing rubberized roads since the early '50's. Yet their strongest comment to date is that they see no deleterious effects of rubber additives.

State road engineers have been criticized for the wide variation in their testing procedures for different mixes and ingredients (including asphalt). Although ASTM standards are available, each state may vary the accepted procedure—even the federal government has not established a universally-accepted set of testing rules. Texas, Louisiana, Michigan and Pennsylvania, for example, are listed among those using both penetration and viscosity tests to

establish acceptable performance characteristics for highway materials (including asphalt). Many other states use the penetration test only; however, even these are not uniform across state boundaries.

Consequently there is little common ground on which to compare testing results, the upshot being that there is a striking lack of uniformity in research data. State roadmen, therefore, are apt to reject the case histories of outsiders' trials with the comment, "We can only believe the work we do here ourselves."

Sizing the Market

Surprisingly, there are only a handful of rubber companies actively engaged in this sizable but still aborning market. At present the prime movers and chief apostles of the rubber roads movement are Goodyear, Firestone (through its Xylos Rubber Co. division) and U.S. Rubber Reclaiming Co.

Typical of those cast in important but definitely quieter roles are Uniroyal (long established in the rubber roads business), Du Pont and Midwest Rubber Reclaiming Co. While the more publicity-oriented firms have become closely identified with the roads picture, the others tend to labor backstage with very low-keyed marketing efforts. But like their more vocal competitors, these firms have their products included in road test strips across the country. This, they feel, will put them in a ready-to-roll competitive position if the market expands in a big way.

While these are some of the more active advocates of rubber roads, many other rubber companies—large and small—are keeping close tabs on the development. In fact, some of these firms are experimenting with new products which may bloom to the surface at any time.

The next question, then, is just how big is the rubber roads market? In order to pin down the size and potential of this new application area, it is first necessary to consider the make-up of the pavement itself.

Asphalt is primarily a binder in the highway, used to "glue" together the sand and rock aggregate mixtures. As such the asphalt may account for only 5-10% of the total pavement weight. The rubber additives may be incorporated in amounts of perhaps 2-6% of the already small proportional weight of asphalt in the road. (Some surface coatings, however, may have as much as 1:2 rubber/asphalt ratio, but these are applied in relatively thin coats.) Another factor to be considered here is the booming asphalt-in-roads market. Sales of asphalt for use in highway pavement have increased some 80% over the past decade. In 1965 (the latest year for which statistics are available) roadbuilders consumed 17.4 million long tons of the material.



Buffalo, N.Y.—1.1-mile, 4-lane Skyway resurfaced in late '65 with 5% dry rubber additive may give answers in 10 years (U.S. Rubber Reclaiming Co.).

Thus if the rubber content of asphalt were 5%, some 850,000 long tons of elastomer would be used in this application—more than is consumed by any nation in the world save the U.S. Here in the U.S., where manufacturers used slightly more than 2.2 million long tons of rubber last year, overall consumption would shoot up by a staggering 42.5%.

(The 5% rubber additive figure may be high, however. Although many producers believe the content-percentage will be smaller, say in the 2.5%-4% range, at least one major rubber company is banking on the 5% estimate as an overall average dry rubber content for all applications.)

Another market consideration is the roads picture itself. In 1965 there were some 3.7 million miles of U.S. roads under some kind of government jurisdiction. Of these, about 1.45 million miles (39%) were paved, with these ranging from bituminous surface treatment to bituminous and portand-cement concrete.

As for growth, municipal mileage is increasing by 4% a year. Commerce Department spokesmen say an even greater need [and therefore, rubber market] lies in paving the 61% of present roads that are still bare.

Thus far, the impact of this development has been weighed only in terms of U.S. conditions. The market potential for rubber roads immediately skyrockets when viewed in a worldwide context. Also to be considered is the fact that while the road-construction pie is indeed a big one, the crust on the pie looks good too. Billion-dollar road maintenance programs may well provide a sizable follow-up market for the rubber additive suppliers. For, it must be admitted, even the most optimistic rubber roaders don't foresee highways that will last forever without repairs.

In view of the exceptionally heavy rubber tonnage that could go into this application, it is obvious that the polymer producers are in the best position to swing into the roads business. Theoretically, however, the market is (or may be) wide open—even for the non-polymer producers. The elastomeric road additives are, after all, specially treated products that are tailored to do a specific job. And as in most business ventures, success will be decided by differences and variations in the various products offered. It can be assumed, therefore, that anyone in the rubber compounding industry is a possible—if not immediately logical—contender for a share of the rubber roads market.

The Customers

In marked contrast to the usual commercial ventures that producers (rubber or otherwise) embark on, the rubber roads business is, for obvious reasons, something else again. The big difference, of course, is the fact that the top people who are charged with the care and upkeep of the nation's roads are in the main political appointees or elected officials, usually restrained in authority by departmental and geographic boundaries. Frequently they know only as much about streets and highways as the average car-driving citizen. Most of these administrators are forced to rely on the recommendations of qualified personnel in their departments.

The second echelon of government road people usually includes senior civil service personnel—often more qualified administratively than technically—many of whom, though, are not incapable of understanding engineering concepts. The third level takes in a middle group comprised of many dedicated and professional technically-trained people who understand engineering problems and scientific answers.

At the bottom rung of the larger government structures can be found young, frequently more aggressive—and receptive—junior engineers and executives. They are likely to look at new and creative innovations with an open mind but, unfortunately, usually can't authorize the laying of even 10 feet of test road off in the back hills.

And last but not least, there are the maintenance people. Some of the principals involved in the rubber roads development say that maintenance, heretofore a stepchild in many highway departments, now appears to be gaining new importance and stature. This, they say, could have a very far-reaching impact on the rubber end of the business.

In the past, maintenance funds drew a very definite second-priority rating (i.e., hard to obtain and first to be cut at budget-trimming time). Furthermore, such funds as were appropriated had to be spread over many related operations including snow removal, painting lines, etc.

More recently, however, with a network of 41,000 miles of interstate highways planned (23,000 miles already built; 16,000 more under construction), top highway officials are beginning to pay closer attention to road upkeep.

Maintenance alone represents a big outlet for rubberized road products. In fact, the rubber producers have been knocking on this door for a number of years, with only moderate success to date. Now, however, the situation appears to be more promising. Those who read the changing trends feel that maintenance people will soon have not only a bigger say in new construction but also more dollars to spend on their own specialized work.

Almost eveyone concerned seems to agree that there is no discernible pattern for doing business with these buyers and specifiers of rubber roads. At times a senior man assumes leadership, and a risky rubber road goes down for trial. In other instances, it may be new people growing up with new ideas who get the job done. And in many cases, nobody does anything except talk—assuming the rubber man can get past the door.

One fact seems obvious, though. A majority of federal, state and local government highway engineers are doing their best to keep abreast of developments on the rubber additives front. These public-spirited engineers are faced with daily operations—frequently in a quasi-political environment and often including inadequate public funding—that may not be easily or fully understood by industrial marketing people. But it should be noted that some of these government people, and even a few private contractors, have made significant contributions to the rubber roads movement. However thinly populated the field-test landscape may seem to rubber people, interviews from Massachusetts to California and Michigan to Texas readily turned up a number of knowledgeable people in public highway departments—municipal, state and federal.

A significant number of these government officials told RW that they have had good-to-excellent results with rubberized asphalt, including competitive costs when projected for larger-scale projects.

But this is not to say that all of the rubber road experiments in this country have been resounding successes. Massachusetts engineers, for example, say that to date they haven't seen improvements that are worth the cost of adding rubber. However, 75 miles of rubber roads in the Bay State will be re-examined this summer to get comparative evaluations of new sections using different test variables. Michigan's thus far inconclusive results are also due for another look-over once spring thaws uncover more than 20 miles of rubberized seal coating put down in 1964-65.

(To be Continued)

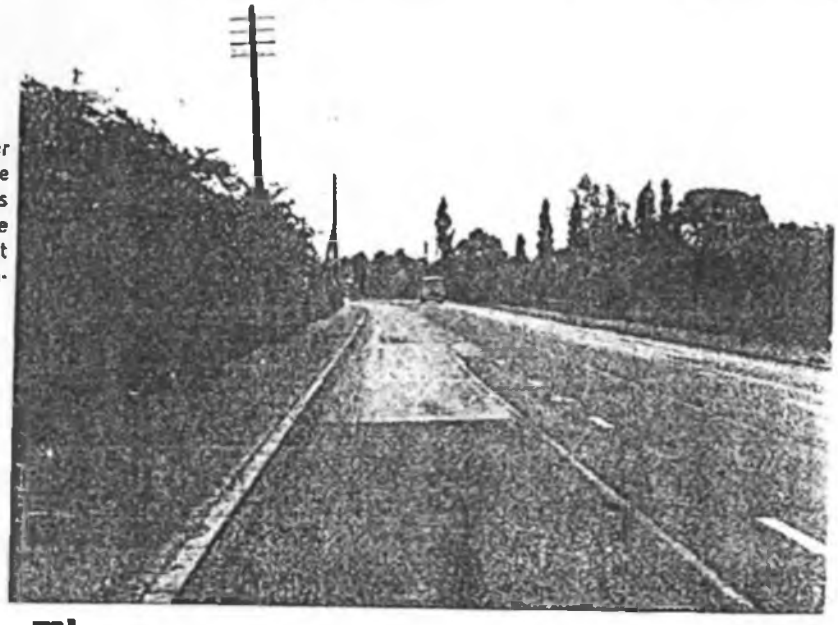
Those Amazing Rubber Roads.

Part II

By.

KENNETH ALLISON.

Rubber World 156:1; 1967. p 91-106.



Bleeding (fatting up) in warm weather causes hazardous slippery spots, loose flying rocks and spattered windshields as softened asphalt floods over the surface. NR rubberized pavement (foreground; Clay Cross, Eng.) is unaffected.

Those Amazing Rubber Roads Part II

Kenneth Allison
Engineering Editor

Thus far we have taken a wide-angled look at the very large subject of rubber roads, providing along the way some of the background and highlights to date. As we have seen, the development—at least in its present stages—is primarily of interest to polymer producers and chemical and equipment suppliers. However, interest in rubber roads does not stop here. Others are looking at the general picture in terms of what it may mean to improved highway transportation and even vehicle production. And, of course, the motoring public has a vested (and not to be underestimated) interest in how the story unfolds.

The all-important commercial aspects of this development can probably be best summarized as follows: a potentially huge market for rubber; customers who are out of the ordinary industrial marketing orbit; and and a technology that is still fraught with many "ifs" and unresolved questions—with these ranging all the way from basic research to final highway application.

It might therefore be helpful at this point to take a reading on just how the experts view the present rubber roads situation, especially in regard to technology, economics, product differences and lastly, to the prime question of highway safety.

R&D Problems

Surprisingly, the first patents issued for modification of bitumen with rubbery materials included the addition of gutta percha, covered in 1843 by British patent No. 10,185. The following year a man named Cassell obtained British patent No. 10,327 concerned with the application of bitumen-rubber mixtures to road surfacing. Nearly a century later in 1935, when rubber technologists were busily working with new synthetic elastomers, Russian literature carried a first reference on the work of D. Pospkhov and A. Fokin titled "Mixtures of Asphalt and Synthetic Rubber."

This early history and other data were summarized by George W. Eckert, research chemist for the Missouri State Highway Dept., in "Bitumen-Rubber Mixtures in Road Construction," a RUBBER WORLD exclusive which appeared in the July 1939 issue. Also see "Rubber and Asphalt Mixtures for Road Construction" authored by British chemist D. C. Broome of Limmer & Trinidad Lake Asphalt Co., Ltd. (RW, Dec., 1937).

These and other technical references of the 1930s clearly show that most of the advantages cited for rubber roads by present polymer producers (both natural and synthetic), were being expounded at least 30 years ago by government-employed highway scientists and asphalt industry spokesmen. True, the data was not as copious and possibly not as accurate nor as fully explored in some areas—but the conclusions being drawn were much the same. And, similarly, many of the unanswered questions of that day remain unanswered today.

Just the sheer number of different asphalts and rubber products now on the market and the variations achieved in modification of physical and chemical properties of their mixtures at different percentage compositions offer a potential book of questions alone. And attempts to reach agreement on which properties are most important to road-builders and exactly how (or if) they can and should be measured further complicates the picture even before leaving the laboratory doors.

Is oxidation resistance of rubber important if other asphalt constituents oxidize far more rapidly, and how do we gain protection? Are fatigue investigations critical? How do methods of mixing influence the final results? Is the molecular weight of the polymer additive a key criterion for selecting better additives and discarding those not worthy of research? Is "in situ" vulcanization a phenomenon that can or does take place with inherent advantages? Is aging of final road mixtures after laying more important than initial hot-phase oxidation and thermal degradation? Is aging involved with both chemical and observed physical dispersion changes in the asphalt-

rubber mixtures? Are static tests meaningful or must testing be done under real or simulated dynamic conditions? How?

These are just a sampling of the questions that are now being explored by qualified scientists in many countries. The scientists at this stage don't all agree on the answers thus far determined, let alone which answers are most important, or even the best ways to go about getting more and better answers.

Mixing Methods

One of the most critical steps in any rubber roads project is the mixing operation. Such veteran scientists as Dr. Herbert A. Endres (now retired) and Dr. Kenneth E. Bristol of Goodyear's research division amply make this point by telling of their experiences with *one* propane-extracted asphalt of Texas origin. The two researchers say they were unable to make *any* type of rubber disperse or dissolve in *any* proportion under *any* conditions with this particular asphalt.

While zero-dispersibility is highly unusual, compounders have found wide-ranging variations in the various asphalt/rubber mixes that have thus far been produced. It is for this reason that most experts are agreed that the various mixing methods should come in for close attention. And, they say, the methods employed seem to influence both the end-product and benefits gained.

Here, then, is a brief rundown on four of the most commonly used (in the U.S.) methods of incorporating rubber into the final asphalt road mixture:

- Crumb rubber—Early attempts to improve the physical properties of asphaltic highway materials included the mixing of relatively large particles of crumb rubber into the final product. These particles exist as discrete "chunks" of rubber in the older test strips of Massachusetts highways that were laid down in the early '50s. It is possible to dig them out of the highway today with the point of a knife, just as one might extract a piece of gravel aggregate in the same road.

British engineers (and others) now report that undissolved rubber has no beneficial effect, and such particulate inclusions of rubber under certain laying conditions may make compaction of asphalt surfacings more difficult, sometimes leading to early failure. To circumvent such difficulties with solid rubber, Australian researchers have been using sheet rubber that is first dissolved in a solvent such as kerosene.

- Powdered or flaked rubber—A second mixing method involves rubber in the form of a fine powder or flake product that is compounded to disperse readily throughout the molten asphalt. Constitutents of the asphalt penetrate the rubber, softening and converting it to a dispersable gel—for at least some measurable depth into the particle. The particle may or may not retain a small "rubber" core. This method continues under active test; products are marketed by Uniroyal and Midwest Rubber Reclaiming.

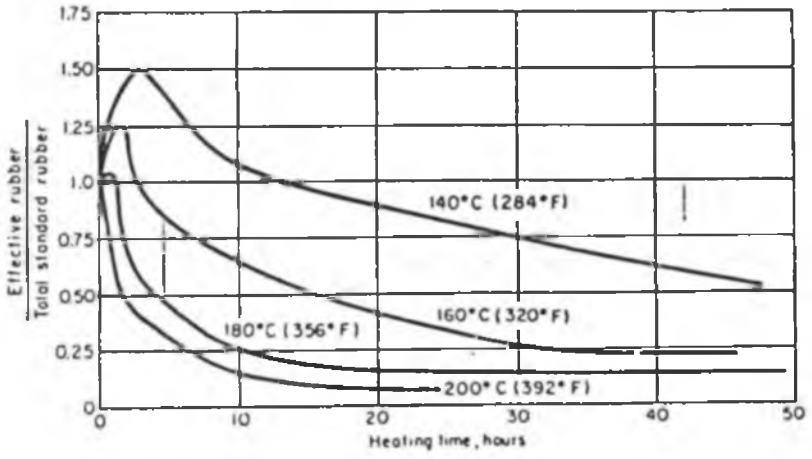
- Latex liquid additives — Colloidal dispersions of rubber added in the form of latexes differ from the above method under microscopic examination—primarily in particle size in the final mixture. The rubber dissolves into a hot one-phase system and upon cooling separates evenly throughout the asphalt in an extremely fine "network" structure. Goodyear, Du Pont and Xylos Rubber (Firestone) offer latex products specially designed for rubberized bituminous pavements. The asphalt may be molten, cutback, or emulsion.

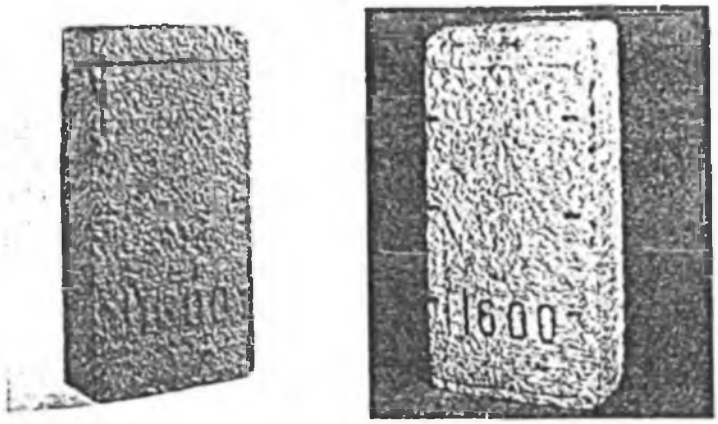
- Aggregate coating technique—The fourth method of incorporating rubber into the highway involves the addition of a special reclaimed rubber product to the heated aggregate in the pug mill (hot paving material mixer) before mixing in the asphalt. The heat-activated rubber additive quickly becomes liquid, thus coating and encapsulating each aggregate particle in a rubberized sheath. The interstitial asphalt in the pavement contains a smaller proportion of the rubber additive, since one prime purpose of the rubber in this case is to provide better adhesion between asphalt binder and aggregate (stone) surfaces.

U.S. Rubber Reclaiming is the only U.S. firm known to be manufacturing and selling a product based on this concept, and their additive production process is patented. It is reported to be a masterbatch of rubber in asphalt, as is a similar Japanese product.

Rubber additives may be blended into the asphalt at the refinery and from that point on the mixture is handled by contractors about the same as if it were asphalt—except perhaps for temperature, viscosity and setting-time considerations (which do not present serious problems). Some of the powder or flaked products and latexes may be added at the pug mill, or into the pressure distributor of seal-coating equipment. At least one non-aqueous product (Xylos' R-524) is dispersed in a polyhydric alcohol for seal-coating, among other hot applications, to eliminate flashing of water and possible foaming when mixing aqueous latex and hot asphalt (some use silicones for anti-foaming).

Variation of the effect of NR in asphalt when heated as described by P. D. Thompson of NRPRA[3].





For ease in compounding, all Baytown® masterbatches are marked in quarter bales. Also note that the stock 7"x14"x28" bale, available either talced or "bareback", carries an appropriate IISRP number plainly visible for easy identification.

Advantages in Mill Room

Quite naturally, some of the warehousing advantages of black masterbatch carry over to the mill room. Among them are improved handling, easier, simpler waste disposal and reduced storage space. Another carry-over benefit is less capital expenditure when you expand capacity and output. The ability of black masterbatch to make optimum use of existing equipment can be a key factor. Naturally, the accompanying, less-maintenance feature is an additional saving. Also, with black masterbatch, no dust-collecting equipment is required.

Those savings that are peculiar to the mill room would include:

1. Improved Weighing-In
   The batching-up operation is made simpler and faster because fewer items need weighing. The proportional markings of the bale permit fractional compounding of black masterbatch. (See photograph).
2. More Accurate Compounding
   The bales of masterbatch, weighed to close tolerances, contribute to a more precise compound. The weighing of fewer ingredients only enhances this accuracy. Better material identification (labeling on each bale) reduces chance of error. Elimination of free black during mixing not only adds to accuracy but saves on material costs.
3. Better Mixing
   Faster mix cycles result from the fact that black begins to disperse immediately upon working. Accuracy of masterbatch ingredients contributes to uniformity of mixing cycles.
4. Better Product Uniformity
   The initially improved compound uniformity can only result in a more uniform end-product. This advantage of uniformity, naturally, carries through all processing operations. As a consequence, you experience fewer rejects; fewer rejects spell prompter customer delivery.
5. Effective Color Changeover
   Changeover from black to colored or white compounds is easier, faster, and more complete since there is no free black nor extending oil to act as contaminates.

However, black masterbatch allows additional dollar-savings beyond those of the warehouse and mill room. Less transportation costs due to one combined shipment instead of three individual shipments cut costs. So does less control testing of incoming materials. But certain benefits of black masterbatch defy measurement. How do you equate the improved employee relations to money? Or the improved community relations through elimination of air pollution in the event your dust-collection system breaks down?

In the next Technote, we shall pass on some tips for capitalizing on the mixing and processing advantages of masterbatch, as distinguished from its inherent benefits as enumerated here. In the interim, please let us hear from you if we may be of service in helping you use or adapt your operation to masterbatch. Naturally, we always welcome such an opportunity.

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Most of the rubber additive producers have different recommendations for handling their products and in several cases patents are involved. Some, like the U.K.'s Natural Rubber Producers Research Assn., indicated that their NR-based products should not be pre-blended and held at high temperatures (max. 350° F) for extended periods because of breakdown of the rubber molecules. Blending time reported in British literature[3] covers mechanical mixing time plus transportation time at high temperature—i.e., a minimum specified blending time of 15 min can be 1 min mixing and the remainder in the truck.

The NRPRA studies also show up to 50% increase in "rubberizing effect" over that normally expected for a given amount of NR mixed with asphalt. This comes as a result of heating at 140° C (284° F) for about three hours—falling off thereafter as the rubber decomposes or vulcanization bonds break. Optimum time and effect decrease with increasing temperature. This anomalous behavior of rubber-asphalt mixtures has yet to be explained in detail but may account in part for wide variations observed in some road test results. Pug mill temperatures vary widely in practice, as do time-temperature considerations.

To carry any description much beyond the above information quickly bridges into the proprietary claims of particular manufacturers. For example, U.S. Rubber Reclaiming has patented the process of manufacturing their heat-activated additive which is introduced into the pug mill for hot-mixes ahead of the asphalt. Firestone, on the other hand, believes adding rubber (latex) to hot aggregate first in a pug mill will coat the stones with a dry rubber film that is difficult to disperse. They therefore have patented the technique of adding latex a fraction of a second after the asphalt to prevent this from happening. Then there is Goodyear which recommends "simultaneous" addition.

[3] Readers in North America may address requests for general NR application information and copies of NRPRA technical papers to the Natural Rubber Bureau, 1108 16th St., N.W. Washington, D.C. 20036.

Economic Considerations

Costs[4] of rubberized asphalt vary widely in the as-laid condition, largely due to contractor variables, material costs and many other factors. A major point raised by customers, though, is whether the benefits of rubber additive are worth the cost. Although such data (in terms of the overall road job) is difficult to obtain, it is safe to say that the present economics of rubber roads is decided by the specific job. And therein lies one difficulty in attempting to pinpoint costs.

Another stumbling block here is the need to know how much rubber polymer (or rubberizing effectiveness) is in a given additive. The price per pound (or gallon) of additive itself may not be particularly meaningful as it relates to resultant benefits. For even the unvulcanized powders must have at least some inert filler material to prevent caking; and the latex products contain different amounts of water or alcohols that do not add elastomeric benefits.

Still another variable that complicates any cost calculations is the fact that various types of rubber appear to improve the final asphalt mixtures to a greater or lesser extent. Although findings differ from one asphalt to another, the results are broadly similar.

One study[5] shows that a particular natural rubber tested is superior in certain properties to some SRs and not nearly as good as certain others—at least under the laboratory test conditions employed, the properties measured, and the methods used to incorporate the rubber. (As was often the case in the early '50s, the powered rubbers here were treated as "aggregate" and several photomicrographs show what are now recognized as very transient forms of dispersion.) A French study, on the other hand, shows that high-molecular-weight NR performs better than most SR types except possibly in oxidation resistance.

As a result, it may not be meaningful to reduce cost caluclations to dollars per pound of dry rubber hydrocarbon unless the buyer knows that he is comparing the same kinds of rubber added to the same asphalts and aggregates and using the same method of incorporation. Furthermore, additives within the same category are not comparable by general type—i.e., SBR types vary in composition, processing, and in the special ingredients that are added by the manufacturer.

Because it is generally accepted by rubber manufacturers that a thinner section of "good" rubberized asphalt will do the equivalent (or better) job of a much thicker slab, layer or coating of ordinary asphalt, some companies find it advantageous to estimate relative costs on a square yard basis. This takes some advantage of improved materials to reduce intitial capital costs. British field tests indicate that three inches of NR rubberized asphalt is at least as good in resisting cracking as five inches of normal asphalt, provided the binder content of the rubberized material is slightly increased. However, the Britishers caution that these findings are neither firm nor comprehensive at this time.

U. S. Results

Data showing increased pavement life and decreases in maintenance costs in U.S. applications run the gamut, generally ranging from zero (or below) to 50-100% or more. Unfortunately it seems likely that only the more recent U.S. tests utilizing newer products, methods, more accurate record-keeping will provide data that can be utilized with confidence. (NRPRA's 15-year survey also cites this shortcoming in full-scale road trials around the world.) In short, it is obvious that many of the rubberized road strips now being tried out on highways need more time in service for adequate evaluation.

For example, Orrin Riley, project

[4] (NOTE: All costs reported in this section are based on U.S. short tons (2,000 lb), U.S. gallons and English pounds—unless otherwise stated. Monetary values: $0.204/Franc (1964); $2.80/£ (present).

[5] Investigations of Rubber Addivities in Asphalt Paving Mixtures, Proceedings of the Assn. of Asphalt Paving Technologists, Vol. 23, 1954, pp.28-63, L. E. Gregg, Director of Research, Kentucky Dept. of Highways.

Under a Firestone research contract, Gregg developed a flexure-fatigue testing machine to measure quantitatively the fatigue resistance of as-laid asphalt paving mixtures including aggregate, additives, etc. He also used a mechanical convection oven which enabled accelerated aging and oxidation of test specimens.

engineer for the consulting engineering firm of Howard, Needles, Tammen & Bergendoff (Fairfield, N.J.) says his firm has been specifying rubberized asphaltic concrete (also with asbestos) to eliminate fatigue-cracking of wearing surfaces of bridge decks since 1961. Since 1963, he says, all major bridges on the New Jersey Turnpike have been so covered, plus some on the Massachusetts Turnpike, the Delaware Memorial Bridge, etc. Their purpose was primarily to cover 6-½ to 8 in. thick portland-cement concrete on the bridges with a thin coaltar-epoxy membrane and a 1½-in. overlay of high-density asphaltic pavement (¾ in. maximum aggregate size; 8% asphalt) to prevent water from cracking and otherwise damaging the concrete.

To prevent this very high-density asphalt (which tends to be more brittle than other types) from cracking. Riley says they have been adding small amounts of rubber. Much of this has been mixed with Du Pont's neoprene latex (LD-260 is 37.5% rubber solids; the binder was 1½% mix by weight including water). Cost per short ton of asphalt mixed and laid in place has been about $2.50/ton more for rubberizing (not including asbestos) than for conventional asphalt paving. They have also used other rubber additives with as-laid costs ranging down to about 50¢/ton extra[4] for Ramflex (U.S. Rubber Reclaiming Co.). The latter product contains a devulcanized reclaim rubber made mostly from tire stocks and presumably is a mixture of SBR polymers with some NR from truck tire carcasses.

As for results, Riley first points out that costs are always higher for small quantities of rubber pavements mixed for bridge work, generally running about $20/ton, or $1.62/sq yd as laid. Thus far, he says, the rubberized bridge strips have given satisfactory life and are expected to bring continued sharp reductions in maintenance costs. He adds that bridge concrete slabs can crack very soon after they are poured, but they usually may be expected to last 7-8 years before this happens.

In an interim report to the Highway Research Board last January, Riley stated that the best wearing course for his purposes is a dense asphaltic concrete (for impermeability) fortified with asbestos (for stability) and modified with latex (for flexibility). This mixture, he said, doubles the cost of the system—but increases its service life at least fivefold.

"The results to date have been most heartening," Riley notes. "So far, over the past three years we have provided this treatment (i.e., membrane, raised dams and inlet covers, and rubberized wearing course) on three large bridges, two very large viaducts, and about 30 smaller overpasses. The total cost of the protective treatment has so far run to $3 million. On each bridge the treatment cost was about equal to the cost of the previous year's repair program on the old concrete deck. Insofar as we are concerned, the protective treatment has already paid for itself—$3 million spent to halt a rising $6 million repair bill."

In still another neoprene application, the Public Works Dept. of Grand Junction, Colo., recently reported that in the eight years since they first began using rubberized asphalt for seal coating, their maintenance costs for these streets have dropped to zero. The city has been using a cutback containing 1½% neoprene for all coating jobs since 1958. The previously used non-rubberized seal coating was applied in 1952 and after five years, city officials say, the annual street maintenance repair costs were exceeding $2,500/mile.

Grand Junction's initial costs for sealing 58,420 sq yd of street surface with conventional cutback asphalt are figured at $0.1132/sq yd, with an expected life of five years based on past history. Use of Du Pont neoprene latex increased the cost 17.7% to $0.1332, but no maintenance of any kind has been necessary thus far—and city officials foresee at least a 10-year life for the rubberized surface. Advantages reported include ease of handling, nonbleeding characteristics, higher chip retention, coverage of all types of surfaces including portland-cement concrete, brick, asphalt and hard-packed dirt. The Coloradoans also say the material can lie up to an hour before chipping but subsequently sets up faster than regular asphalt. This permits road workcrews to paint lane and traffic control markings in quick order.

What the Producers Say

Firestone estimates that thin overlays about half an inch thick should range from about $14 to $17 per ton total laid cost. This of course depends on many variables: quantity ordered, contractor experience, regional labor rates, percentage of rubber additive, variables in aggregate, etc. These figures include a premium of about $3-5/ton for their Rub-R-Road materials and the costs of adding the rubber, all other factors being equal. A thicker layer using more (and larger size) aggregate and less rubberized asphalt might run $8-10/ton total laid cost, the company says.

Firestone's Harold V. Carlson says these cost figures are based on actual rubber road projects that have been undertaken. In one typical case, the city of Rocky River, Ohio, resurfaced more than 10 miles of streets in a two-year period with ¾-in. hot-mix skid-resistant overlay, and so eliminated the small-quantity factors. The contractor (Horvitz Co. of Cleveland) laid about 375 tons a day; in-place costs were in the $14-15/ton ($28.15/cu yd) range.

Carlson also noted that the above cost figures are for a blend of five parts latex solids to 95 parts of asphalt cement, thus eliminating the water content from calculations. The materials used here range from thick, coarse-aggregate paving with 5% rubberized asphalt in the finished pavement, up to 10% rubberized asphalt in thinner, finer overlays. As an added comment, Carlson says if the $14-17/ton fine-grained rubberized material were being laid in half the thickness of the $8-10/ton coarse aggregate asphaltic concrete, the costs would be about comparable on a per-sq-yd basis.

S. P. Tauber, sales consultant for Uniroyal (Chemical Div.) in New York, says they do not recommend using more than 3% of their flaked masterbatch based on the weight of asphalt. He quoted 40-43¢/sq yd including all costs with the pavement laid—indicating that a ton of mix will cover 35-40 sq yd. This

Remember when silicone rubber was about as tough as cheese?



Time was when silicone rubber just didn't have the toughness some industries required. Sure, it was flexible at —75°F. And it was serviceable at 450°F, too. The electrical properties were superior to any other elastomer. And it was unmatched in its resistance to aging, weathering, ozone and many chemicals. But physically, it was like cheese.

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GENERAL ELECTRIC



Rising $6 million maintenance bill for (portland-cement) concrete bridge decks like this was halted on the New Jersey turnpike with $3 million treatment including DuPont neoprene and Ramflex rubberized asphalt wearing courses.

puts Uniroyal also in the $14-17/ton range.

Typical costs reported by New Mexico's State Highway Dept. for sizable jobs (as shown in last month's cover photo) run about $6.00 and $8.80 per ton as laid (without rubber) for a dense-graded surface course and open-graded finish course, respectively. Adding 3% of Goodyear's Pliopave L-170 by weight of asphalt increases the cost $1.05/ton for material and $0.73 for contractor extras. (Pliopave is 68% SBR latex solids and the balance is water, says sales manager Donald A. Kaliin. Thus the New Mexico binder contains about 2.0% rubber since they do not decrease the asphalt quantity when rubber is added.)

New Mexico purchases its asphalt on separate bids. It is interesting to note that at their average price of $6 per 42-gal barrel of asphalt, their standard 6% asphalt pavement has about $2.02 worth of asphalt per ton of highway mix. Thus the rubber additive increases the binder material cost by about 52%.

The New Mexican cost per ton of rubberized asphalt concrete pavement in place is about $7.80 for the dense-graded surface course and about $10.70 for the open-graded finish course. Overall as-laid cost increases due to 2% rubberizing are thus 30% and 20%, respectively.

The cost of Ramflex is quoted by U.S. Rubber Reclaiming Co. at a flat $0.12/lb f.o.b Vicksburg, Miss., or Buffalo, N.Y. Although the firm does not indicate the actual percentage of rubber in the product, their minimum suggested concentration is 6% based on weight of asphalt in the final mix. Robert H. Moberg, sales manager, says total materials costs including freight can usually be figured at about $1.00 per ton of mix (excluding contractor labor). A short test section laid in Oakland, Calif., by contractor Ransome Co. (Emeryville) involved a 1-in. thick mat over an old bitulithic pavement. Addition of Ramflex increased the cost of the mix $1.10/ton, they say. Midwest's SBR flakes cost 18¢/lb. in truck loads f.o.b. E. St. Louis, Ill. with freight allowed.

Overseas Cost Experience

Although there is little in the way of published data on rubber road costs in the U.S., overseas literature is even less informative on this score. However, the French Central Laboratory of Bridges and Highways has released some data that was provided by registrants at a conference held in May 1964. Here are some of the highlights of that session:

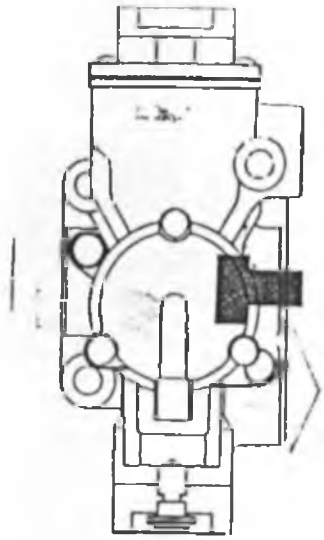
- The raw material price, based on about 10% rubber, doubles the price of asphalt. The incorporation costs are quite variable and can fluctuate the total price between double and quadruple.
- In 1956-57 a rubberized asphalt job including fabrication and application cost 25-30% more than would have been expected for conventional asphalt.
- Including incorporation, a 6% polyisoprene mixture would be expected to cost $92.70—111.20/ton.
- SBR Shell asphalt (no percentage given) costs $111.20/ton.
- A 5% butyl asphalt costs $92.70/ton in test quantities. For larger quantities and less critical applications, the price would be lower.
- The price of a ton of coating rises at least 30% for rubberizing.
- A job involving 250 tons of thick 0/6 coating with Routoflex (Gerland) rubber-asphalt gave the following costs: rubberized asphalt at $111.20/ton vs. ordinary asphalt at $34.80/ton (or about $6.20/42-gal barrel). Rubberized coating cost $13.45/ton vs. $8.08/ton for regular asphalt coating. The 66% increase in cost was achieved under very advantageous conditions.

British cost estimates and some of the qualifying factors that have been noted during their extensive full-scale rubber road program are provided by P. D. Thompson, road consultant for NRPRA. His summary of U.K. experience—all with NR additives—runs as follows.

Costs are based on trial work since it is difficult to obtain commercial figures, he reports. Typical English costs, which vary quite widely even for conventional asphalt, are:

- Rolled asphalt wearing course —normal cost about $14.90/ton.
- Rubberized rolled asphalt wearing course (4% rubber by weight of binder)—an extra $6.30 short ton.

The added cost due to rubber is therefore about 40% of the wearing course only. In thicknesses over 1½ in., the British use a combination of base course and wearing course. The base course is a leaner mix, having less binder and therefore less rub-



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ber. The extra cost is then about 35% if both courses are rubberized, or 15% if only the wearing course is rubberized. Taking the first figures, the cost of the rubber (as powder) is $5.60 out of the $6.30/short ton.

This, however, is not a typical example. In the first place, this form of rubber is expensive (52½¢/lb of powder which is 60% rubber, 40% filler). Its use is justified where the contractor is using rubber for the occasional job. It has the advantage that even a single load can be rubberized at scarcely any extra cost other than the actual cost of the additive (some additional cost is reasonable here in that mixing times are slightly longer, which cuts output by about 5%).

NR latex contains 5.7 lb rubber gal—now about $1.40 per gal. This comes to roughly 24½¢/lb of rubber vs. 87½¢/lb of rubber in the powder. To use latex in rolled asphalt, a metering pump is necessary (this can be set up as an integral part of the asphalt plant) to meter the required amount of latex into the pug mill. Cost of this set-up is about $280—a small capital outlay for a plant turning out substantial tonnages of rubberized asphalt.

Thompson, surveying the British roads picture, estimates that in cases where rubber is used extensively, the additional cost for rubberizing (with latex) is about $2.80/short ton. This brings the added cost down to about 20% for a good rubberized asphalt (for wearing course only).

England, it should be noted, has a large number of contractors and its road authorities are responsible for areas which are quite small in comparison with those of their U.S. counterparts. Therefore, says Thompson, even with substantial tonnages of rubber used, no one contractor today would work for long periods continuously turning out rubber asphalt—hence the use of more expensive powder for convenience. The exception here is in spraying and chipping—i.e., where one contractor markets several hundred thousand gal/yr of rubber binders for spraying and chipping.

To the British binder suppliers, addition of rubber "at source" is an added complication and the whole



Reclaimed SR patches (1:2 mix, 85-100 asphalt, 420°F, ¼ in. stone) have withstood 30,000 cars and trucks/day in Phoenix, Ariz., since Jan. '65. No reflection cracking to date—unlike adjacent conventional strips.

emphasis (except for spraying and chipping) is on addition of rubber in the pug mill. A side-effect of this is that rubber is only used where the independent road authority is convinced that a substantial improvement results.

As to demand for rubberized surfacings, Thompson says that in 1964 the U.K. used an estimated 12,000 long tons (mixed materials) and some 400,000 gal of binder for spraying and chipping. In '65 the comparable figures were 20,000 tons and 500,000 gal.

These consumption figures are meaningless of course without taking into account the total tonnages used yearly. Thompson estimates that in 1965 this represented about 1/3 of 1% of the total theoretical potential for rubber—i.e., the amount of rubber used if all surfacings were rubberized.

Figures for other countries are largely realistic guesses based on reasonable knowledge of the amount of rubber sold. On this basis, Thompson says, Europe probably uses as much as the U.K. (mostly for bridge surfacings, however). Malaysia uses about the same amount; Australia about half the U.K. consumption, but increasing rapidly; and Japan at least double the U.K.

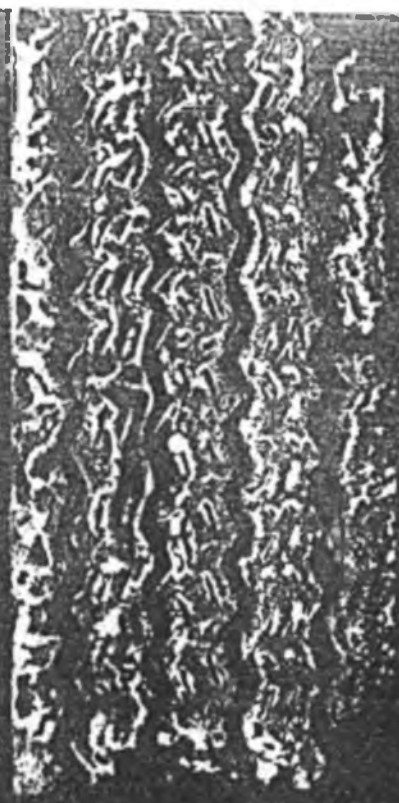
In summarizing the economics of rubber roads, it should be noted that the increased cost of the binder alone—even with very expensive additives—is a very small fraction of the total highway cost. Regardless of the materials selected, there are preliminary surveying and engineering requirements, traffic studies, condemnation and land acquisition expenses that may be extremely high, especially in heavily populated areas. Then there is the costly preparation work for excavating, grading, filling, constructing bridges and overpasses, etc. Viewed in these overall road picture terms, the percentage increase in cost for rubberizing per mile of highway is small indeed.

The Safety Story

The cost of human life on today's high-speed highways and congested city streets is not usually considered an economic factor, but this highly emotional subject can and does influence industry economics. So it is that rubber roads—despite their slightly higher initial costs — are coming in for more and more attention as a contributor to safety. Decreases in the number of dangerous chuck holes, ruts and cracks in the nation's roads—along with improved traction and anti-skid properties—appear to be obvious selling points for rubber roads. And, some feel, these points may yet provide the impetus for future market expansion and growth.

At least one U.S. company has collected some firm statistics on highway safety gains achieved through use of rubber road additives. In addition, there are more difficult-to-measure statistics on accidents caused by poor roads in general. Even improved road construction methods come into play here. Reason: use of rubberized asphalt permits road officials to open new and quickly-repaired highway sections with less congestion, traffic delay and rerouting—in short, without obstructing normal vehicle movements and increasing accident potential.

The city of Charlevoix, Mich., provides an interesting case study . . . one where there are no statistics—only plainly visible results. A thin rubberized hot mix was applied with siliceous sand and Aloxite Highway Safety Grain (Carborundum Co., Niagara Falls, N.Y.). The resulting non-skid pavement made it possible for the first time for large trucks to climb safely a notoriously slippery



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hill under wet conditions. (One advantage of rubber is its better holding of abrasive aggregate particles.)

Firestone's Rub-R-Road additives for asphalt have also scored a string of safety successes in Ohio where statistics recorded before and after application leave little doubt in the minds of the motoring public:

- The highway cutoff on a curve of busy U.S. Rte. 20 leading to the city of Freemont in 1960 had nine accidents with four injuries; during the first 11 months of 1961 there were seven accidents with two fatalities and three people injured. There were also dozens of unreported accidents with no injuries or less than $100 damage to a single vehicle. During the following 12 months after rubberized paving was applied on a half-mile section, only four accidents were recorded on the curve—with no fatalities.
- In 1953, dangerous intersections in Lucas County recorded 21 accidents. A conventional anti-skid pavement reduced accidents 81%—but the nonrubberized material would not adhere well to concrete or brick, weathered badly and soon became polished and slippery under the ordinary buffing action of vehicles. The County then tried rubberized pavement. Results show that it maintained the safety advantages and cured the adhesion and wear problems as well.
- Four busy state highways join to funnel up to 60,000 vehicles through Fostoria on a Labor Day weekend; a normal week sees 55,000 vehicles (with a high percentage of trucks) pass through. Intersections were often slippery even in dry weather; asphalt paving had pushed up over curbs; corner houses were even hit by trucks unable to stop on several occasions. After rubberized paving was applied over a five-mile area in the city, accidents dropped 95%. One bad intersection previously recorded 11 wet weather accidents and one on dry pavement during a 12-month period. In the seven months after rubberized, skid-resistant pavement was applied, only one wet and one dry weather accident were reported.

Conclusions reached by these and other communities using the rubberized asphalt materials are well summed up by Donald R. Patton, director of Public Safety-Service for Rocky River, Ohio, a Firestone customer since 1961. "One of the chief advantages of this material is that it is skid-resistant . . . tested by city officials and found to be good even on snowy and rainy days. Citizens have also reported better traction. I am sure . . . on streets where this material has been used our accidents have been reduced measurably."

Technical Roundup

As noted previously, U.S. development of rubber-road products has been confined primarily to synthetic rubbers, Britain has devoted its prime efforts toward natural rubber, and the French have done research on both.

Any attempt to summarize in detail the technical conclusions of the various rubber-roads reports is beyond the scope of this survey article. In addition, the technical conclusions on specific products are not all in agreement—except, perhaps, as they relate to overall effects of rubber additives. A few of the problems and thoughts on R&D methods are worth noting, however.

Lack of adequate communications is a problem people have been in the process of solving since sign-language times or before. One example of this can be found within U.S. government structures—where maintenance engineers sometimes may be off researching on their own with various materials including rubberized asphalt. Construction engineers in the same bureau or department are supposed to be kept advised of such independent work (and vice versa), but at some points the wires obviously go down.

Similar problems are brought up in French discussions. As one scientist stated, responsible engineers from the regional laboratories shouldn't be kept in ignorance of technical details, in spite of necessary fabrication secrets. At the closing of the 1964 conference on rubber asphalts in France, one proposal suggested the formation of a working group of four or five people representing the various interests to facilitate research and the exchange of information on rubber roads.

Problems related to aging of rubberized asphalts are bought up repeatedly in the literature of all countries. Oxidation is believed to be a significant influence, particularly with respect to NR. Some French researchers are concerned initially with thermal degradation and later with long-term oxidation after pavements are laid. Dr. Kenneth E. Bristol however, says Goodyear tests of SR pavement samples aged in the highway show little degradation due to post-laying oxidation. He believes the principle oxidation, for SRs at least, takes place during the heated period at a much more rapid rate. Consequently Goodyear recommends laying its product in minimum time at 325-350°F, and never higher than 375°F. (Others also suggest about the same temperature limits.)

Current Research Efforts

Research is also going on in methods of protecting both rubber and asphalt constituents from oxidation, since it is known that some asphalt materials oxidize at much higher rates than the rubber. Dr. Bristol has studied the effects of up to 10 times the usual concentrations of conventional rubber antioxidants with no observable protection increase for either rubber or asphalt.

The physical mechanism of aging appears to require further study. French reports indicate in some instances a time-delayed modification of rubber/asphalt microstructure as seen under the microscope. The exact nature and effect of this phenomenon is as yet unknown. Some scientists feel the "insoluble" gel content of the rubber has much to do with initial dispersion and final properties. Some SBR polymers, Dr. Bristol says, may contain 30-60% of such gel fractions which are perfectly good for production of all other types of rubber products. They are excluded from Goodyear Pliopave to obtain the best possible microstructure on mixing with asphalt, however.

The effect of molecular weight or chain length of polymers apparently is yet to be determined with exactness. One French study on NR gives excellent correlation of MW with certain properties of the rubber/asphalt mixture, even to molecular



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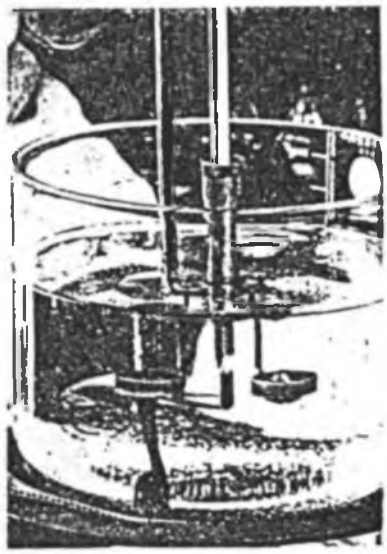
cal mixing techniques as well as high processing temperatures.

However, the addition of synthetic NR in the form of a high MW polyisoprene did not match up with the tree-grown rubber data, falling below the expected correlation. The reason for this is not understood. Studies in 1964 were continuing on correlations of butyl MW data to determine the effect, if any, on asphalt mixture properties. Still another French paper dealing with SBR 1509 additive states, "Whatever the method in incorporation, experience has shown that the effect of the polymer is more important than the percentage present or the length of the chain."

The second phase of the study program proposed by IISRP to the U.S. Bureau of Roads looks interesting to many since it incorporates a much more comprehensive field test experiment that is statistically designed to provide definitive answers. It would take into account—simultaneously in a single effort—the primary variables that have been or are being researched individually on a more haphazard basis by empirical methods in the scattered tests that are being carried out by various state highway departments. (Roland Vokac, internationally recognized highway expert, is one of IISRP's prime consultants on this work.)

Some government highway engineers have expressed an interest in a program such as IISRP proposes, particularly if the more advanced techniques of highway engineering data analysis and fatigue investigations can be tied into the total project. The federal government has been funding studies of this type at Ohio State University (by Prof. Bonner Coffman) and the University of California (by Prof C. L. Monismith at Berkeley). Prof. Charles Pagen at OSU says the studies involve development of complex equations directed toward structural pavement design criteria based on visco-elastic properties and repeated stress applications. OSU has also done extensive rheological tests.

By using visco-elastic theory, it is possible to evaluate both time and temperature-dependent responses of highway materials. The arbitrary "fudge factors" that appear in present equations can be eliminated. Electrical model circuitry using capacitors to represent the elastic elements and resistors for viscous elements of the equations provide a ready method for getting answers. Another benefit is that parameters and strength properties of the paving mixture are independent of the type of test, allowing a lot of the present miscellaneous and uncorrelated data on rubberized asphalts to be fed into calculations.



Plain asphalt (left) softens quickly and drops to the bottom of the vessel at elevated temperatures of streets on warm days. Pliopave asphalt (right) remains firm due to higher softening point; resists bleeding.

Materials & Methods

In other areas, materials development work is reported for special applications where silicone rubbers might be useful. General Electric's Silicone Products Dept. has been marketing its Silicone Traffic Topping for some time (see RW, Aug. 1965, p 69). GE is looking at specific problem areas, such as improved water-proofing and corrosion-proofing of bridges. At present, GE believes it is not practical to consider silicone rubber applications involving complete highway surfacing because of the high cost.

Other major silicone producers—i.e., Dow Corning and Union Carbide—say they are not in the rubber roads business even experimentally, except for sales of products such as dimethyl silicone to prevent foaming of asphalt when mixed with latex pavement additives that contain water. (The Carolina Asphalt Pavement Assn. also reports other benefits of silicones for paving mixes with or without rubber.)

been active in several countries. The Severn Bridge in England, which was opened for traffic last year, involves a new concept in suspension bridge design in that a steel-plate hollow box is used in the suspended structure. The top surface of this box forms the roadway.

Taking a cue from Europe's bridge designers, the Britishers chose a surfacing system that involves cleaning of the steel deck, application of a tack coat, use of a rubber-bitumen insulating material, and the laying of a mastic asphalt wearing course. This, it was considered, would meet the problem of providing a crack-proof surface on a structure subject to local bending. The insulating layer is 75% filler and 25% asphalt with an added 5% unvulcanized NR powder.

In the U.S., various rubber road experts make their own technology points. For instance, A. W. Eatman, materials and tests engineer at the Texas Highway Dept. in Austin, believes viscosity measured at temperatures of asphalt as it is applied onto the road—rather than the usually-accepted standard penetration tests at 77°F alone—provides better control of asphaltic materials under various conditions as the highways are being laid. He is still evaluating data gathered over the past three years but already notices advantages of these measurements in applying pavement materials. Among other factors, he feels proper viscosity can assure better immediate retention of aggregate during early road life.

Texas engineers (as well as some northerners interviewed) believe one of the first measures of success of any road is the ability of the asphaltic cement to tie the rocks down. If aggregate is lost at the outset, the road cannot be successful.

Several state engineers are boosters of rubber additives with this in mind, feeling rubber adds measurably to the cohesive and adhesive properties of asphalt. Viscosity checks aid in control of the rubberized asphalt cement. One points to the increased highway safety in reduction of flying stones kicked up by high-speed vehicles. Other safety aspects noted in addition to improved retention of anti-skid aggregates (rubber also reduces flooding or bleeding of asphalt with slick surfaces covering up the abrasive ag-



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Robert H. Moberg of U.S. Rubber Reclaiming Co. says that some rubber additives may help cure the natural (cationic/anionic) rejection of certain aggregate materials by certain asphalts. Both aggregates and asphalts can vary widely in their properties as they relate to anti-stripping qualities. These changing factors also add to the entangling maze of variables that must be considered by highway engineers, he says.

Moberg also cites the lower quality of asphalts and aggregates available today as one reason for his firm's concerted efforts in the development of rubber roads. In some areas much of the high-quality aggregates has been used up in the construction industry's postwar boom. Remaining aggregates may be of lower quality; hence the need for improving asphalt binders with rubber is constantly increasing.

Asphalt quality has also decreased in some ways, he says, simply by improved efficiency of the petroleum industry in recovering more of the higher-profit fractions from the crude oil before reaching the refinery "waste" product we call asphalt. This also increases the need for rubber additives just to maintain pre-war standards, let alone upgrade highway materials in order to handle higher speeds and loads of vehicles.

John M. Ball of Midwest Rubber Reclaiming Co. (a past-chairman of the ACS Division of Rubber Chemistry) points to the successful use of his firm's F-1500 elastomeric modifier in recent road-test trials in Phoenix, Ariz. Midwest's product, which is in flaked form, has also been used in a number of other rubber road projects, most notably in Virginia, Ohio and Texas.

Experimental Projects

The Phoenix work of Charles H. McDonald, city engineering supervisor, is being followed closely by other rubber additive producers since he has also used Ramflex and Pliopave (as well as tire buffings from a local retreader) for comparative purposes. His preliminary reports indicate significantly more distress in control test sections of pavement without the rubber additives than in those with rubber where elastic-type pavement failures were predominant.

McDonald has developed a unique rubberized patching material which has high elasticity and flexibility together with low temperature susceptibility. He makes a slurry by mixing approximately one part rubber with two parts of 85-100 penetration asphalt at 420°F for a couple of minutes to obtain a partial solution or gel. Aggregate is used primarily to prevent pick-up and excessive wear.

For field testing he selected road sections having the most severe conditions of traffic and drainage so that answers to the experimental work would be quickly forthcoming. He concludes that the method "... should prove to be a new weapon in the hands of maintenance forces against the ever-increasing deterioriation of our roads and streets."

A patent has been applied for covering a Band-Aid type of patch consisting of the above rubber/asphalt slurry combined with crushed cover aggregate applied to a paper backing. The fatigue-cracked road is first tackified and then the patch is put on and pressed into place with the wheels of a vehicle. The paper wears off and the patch will hold a failing surface for years, McDonald says.

Other new developments involve some equally spectacular results McDonald has achieved with high percentages of rubber in slurry seals up to an inch thick—in some instances approaching overlay thicknesses. Jack Mitchell, a contractor and local highway construction equipment expert and former president of the National Slurry Seal Assn., cooperated in the development using Young Slurry Machines.

Mitchell is quite enthusiastic about results and feels that this technique will be an adjunct to his slurry business for use where no other type of seal, containing asphalt only as a binder, would serve.

Other applications for rubber in asphalt are interesting to note in passing but do not appear to equal in any degree the long-range market potential of rubberized roads. Some however, may make good bread-and-butter sales items in the long run.

Among these are rubberized running tracks, playground and other recreation-area surfaces, etc., for educational institutions and professional athletic events. Another is asphaltic roofing applications which consumed more than four million tons of asphalt in 1965. GE's latest product, Silicone Rubber Roof Coating (RW, Mar. 1967, p. 34), is a non-asphalt material competing for the same market, although rubberized asphaltic types are being researched by others. Parking lots, garage floors, residential driveways, airport runways and taxi strips, etc., also are getting attention.

Somewhat in the same vein, a significant effort has gone into rubberized coatings for portland-cement concrete for special road purposes, particularly to protect against water and salt damage as well as to act as a blanket to prevent excessive premature drying during curing. Numerous road patching materials have been tried, too, and many of these are now being produced by a number of companies.

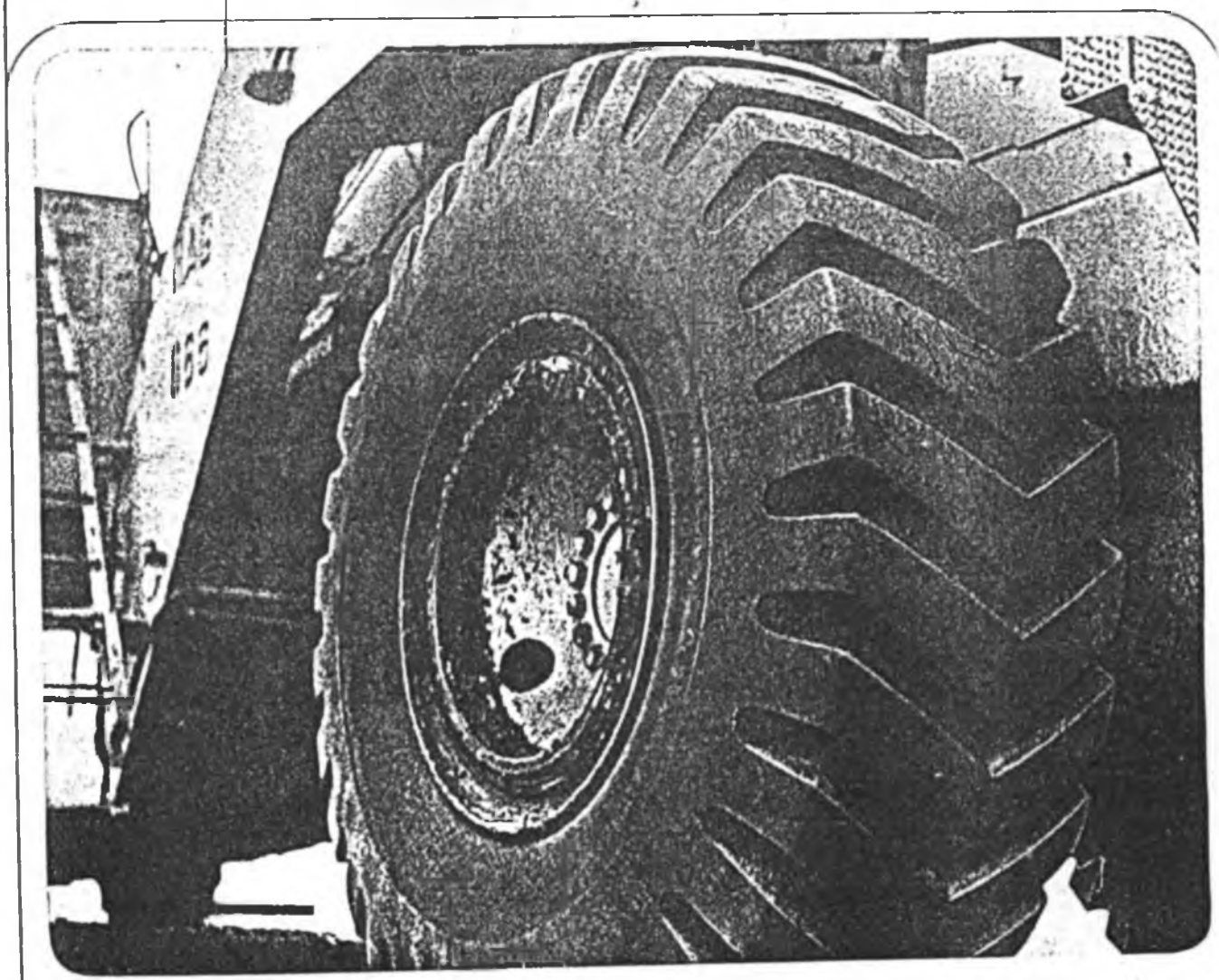
One interesting literature reference[*] deals with various patented additives for mortar including latexes of SBR, NR, chloroprene, and polysulfide. Others include plastics such as vinyl, acrylic, styrene, etc. Reports are, though, that to be acceptable to the concrete industry, the rubber product should be white in color so the final highway, bridge or structure will look like concrete.

Research data available from the Portland Cement Assn.'s laboratory shows that at least one SBR mixed into cement has passed standard freeze-thaw cycling tests required for highway use, although many other rubber additives failed. The rubber increases the flexural strength but does not decrease compressive strength so much that the resultant material is without value. However, the benefits achieved do not appear to warrant the cost, particularly when one considers the price of mixing latex into the product as a substitute for water.

Rubberizing tar with nitrile rubbers to make them resistant to fuels, lubricants and cleaning solvents is an application pioneered by Uni-

[*] Polymer-Modified Cement Mortars *Journal of the American Concrete Institute*, Dec. 1966, Jiri Hosek, Div. of Building Research, National Research Council, Ottawa, Can.

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The wish for accelerators with delayed onset of cure and quick completion of the cure is as old as the technology of moulded rubber goods. As early as 1931/32, Farbenfabriken Bayer were granted patents for the first sulphenamide accelerators based on benzothiazolyl sulphenamides doubly substituted at the nitrogen atom.

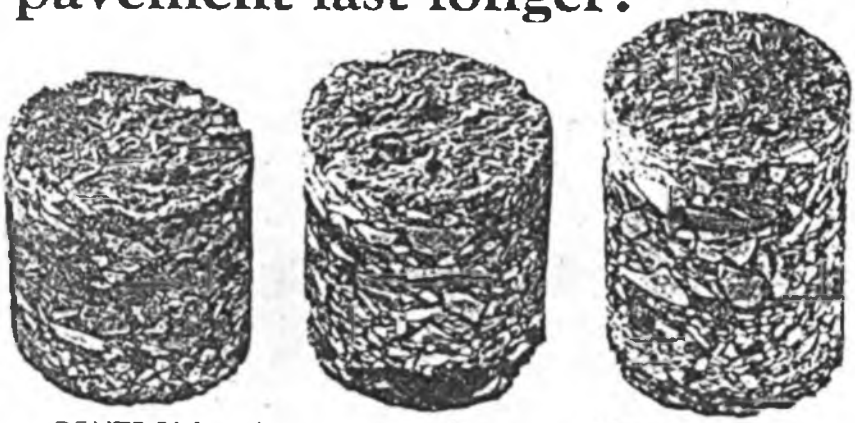
These basic patents (DRP 573 570, DRP 587 608 and DRP 586 351) include in addition to benzothiazyl sulphenpiperidide (Vulkacit BZ), the very first sulphenamide accelerator put on the market, a number of further sulphenamide accelerators, partly belonging to our range even today, for example benzothiazyl sulphenmorpholide (Vulkacit MOZ), secondary aliphatic (Vulkacit AZ), and secondary alicyctic sulphenamides (Vulkacit DZ).

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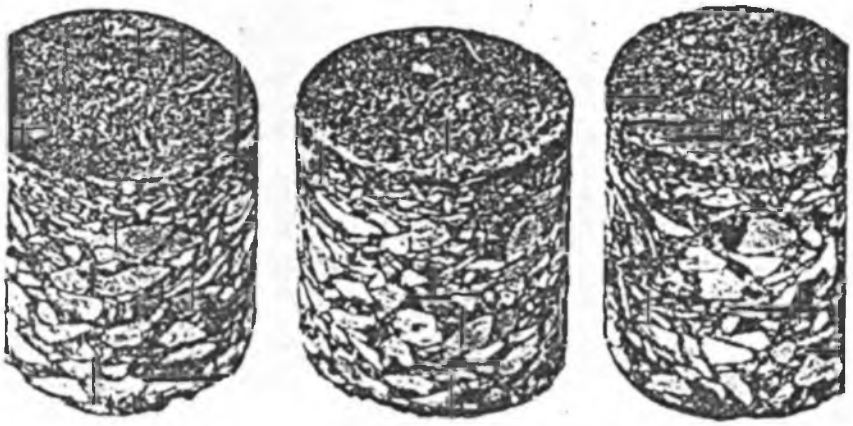
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royal with the U.S. Air Force back in 1947-50. Uniroyal's product for this application is a powder called Paracril. These rubberized tar compounds are used worldwide by many countries for airport aprons and hard stands for parking, refueling, checking and maintenance areas where solvent spillage is common. Most U.S. and foreign producers of such petroleum-resistant elastomers have products available for these specialized applications.

Market Should Grow

From the early 1840s to the late 1960s is, indeed, quite a stretch of time for our aborning rubber roads to become amazing. However, the pace has been noticeably stepped up in recent years and, judging from all comments, the tempo will continue to quicken. Already the trend appears to be turning sharply upward in several world markets; increasingly more rubber companies are eyeing the market; and most significant of all, potential highway customers are clearly interested—now.

Adding to the urgency of U.S. rubber interests in broadening highway engineers' acceptance of their additives is the release late in February of part of the previously frozen federal highway funds. Congress had authorized $4.4 billion for the present fiscal year and an equal amount for the next, but as a curb on inflation President Johnson withheld $1.1 billion of this year's appropriation.

He has since decided the current moderation in economic activity warrants removal of restrictions on $400 million by July 1—and possibly an additional $100 million if economic conditions remain satisfactory during the next few months. The Administration has also promised to dole out the full $4.4 million next year. Senate and House Public Works Committee leaders are still pressing for the full amount in '67, however.

Changes in the roads money picture are of primary importance since the federal government finances 90% of the costs of interstate highways and half the cost of primary, secondary and urban highways . . . all constituting a sizable potential for rubber roads in the immediate future. ■

(50) 78

Torsional Braid Analysis of Bitumen-Liquid Rubber Mixtures

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The performance of liquid rubbers as low-temperature plasticizers for bitumen was evaluated by the torsional braid technique developed by Gillham. The low-temperature dynamic mechanical properties of bitumen-liquid rubber mixtures were measured from ambient to −100°C and compared with the corresponding fracture behavior using a modified Fraass test. Microscopic observation of the mixture revealed that the liquid rubber was partially soluble in the bitumen at 23°C and at concentrations greater than 10 percent tended to form colloidal dispersions of rubber particles having mean diameters of approximately 10 μm. The loss tangent maxima shifted to lower temperatures and became less pronounced as the concentration of liquid polybutadiene increased. The colloidal rubber dispersion further contributed to the ductility and reduced the brittle temperature of the bitumen at −30°C at 20 percent liquid rubber concentration. The reduction in the brittle temperature of the bitumen is related to the glass-transition temperature of the added rubber, those rubbers having the lowest glass-transition temperatures being most efficient. Such modifications are necessary to reduce the tendency of asphaltic paving materials to crack in cold climates.

INTRODUCTION

Most asphaltic bitumens undergo a pronounced change in consistency when the temperature is increased from 0°C, at which temperature the asphalt is a relatively hard and brittle solid, to 100°C where the asphalt is transformed into a viscous liquid. Such a pronounced change in viscosity can have important consequences for the performance of asphalt paving materials, and many researchers have attempted to characterize the temperature susceptibility and correlate this property with pavement performance in terms of resistance to cracking or improved dimensional stability.

Temperature susceptibility is a measure of the rate at which the consistency of an asphaltic material changes with temperature. One of the first attempts to characterize the viscoelastic properties of asphalt may be attributed to Van der Pohl (1), who expressed the viscoelastic behavior in the form of monographs. His classical studies were later modified by several workers, including Pfeiffer and van Doormal (2), who introduced the "penetration index" (*PI*) as a measure of temperature susceptibility. Heukelom (3, 4), McLeod (5), and Corbett and Schweyer (6) have introduced other variants of the penetration index which are briefly reviewed by Kandhal (7).

The non-Newtonian behavior of many asphalts and the complex rheology frequently encountered with modified asphalts makes the penetration index of limited value when attempting to predict the performance of paving materials. In this study the torsional pendulum has been selected to measure the dynamic mechanical properties of asphalt mixture in the low-temperature region and to correlate the loss tangent with the low-temperature crack resistance.

The torsional pendulum has been used extensively to measure the dynamic mechanical properties of plastics and is described under ASTM D2236.

The use of rubber as a means of increasing the fracture toughness of brittle plastics is well known (16, 19, 25, 26). When a rubbery particulate phase is dispersed in a brittle medium, the low-modulus rubber particles help to disperse stress concentrations by means of crazing and shear yielding so that a large amount of energy can be dissipated before catastrophic crack failure takes place (27). These rubber particles are preferably bonded to the brittle matrix in order to maximize the fracture toughness.

There have been numerous attempts to modify the viscoelastic properties and the temperature susceptibility of bitumen through the use of elasto-

s (15, 23, 28). Previous investigators ured elastomers (19), thermoplastic 23), latices (14), depolymerized (20), or ground vulcanized reclaim from discarded tires (18). This investigation differs from many of these previous studies since the rubber is in a liquid state instead of the usual powdered, emulsified, or crumb state.

Liquid rubbers are available from many sources, most being derived from natural rubber or butadiene copolymers. In this particular study, a hydroxyl terminated polybutadiene (Arco Poly blend R-45M Resin) was selected for examination as a low-temperature plasticizer in a commercial asphalt binder (Shell Venezualan 85 to 100 penetration). Liquid elastomers have been employed as additives in thermosetting resins (epoxy resins, polyester resins) to increase fracture toughness (16) and in poly(vinyl chloride) to increase the Izod fracture energy (25, 26). Rubber modified asphalt shows many of the characteristics of rubber modified plastics.

These investigations suggest that liquid elastomers may be economically attractive agents for reducing or eliminating low-temperature cracking of asphalt pavements (29).

MATERIALS

Shell Venezualan asphalt (85 to 100 penetration) was selected for examination since this grade of asphalt is commonly specified in the Ontario region for paving surfaces. The properties of this grade of asphalt are summarized in *Table 1*. The liquid polybutadiene samples were obtained from the Arco Chemical Co. (tradename Poly blend resin) and have the properties listed in *Table 2*. Since these two grades of liquid rubber were nearly identical (differing only in hydroxyl number), results are presented only for the Poly blend R-45M grade. A small experimental sample of liquid polybutadiene prepared by Monsanto was also evaluated, although no technical information was available on this particular rubber sample.

Table 1. Shell Venezuelan Asphalt Properties.[a]

	Unaged	Aged[b]	ASTM No.
Viscosity, Pas, 60°C	1519	3629	D-2170
Penetration, 5°C	10	8	D-5
25°C	96	58	
Penetration Index	−1.3	—	
Ductility, 4°C	11.5	—	D-113
25°C	150+	150+	
Flash point	299°C	—	D-92
Density, g/cm³, 25°C	1.011	—	D-70

[a] Shell Canada Ltd., Oakville, Ontario.
[b] Thin film oven test, D-1754.

Table 2.

Poly blend Resin	R-45HT	R-45M
Nonvolatile Material, weight percent	99.9	99.9
Viscosity, poise @ 30°C	50	50
Hydroxyl Value, meq/gm.	0.83	0.75
Hydroxyl Number, mgKOH/gm	46.6	42.1
Molecular Weight, No. Average	2800	2800
Moisture, weight percent	0.05	0.05
Specific Gravity @ 30°C	0.901	0.899
Iodine Number	398	398
Glass Transition Temp. °C	−75	−76
Microstructure (both polymers):		
Trans-1,4 unsaturation 60 percent		
Cis-1,4 unsaturation 20 percent		
Vinyl-1,2 unsaturation 20 percent		

EXPERIMENTAL

The torsional pendulum testing method (ASTM D2236) is an important dynamic mechanical test for measuring the viscoelastic properties of plastics. In this study the torsional braid analysis (TBA) technique has been adapted to measure the viscoelastic response of rubber-asphalt mixtures from ambient temperatures to −100°C (21, 22). Kevlar roving was selected for the braid since it is easily impregnated with the hot asphalt solutions and is sufficiently tough and strong to support the inertial disc. In order to apply a uniform, controlled quantity of the asphalt-rubber mixture to the Kevlar roving, the saturated Kevlar strand was drawn through an orifice (0.095 mm diameter) which had been drilled into a thin metal plate. Care was required not to exceed a temperature of 140°C during the mixing process in order to avoid excessive oxidation of the asphalt-rubber mixture. A section of the Kevlar braid after saturation with bitumen is shown in *Fig. 3* in which good wetting of the individual filaments is evident. The coated strand was allowed to cool and cut to length (26 cm) ready for insertion in the screw clamps attached to the pendulum (see *Fig. 1*). The inertial brass disc had a mass of 1.20 kg and a moment of inertia equal to 12.08 kg·cm². A transparent acrylic tube was attached to the fixed support in order to insulate the strand from the atmosphere and permit controlled cooling to −100°C using a dry air stream chilled with liquid nitrogen. This was conveniently accomplished by passing laboratory-compressed air through a copper coil immersed in a Dewar of liquid nitrogen. A cartridge filled with Drierite was used to predry the air in order to prevent frost formation. The temperature was easily regulated to ±1.0°C by the use of valves to control the air flow. Each sample

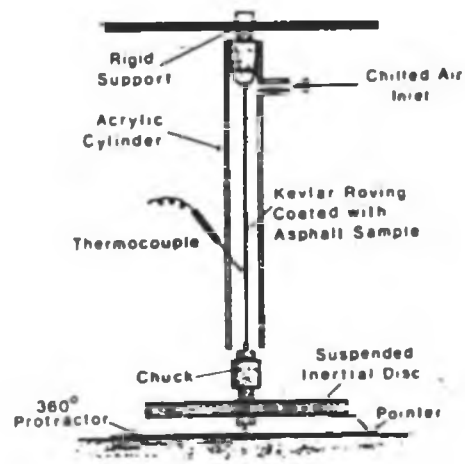


Fig. 1. The torsional pendulum modified with a Kevlar braid for low-temperature dynamic mechanical analysis of bitumen mixtures.

was cooled to the lowest test temperature and then readings were taken at 5 degree intervals over the region of interest. The amplitudes and mean frequencies were recorded at each temperature using a stopwatch and a protractor, which was positioned under the pendulum disc. Despite the simplicity of the apparatus, the data were quite reproducible and agreed with measurements obtainable from a Rheovibron. The oscillation frequency was generally between 0.025 and 1.0 Hz and not far removed from traffic induced frequencies of 1 to 16 Hz (9).

From the dimensions of the strand and the measured angular amplitudes, the loss tangent (tan δ), elastic storage modulus (G'), loss modulus (G''), and complex shear modulus (G^*) were calculated and plotted at each test temperature. The maximum value of the loss tangent (tan δ) occurred near the glass-transition temperature of the asphalt-rubber mixture.

In a supplementary test, small samples of the heated asphalt-rubber mixtures were spread onto a Mylar polyester film and placed in a temperature controlled system, as illustrated in *Fig.* 2. By applying tension to the Mylar film, cracking could be observed at various temperatures. A light bulb placed directly under the specimen clearly showed the appearance of cracks as the Mylar film was stretched. In this manner the appearance of cracks at a particular temperature could be correlated with the tan δ maxima. This test is similar in principle to the well-known Fraass test (IP 80/53).

TORSIONAL BRAID ANALYSIS PROCEDURE

The torsional pendulum was developed by Gillham (10, 11, 21, 22) for characterizing the thermomechanical behavior of polymeric materials. The theory of dynamic mechanical testing has been described by Koo (12) and Nielsen (13). The complex modulus G^*, is a function of the storage modulus G' and the loss modulus G'' according to the relationships

$$G^{*2} = G'^2 + G''^2 \tag{1}$$

where

$$G' = G^* \cos \delta \tag{2}$$

$$G'' = G^* \sin \delta \tag{3}$$

and

$$\frac{G''}{G'} = \tan \delta \tag{4}$$

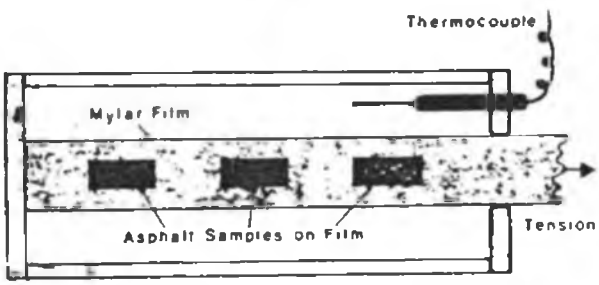


Fig. 2. Crack susceptibility of asphalt-rubber mixtures determined by applying stress to a Mylar tape coated with a thin film of asphalt-rubber

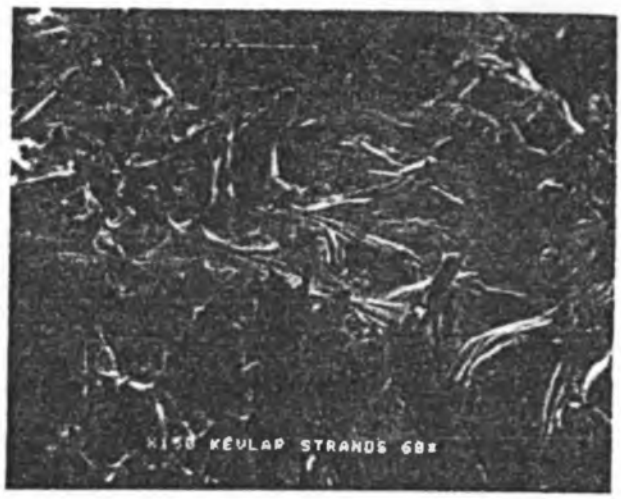


Fig. 3. A cross section of a Kevlar strand coated with bitumen shows the distribution of the individual Kevlar filaments (average diameter 11.9 μm) which are visible in the fractured surface.

The phase angle δ is a measure of the amount by which the strain lags behind the applied stress.

The torsional pendulum may be used to determine the value of G' from the equation

$$G' = \frac{8\pi LI}{r^4 p^2} \tag{5}$$

where

L = length of braid
I = moment of inertia
r = radius of coated braid
p = period of oscillation

The apparatus may be easily calibrated with a steel wire of known dimensions and shear modulus G'. The loss tangent is then calculated from the logarithmic decrement of the amplitude Δ, i.e.,

$$\delta = \frac{1}{n} \ln \frac{A_i}{A_{i+n}} \tag{6}$$

where n = number of oscillations and A_i/A_{i+n} = angular amplitude ratio of the first (ith) complete oscillation divided by the amplitude of the last ($i + n$) amplitude reading. The loss tangent is then calculated from the observed logarithmic decrement.

$$\tan \delta = \frac{\Delta}{\pi} \tag{7}$$

The calculated phase angle δ is used to determine the loss modulus G'' and the complex modulus G^* at each temperature.

The reader is referred to a critical analysis of the interpretation of dynamic mechanical values obtained by the torsional braid technique and its relationship to the glass-transition temperature (14).

RESULTS

Typical values of G', G'', G^*, and tan δ calculated from the angular displacements and frequencies at various temperatures are plotted in *Figs.* 4 and 5 for two asphalt samples, the Venezualan asphalt control and the same asphalt containing 5 percent by weight of Arco Poly blend R-45M Resin. Shell

Venezualan asphalt (*Fig. 4*) has a tan δ maximum near 0°C whereas the addition of 5 percent liquid polybutadiene displaces the tan δ maximum to −8°C. Notice that in each figure the inflection point in the G' curve coincides with the tan δ maximum as expected from theory. *Figure 6* shows the influence of further increasing the liquid rubber concentration on the tan δ values. Note that the maximum tan δ values are shifted to lower temperatures as the rubber concentration increases and that the curves become broader as expected from theory (13). The low-temperature behavior of Shell asphalt containing 30 percent liquid rubber is particularly interesting. This data has been replotted in *Fig. 7* and extended to temperatures near −100°C. It is evident that there is a second glass transition appearing near −60°C.

The tan δ maxima values have been plotted versus the liquid rubber concentration in *Fig. 8* for two samples including one of unknown structure from Monsanto with a glass-transition temperature near −39°C. The standard deviations for the tan δ maxima were typically near 1°C in repeat measurements. The vertical bars represent the width of the transition region. The dashed curves correspond to the rule of mixtures relationship assuming a glass-transition temperature of −76°C for the Arco Poly blend resin and −39°C for the Monsanto rubber. Also shown for reference is the theoretical tan δ maximum curve for mixtures with linear cis polybutadiene (T_g = −108°C). Good agreement is evident between the measured values of tan δ and the rule of mixtures prediction despite the limited solubility of the Arco Poly blend resin. The solubility of the Arco Poly blend resin in bitumen was approximately 10 percent, since no second phase appeared at concentrations less than this quantity. The experimental data in *Fig. 8* shows a slight discontinuity near this concentration for the Arco Polv blend resin. Nevertheless, the predicted depend-

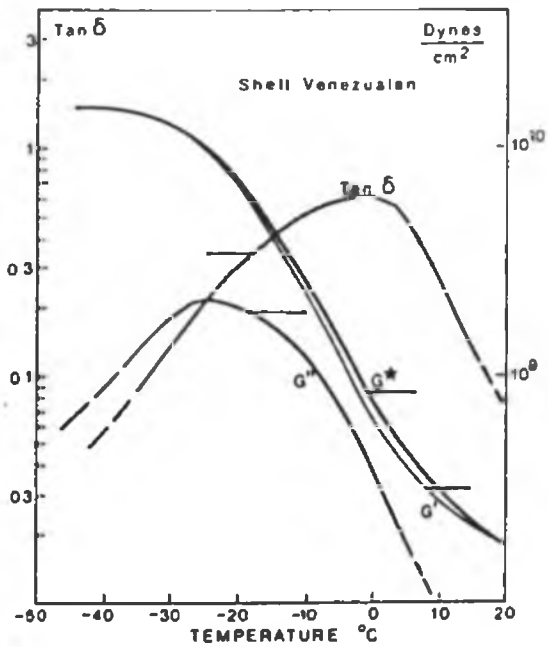


Fig. 4. The data from the torsional pendulum plotted versus temperature for Shell Venezualan asphalt (85–100 pen).

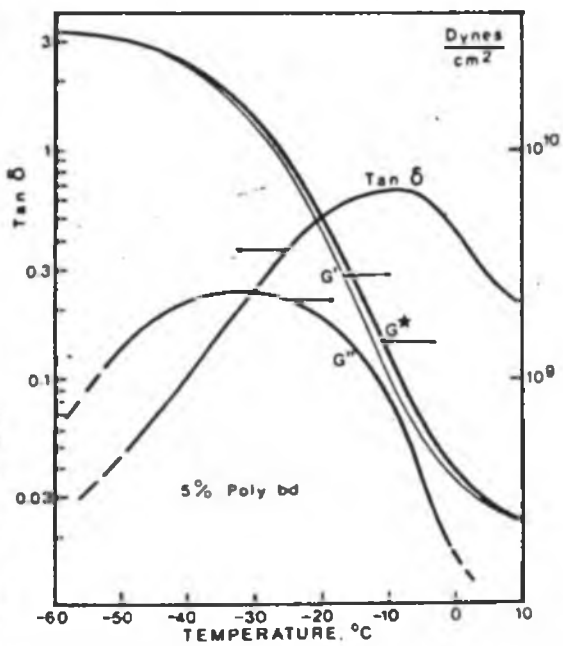


Fig. 5. Dynamic mechanical properties of Shell Venezualan asphalt containing 5 percent liquid polybutadiene (Arco Poly BD R-15M resin).

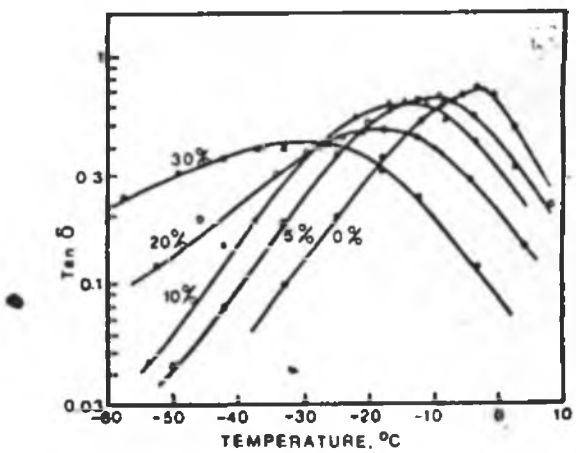


Fig. 6. The loss tangent maximum shifts to lower temperatures and the peak becomes broader with increasing rubber concentration.

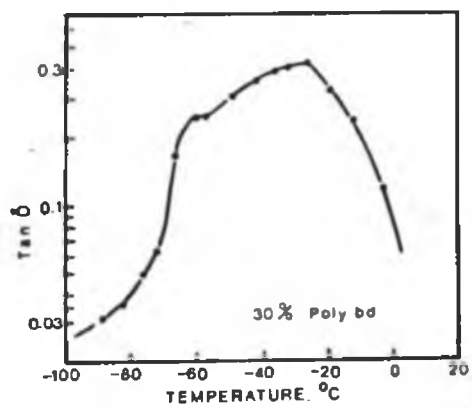


Fig. 7. At 30 percent liquid rubber concentration, a shoulder appears at −60°C in the loss tangent curve attributable to the formation of a dispersed rubber phase as the solubility limit is exceeded.

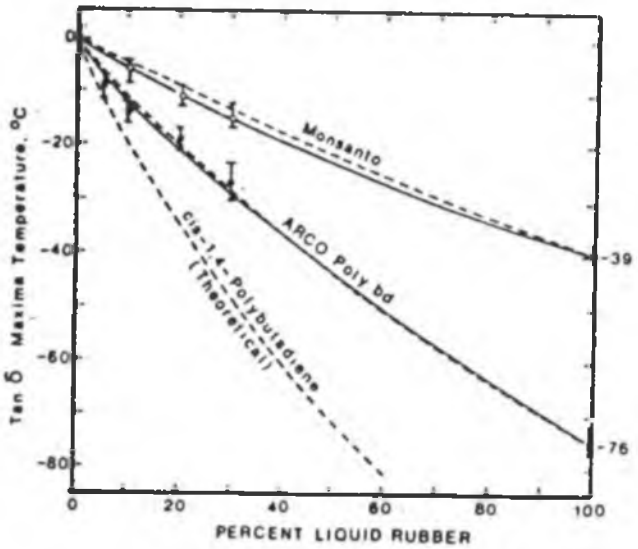


Fig. 8. The theoretical rule of mixtures curves (dashed lines) are compared with the experimental data (solid curves) at different liquid rubber concentrations.

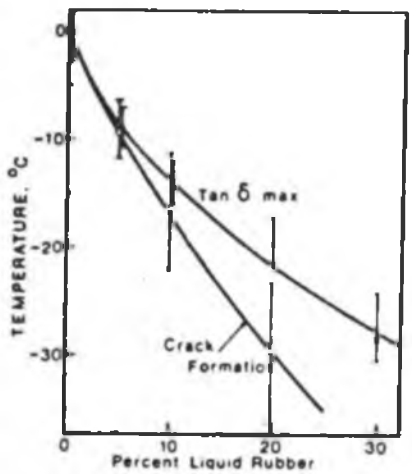


Fig. 9. The crack-initiation temperature decreases more rapidly than the loss tangent maxima as the liquid rubber concentration increases.

ence from the rule of mixtures equation is still within experimental error.

The crack susceptibility results obtained with the Mylar polyester tape are compared with the tan δ maxima in *Fig. 9*. The standard deviations are included for six trials. Although the trend is the same, the crack-initiation temperature differs markedly from the tan δ maximums as the concentration of liquid rubber increases, and indicates a greater degree of ductility than the tan δ maximum values and corresponding glass-transition temperatures would suggest.

DISCUSSION

When the asphalt-rubber mixtures were viewed under the microscope, it was apparent that the liquid rubber which was partially soluble in the bitumen had formed a dispersed phase of tiny, microscopic spherical particles (*Fig. 11*). Also visible were the black opaque asphaltene particles having dimensions approximately the same size as the rubber particles (1 to 10 μm). The presence of the dispersed rubber phase accounts for the shoulder in the tan δ maximum curve shown in *Fig. 7*. The presence of the dispersed rubber apparently extends the ductility of the mixture below the glass-transition temperature of the bitumen phase so that crack susceptibility is also reduced below the brittle temperature. This is substantiated by the observed crack initiation temperatures in *Fig. 9*, which are seen to occur well below the apparent brittle temperatures indicated by the tan δ maxima. This suggests that the dispersed rubber phase assists crazing and shear yielding below the temperature where the surrounding bitumen matrix becomes brittle, analogous to the effect of particulate rubber particles in toughened plastics such as ABS (acrylonitrile-butadiene-styrene terpolymer). The rubber particles are in the 1 to 10 μm range, a size which may be influenced by the temperature, mixing time and shear rate, asphalt composition, concentration, and liquid rubber viscosity. Additional studies may be needed to assess oxidative stability, interfacial bonding, crosslinking of the rubber particles, and other factors affecting performance in paving materials.

The influence that a rubber additive has on the viscosity of an asphalt-rubber mixture will depend upon the concentration of the added rubber, its molecular weight, its solubility, and whether it is crosslinked. Liquid rubbers have much smaller molecular weights than most solid elastomers, 5000 number average versus 150,000, for example, so that liquid rubbers can be added in larger quantities without unduly increasing the viscosity at mixing and paving temperatures. The influence of liquid rubber on the low-temperature ductility of the asphalt will be dependent upon the glass-transition temperature of the liquid rubber, the concentration, solubility, particle size, and interfacial bonding. Assuming complete miscibility, the glass-transition temperature of the asphalt-rubber mixture can be easily calculated from the rule of mixtures relationship described by Nielsen (8)

$$\frac{1}{T_g} = \frac{W_a}{T_{ga}} + \frac{W_b}{T_{gb}} \tag{8}$$

where T_g, T_{ga}, and T_{gb} are the glass-transition temperatures of the mixture, the liquid-rubber additive, and the bitumen, respectively; W_a and W_b are the weight fractions of liquid rubber additive and the bitumen, respectively. Note that the temperatures must be expressed in absolute values, i.e., kelvin degrees. If it is assumed that the glass-transition temperature occurs at the tan δ maximum, then the above rule of mixtures relationship should also apply to the tan δ maxima values. The solid curve in *Fig. 10* is the rule of mixture relationship for the asphalt-rubber system, compared with several measured values for the same asphalt containing 20 parts of various rubbers (16.7 percent by weight). Some of the values are replotted from a previous publication (15). A simple calculation predicts that liquid polybutadiene having a linear 1,4-

...s structure ($T_g = -108°C$) would predict a tan δ maximum near $-30°C$ at this concentration.

The crack susceptibility is indicated by the trend shown in *Fig. 9*, where the appearance of cracks occurs at a temperature less than that of the tan δ maximum temperature. This additional ductility, which may be inferred from crack-initiation data, may be due to the dispersed liquid rubber droplets, which can be seen in *Fig. 10*. Such heterogeneous systems comprising a glassy matrix with a dispersed rubber phase are known to possess extreme toughness and ductility, for example, the well-known ABS-type polymeric resins (16). This dispersed rubber phase probably accounts for the shoulder in the tan δ curve of *Fig. 6*.

Figure 10 attempts to summarize the low-temperature plasticizing action of several rubber materials in bitumen, including earlier studies using powdered vulcanized tire rubber (15). Literature values

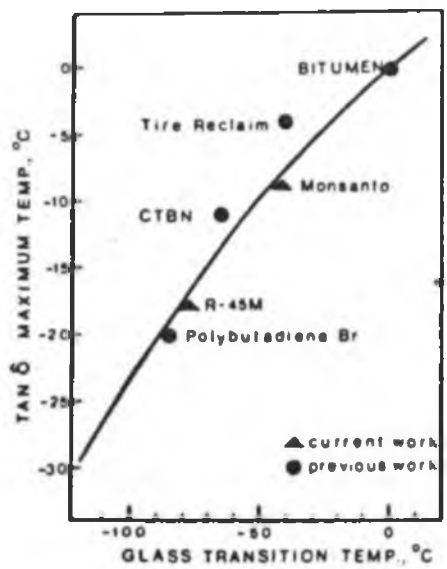


Fig. 10. The experimental loss tangent maxima agree quite well with the rule of mixtures relationship (solid curve). Linear polybutadiene should appear on the curve at −30°C and yield a crack-initiation temperature near −43°C at this concentration (20 parts).

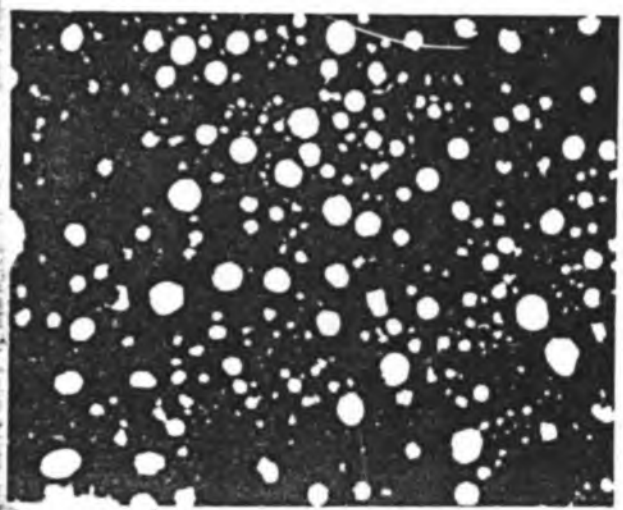


Fig. 11. A thin film of the asphalt-rubber mixture clearly shows the liquid polybutadiene particles (white) and the asphaltene particles (black). Magnification 550 times.

for the glass-transition temperatures of each elastomer have been plotted versus the tan δ maximum values for mixtures containing 20 parts of rubber in bitumen. These results predict that cis-1,4-polybutadiene ($T_g = -108°C$) should have a tan δ maximum near $-30°C$. The greater plasticizing efficiency of the liquid rubbers helps to offset their higher costs compared to reclaim rubber.

Although rubbers have been extensively studied as asphalt modifiers, thermoplastics such as polyethylene are also candidates for increasing the toughness of asphaltic paving materials (30).

CONCLUSION

Liquid polybutadiene elastomers are efficient low-temperature plasticizers for bitumen, capable of reducing the crack susceptibility to −30°C. The low-temperature dynamic mechanical properties of bitumen-rubber mixtures may be conveniently characterized by torsional braid analysis, a relatively simple and inexpensive technique. The partial solubility of the liquid polybutadiene in bitumen produced a colloidally dispersed rubber phase which further aided the ductility and fracture toughness. The reduction in the brittle temperature of bitumen may help to eliminate stress cracking in asphaltic paving materials.

ACKNOWLEDGMENTS

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The Use Of Mechanical Tests In The Design of Bituminous Road Surfacing Mixtures: II. Stability Tests On Rolled Asphalt.

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THE USE OF MECHANICAL TESTS IN THE DESIGN OF BITUMINOUS ROAD SURFACING MIXTURES.* II.† STABILITY TESTS ON ROLLED ASPHALT

By D. C. BROOME and A. PLEASE

A comparison of resistance to deformation of rolled asphalt has been made at 45° using eight mechanical tests. The compositions tested conformed to B.S.594 and the comparison showed that these cover a wide range of stability. Some rich plastic mixtures included in B.S.594, although rejected after mechanical tests, can be used successfully on the road. Dynamic loading tests employing pressures experienced on the road appear to give the best relative assessment of stability for the compositions best suited to conditions in Great Britain.

Introduction

British Standard 594 gives a range of rolled asphalts having adequate resistance to heavy traffic and which are durable in the climate of Great Britain. Certain compositions are recommended for the heaviest traffic and the specifications as a whole have given good service for many years. Mechanical tests on laboratory-prepared specimens are used in some countries in the design of mixtures of this type and it would appear that such tests might be of value in the evolution of specifications for economic dense surfacings employing local aggregates. As a first step in this, an experimental comparison has been made of eight mechanical tests for the measurement of the relative resistance to deformation of sixteen rolled asphalts covering the range of wearing courses in B.S.594. The investigation has some parallel with that on dense tar surfacing reported in 1945.[1]

Benson,[2] in the United States, has shown that the results obtained by different tests disagree among themselves. In view of this, the present investigation was undertaken to gain experience of a number of such tests with the following objects:

(*a*) to determine whether any of the tests are of use for the design of dense bituminous surfacings for full-scale experiments, and

(*b*) to provide information for road engineers considering the employment of mechanical tests for design purposes.

The work described here was a joint investigation between the Road Research Laboratory and the Limmer and Trinidad Lake Asphalt Co. Ltd.

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*Read before the Road & Building Materials Group, Nov. 8th, 1956.

†Part I: *J. Soc. chem. Lond.*, 1945, 64, 153.

Experimental

Scope of the comparison

(i) *Test compositions.*—Sixteen B.S.594 wearing-course compositions were selected to compare the mechanical tests. They comprise:

(a) *Compositions* 1–12. Details of the twelve B.S.594 compositions which form the main series are given in Table I. They comprise four sand asphalts (1–4) with 75/80 pen. residual bitumen, four rolled asphalts (5–8) containing 25% coarse aggregate with 40/45 pen. residual bitumen, and four rolled asphalts (9–12) containing 55% coarse aggregate with 40/45 pen. residual bitumen. They have been placed in an approximate order of increasing resistance to deformation on the road, assessed from general practical experience in the industry. The assessment is based upon the expected relative performance under heavy city traffic of wearing courses approximately 2 in. thick, firmly adhering to a well-constructed base in the general conditions prevailing over the last twenty years in the United Kingdom.

In the order adopted here, greatest reliance is placed on the estimate that the stability increases within each group 1–4, 5–8, and 9–12 as the binder content decreases. There is less confidence in the estimate that the stability of the driest mix of one group is less than the stability of the richest mix of the next group.

Although no test could be rejected as unreliable if it gave these 12 compositions in a slightly different order from that predicted, the existence of a really marked lack of correlation would throw doubt on the ability of the test to assess resistance to deformation of dense bituminous wearing-course compositions of the type employed in the United Kingdom.

Table I

Main test compositions in increasing order of resistance to deformation

Composition No.	Bitumen content, %	Penetration of bitumen at 25°C	Passing No. 200 B.S. sieve, %	Retained No. 200, passing No. 7 B.S. sieve, %	Retained* No. 7 B.S. sieve %
1	12·8	75–80	18·0	69·2	Nil
2	11·8	75–80	16·0	72·2	Nil
3	10·8	75–80	14·0	75·2	Nil
4	9·8	75–80	12·0	78·2	Nil
5	10·7	40–45	14·5	49·8	25·0
6	9·8	40–45	12·5	52·7	25·0
7	8·8	40–45	10·6	55·6	25·0
8	7·8	40–45	8·6	58·6	25·0
9	8·1	40–45	10·4	26·5	55·0
10	7·2	40–45	8·4	29·4	55·0
11	6·3	40–45	6·4	32·3	55·0
12	5·4	40–45	4·4	35·2	55·0

*¾ in. to ⅜ in. Hornfels.

(b) *Compositions* 1*A*–4*A*. It is known from road experience that a significant improvement in the resistance to deformation of an asphalt is obtained by the use of a more viscous binder, and in order to investigate the extent to which this is shown by the tests under consideration, four sand asphalts were chosen corresponding to compositions 1–4 of the main series except that 40/45 pen. residual bitumen was used.

(ii) *Tests.*—Eight tests have been compared. They may be broadly divided into three groups as follows:

(a) *Constant-load tests:* Road Machine (dynamic loading); Wheel-tracking test (dynamic loading); Indentation test (static loading).

(b) *Constant-rate-of-strain tests:* Marshall test; Hubbard–Field test; Hveem Stabilometer; Unconfined Compression test.

(c) *Triaxial test*

(iii) *Temperature of test.*—The resistance to deformation of bituminous materials decreases rapidly with increase in test temperature. The test temperature of 60° commonly used with the

American tests is based upon American climatic conditions. The order of stability on the road given for the main series of test compositions is based upon experience gained in the United Kingdom. Measurements of road temperature within wearing courses made at Harmondsworth, Middlesex, over many years show that temperatures a few degrees above 45° are attained for only a few hours during the year. In view of this, a common test temperature of 45° has been used with the mechanical tests. Because of the difficulty of working for long periods at an air-temperature of 45°, a departure from this principle had to be made for the Triaxial test and 30° was employed here.

Preparation of specimens for tests

(i) *Materials.*—A description of the materials used in the test compositions is given below. Table II gives some physical properties of the binders employed and Table III the gradings and specific gravities of the filler, fine and coarse aggregates.

Table II

Properties of binders employed in B.S.594 test compositions

Description of binder	Sp. gr. 15·5°c/15·5°c	Penetration at 25°c	Viscosity at 45°c, poises*
45 pen. residual bitumen (Venezuelan)	1·038	40	$18·0 \times 10^4$
75 pen. residual bitumen (blend of Venezuelan bitumens)	1·033	74	$4·8 \times 10^4$

*Determined in a coni-cylindrical Couette viscometer using a shearing stress of 3500 dynes/cm.²

Table III

Gradings and specific gravities of aggregates employed

Grading, % by weight	Hornfels	Sand	Limestone filler*
passing ¾-in. B.S. sieve	100	—	—
,, ½-in. ,, ,,	50	—	—
,, ⅜-in. ,, ,,	0	—	—
,, No. 7 ,, ,,	—	100	—
,, No. 25 ,, ,,	—	99	—
,, No. 52 ,, ,,	—	78	—
,, No. 72 ,, ,,	—	28	100
,, No. 200 ,, ,,	—	1·3	91
Specific gravity	2·72	2·65	2·71

*The filler had a bulk density of 0·76 g./ml. and dry compacted voids of 0·31

(ii) *Mixing.*—The mixing was carried out in a sun-and-planet mixer surrounded by a thermostatically controlled oil-bath. All the materials were preheated in ovens to the mixing temperatures which were 130° and 150° for the compositions containing 75 pen. and 45 pen. bitumens respectively. The sand, binder and stone (in the appropriate mixes) were mixed for 1 min. before the filler was added and then the whole was mixed for a further four minutes; the mixture was then transferred to the specimen mould as quickly as possible.

(iii) *Compaction.*—One of the more important operations in the manufacture of specimens is the compaction of the mixed material. Because of the differences in the size and the shape of the specimens it was necessary to use rather varied procedures, adopting where possible the method recommended in the literature for that test. The Wheel-tracking, Indentation and Road Machine tests required specimens of the same size and shape and were compacted by 28 passes of a 1800-lb. roller (total load 150 lb./in. width of specimen). The Hubbard–Field and Unconfined Compression test specimens were both compacted by hand tamping, using the Hubbard–Field compaction method. The Marshall test specimens were manufactured with a Marshall 10-lb. hammer having a free fall of 18 in., 50 blows being applied to each face. As the kneading compactor that Hveem has developed for the manufacture of specimens for the Hveem Stabilometer is not available in this country, the specimens for this test were prepared by a

modified Marshall compaction procedure using 15 blows only on each face of the specimen followed by a levelling load of 5000 lb. for 10 sec. Triaxial test specimens were manufactured in a split mould using a double plunger compression of 12,000 lb. for five minutes.

An idea of the differing compaction that is attained with different methods can be gained from Fig. 1, where the range of air voids in the compacted specimens is given for each of the three main groups of compositions: sand asphalt, 25% and 55% stone-filled asphalt. It will be seen that the compositions provided in B.S.594 cover a very wide range of air voids, the rich mixes with 55% stone having particularly low air voids, i.e. between 0 and 2%.

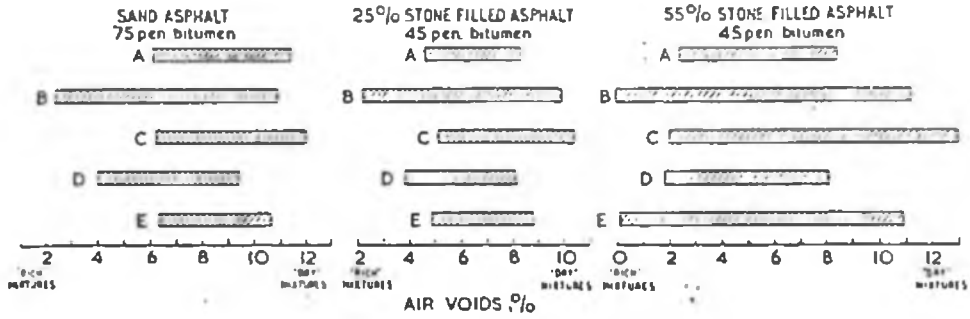


FIG. 1. *Air voids range of B.S. 594 compositions*

Compaction Method

A Road Machine and Wheel tracking
B Triaxial test
C Hveem Stabilometer
D Marshall test
E Hubbard–Field and Unconfined Compression

Test procedures and results

Diagrams of the eight types of machine are given in Fig. 2 and curves of the test results in Fig. 3.

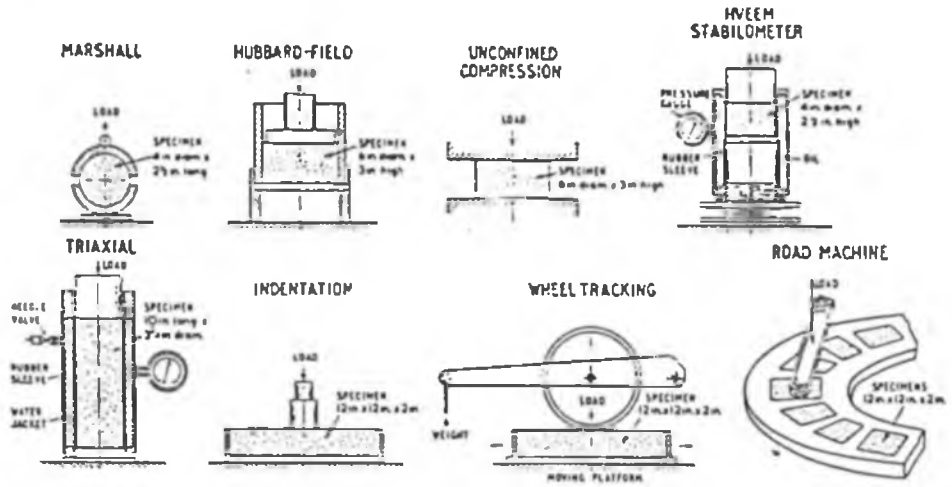


FIG. 2. *Apparatus used in the tests*

A. *Constant-load tests*

(1) *Road Machine.*—As the name implies, the Road Machine was designed to simulate road conditions on a laboratory scale. Specimens, 12 in. square by 2 in. high, were mounted in mastic on the circular track revolving at 1000 revolutions an hour at 3½ m.p.h. beneath two pneumatic-tyred wheels placed at opposite ends of a diameter of the track. The wheels were loaded by 1000 lb. each at an inflation pressure of 80 lb./sq. in., the axes of rotation of the wheels passing through the centre of the revolving turntable so that 'scrubbing' action was reduced to a minimum. After 12 min. running at 45° (400 wheel-load applications) the profiles of the deformed specimens were obtained by means of an adjustable template and the distance

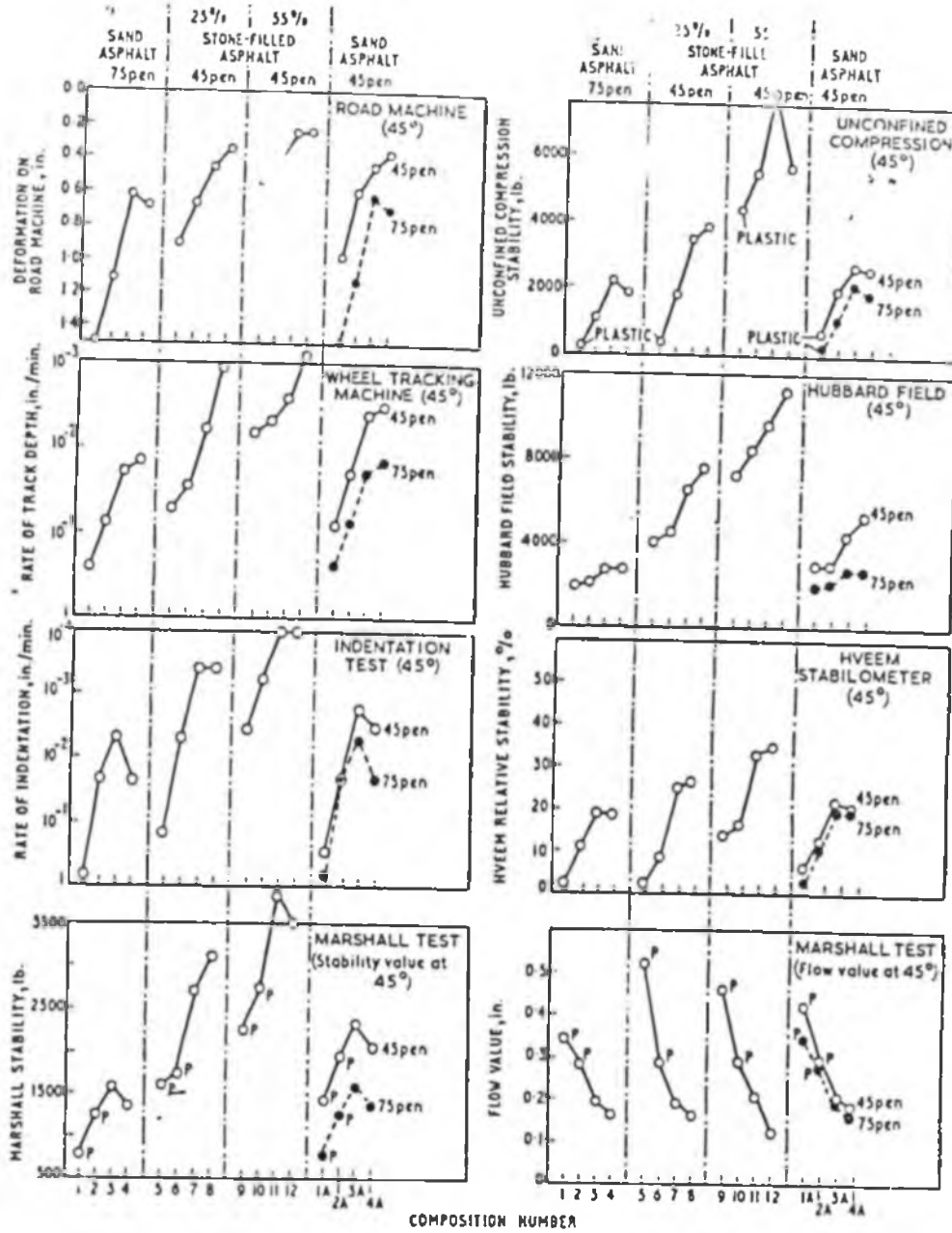


FIG. 3. *Mechanical test results on B.S. 594 compositions at 45°*

No maximum load for the compositions marked Plastic. The load after 3 min. is given for these. Values for compositions marked P are not well-defined.

in inches between the highest and lowest point of each profile was taken as a measure of the deformation sustained. The deformation of the specimen on the Road Machine is coherent, having no apparent surfaces of rupture. This test differs from many others in giving deformation resembling that obtained on the road. The test conditions appear to relate most closely to slow concentrated traffic streams where rutting is the characteristic deformation.

The deformations obtained with compositions 1–12 are given as a function of composition number in Fig. 3, where, to simplify comparison with other tests, a high ordinate value has been given to high stability, i.e. low deformation.

It will be seen that on this test, for which the loading is the most nearly simulative of road conditions of all the tests, the order of stability of the compositions is different from that predicted from road experience. The main difference is that there is an overlap in stability between the three groups of compositions 1–4, 5–8 and 9–12. (This result was found with nearly all the tests.)

The effect of increasing the viscosity of the binder in B.S.594 sand asphalts from 75 pen. to 45 pen. is to increase very substantially their resistance to deformation, a result conforming with road experience. In this connexion it is interesting to see the effect that changing the test temperature has on the results obtained. Although the deformations sustained at 30° and 45° were approximately the same, the times taken to produce them were very different—3 h. or 6000 wheel-load applications at 30° and 12 min. or 400 wheel-load applications at 45°. A limited number of repeat tests at 30° for 3 h. showed the largest discrepancy between the deformations of two similar specimens as 16%, the average being about 6%.

(2) *Wheel-tracking test.*—The Wheel-tracking test consists of a loaded wheel and a table on which the 12 × 12 × 2-in. specimen is rigidly restrained on its four sides. A motor and a reciprocating device gives the table a to-and-fro motion of 42 passes a minute with a distance of travel of 9 in. The 8 × 2-in. solid rubber-tyred wheel (79 on the Dunlop hardness scale) bears a total load of 118 lb. and indents a straight track in the specimen, the depth of the track being recorded at the mid-point of its length by means of a cam and a springless dial guage. The contact area between wheel and specimen is about 1·5 sq. in., giving a mean normal pressure of 75–80 lb./sq. in.

Deformation/time curves obtained are given in Fig. 4, from which it will be seen that they exhibit certain common characteristics—a high initial rate of indentation compared with the fairly constant rate established in the later portion of the curve which, for the harder mixes, occurs after 10–15 min. tracking. There is evidence (compare 4 with 9 and 10 in Fig. 4) that the deformation/time curves can intersect.

It will be seen that within each group of four compositions where binder content is the main variable, the stability increases as the binder content decreases. There is, however, a marked overlap between the deformation/time curves of the three main groups of compositions, i.e. 5 is scarcely more stable than 2, and 6 is softer than 3, and 9, 10 and 11 are softer than 8. A more important overlap is however, that of 9 with 4. Composition 9 deformed very rapidly in the initial stages of the test with a marked reduction in the deformation rate occurring at a track depth of 0·4 in., probably attributable to the high content of ¾–1-in. stone in this composition. No such marked reduction in rate occurred with the dry sand asphalt 4. This has made a comparison of the stability of compositions difficult and the comparison in Fig. 3 has been made on the basis of the minimum rate of deformation observed, taking no account of the deformation at which this rate is measured. Many comparisons might be made but the one chosen has the advantage of permitting comparison of compositions covering a wide range of stability.

From Fig. 3 it can also be seen that the sand asphalts with 45 pen. bitumen are much more stable than the corresponding mixtures made with 75 pen. bitumen, a result similar to that obtained on the Road Machine.

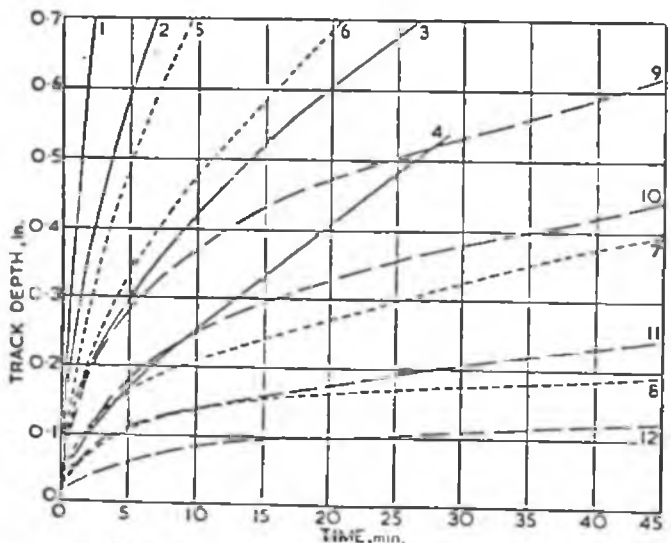


FIG. 4. *Wheel-tracking test: deformation time curves of B.S. 594 compositions at 45°*

Nos. 1–4 Sand asphalt 75 pen. bitumen
5–8 25% stone-filled asphalt 45 pen. bitumen
9–12 55% stone-filled asphalt 45 pen. bitumen

The repeatability of this test has been judged from previous experience to be sufficiently good for conclusions to be drawn from one test specimen of each composition.

(3) *Indentation test.*—In the Indentation test a simple lever system transmits a total load of 300 lb. to a 2-in. diam. steel plunger, giving a mean pressure intensity of 94 lb./sq. in.[3] The 12 × 12 × 2-in. specimen was placed on a flat horizontal steel plate and rigidly restrained on its four sides. The depth of penetration was obtained as a function of time with a dial gauge, the maximum duration of test being 45 min.

Indentation/time curves showed that, as with the Wheel-tracking machine, the order of stability is time-dependent. For the more stable mixtures, the rate of indentation is high in the initial stages of the test (as in the Wheel-tracking test) decreasing fairly rapidly to an approximately uniform rate after 5–15 min. After some minutes of load application, the drier sand asphalts failed by rupture, resulting in an increase in the rate of deformation towards the end of test. A comparison of the minimum rate of penetration for the indentation/time curve is given in Fig. 3.

The two groups of compositions 5–8 and 9–12 show agreement with the predicted dependence of resistance to deformation when the main variable is binder content but the indentation order of stability is not in accord with the predicted order when the main variable is stone content.

Increasing the viscosity of the binder in the drier sand asphalts from 75 pen. to 45 pen. greatly improved the resistance to deformation of these mixes, and failure by radial fracture was eliminated within the testing period.

The definite increase in resistance to indentation imparted by even a small amount of large stone to dry mixes can be seen from a comparison of compositions 7 and 8 with 3A and 4A in Fig. 3. The effect is smaller with the wheel-tracking machine and absent in the road-machine test at 45°. This difference between static loading and rolling may be due to some interlocking during static loading.

B. *Constant-rate-of-strain tests*

In the three tests discussed above, a fixed load has been applied either statically or dynamically and the deformation measured. In the four tests which follow, specimens are deformed at a fixed rate by rigid platens and measurements made of the loads attained.

(4) *Marshall test.*—In this test a constant rate of compression of 2 in. per minute was applied on opposite sides of the cylindrical surface of a specimen 4 in. in diameter and 2·5 in. high using a Marshall test head.[4] The maximum load developed was recorded as the Marshall stability at 45° and the compression undergone when the maximum load was attained as the Marshall flow value. Some of the richer mixes exhibited no sharp maximum and, for these compositions, values of the load and compression were taken at the point where the rate of increase in load began to fall off rapidly. The Marshall stabilities and flow values from quadruplicate tests are given as a function of composition number in Fig. 3.

The wider aspects of the Marshall method of design will be discussed later but for the present it may be noted that the Marshall stability differentiates in the predicted manner between the sand asphalts 1–4 and the group 5–8 containing 25% coarse aggregate, but there is considerable overlap between the compositions containing 25% and 55% coarse aggregate. The results also show that the Marshall stability has a definite maximum in the sand asphalt groups (1–4 and 1A–4A), while there is a possible maximum in the high-stone-content group. A large increase in the Marshall stability occurs when the 75 pen. bitumen is replaced by 45 pen. bitumen, probably as a consequence of the relatively high testing rate employed.

Limits set by Marshall on the stability and flow values for bituminous road surfacing compositions *tested at* 60° are

Stability: 1000 lb. for wearing course for light to medium traffic.

Flow value: Not to exceed 0·16 in.

As the test temperature used in the present work was 45°, a comparison of the stabilities of the compositions in relation to Marshall's criterion is not possible except to say that it seems likely that mixtures 1–6 would not satisfy the Marshall stability limit for medium to heavy traffic. Comparison of flow values at 45° shows that of the twelve B.S.594 compositions 1–12,

only numbers 4, 8 and 12 have flow values within the limit 0·16 in. set by Marshall. The compression undergone when the maximum load is attained (the flow value) can be expected to be slightly lower for tests made at 60° although this does not imply that the material will actually flow less under practical conditions at the higher temperature.

(5) *Unconfined Compression test.*—Many forms of Unconfined Compression test have been used for bituminous materials. The Marshall test itself is essentially a test of this type. In the Unconfined Compression test used here, the dimensions of the specimen were chosen so that the height of 3 in. and the low height/diameter ratio of 0·5 gave a nearer approximation to the size and shape of the most highly stressed region under a tyre than is commonly used for this test. A constant rate of compression of 0·05 in./min. was applied axially to a cylindrical specimen 6 in. in diam. and 3 in. high, and in order to obtain plane-parallel surfaces for testing, the specimen was placed in a split cardboard sleeve $3\frac{3}{8}$ in. high and the space between the top of the sleeve filled with plaster of Paris and made level.

Three specimens of each composition were tested and a typical load/time curve for each of the compositions 1–12 is shown in Fig. 5. Some of the richer mixes give no maximum value of the load and for these specimens the load after 3 min. has been given in Fig. 3, where a comparison of the compositions has been made on the basis of the maximum load. The stability has a maximum value in the sand asphalt group (1–4), while there is a possible maximum in the 55% stone-filled mixes (8–12). The test differentiates sharply and in the predicted manner, between the two groups of stone-filled asphalts, but there is marked overlap between the group of sand asphalts (1–4) and the 25% stone-filled asphalts (5–8). Increasing the consistency of the residual bitumen from 75 pen. to 45 pen. effects a relatively small increase in stability in the four sand asphalts. This is probably due to the low rate of deformation used in this test.

Hubbard–Field test.—In this test a confined specimen 6 in. in diameter and 3 in. high is extruded through a hole $5\frac{1}{4}$ in. wide at a constant rate of 1 in. in 25 seconds.[5] Four specimens of each composition were tested and the maximum load developed recorded (Hubbard–Field stability at 45°).

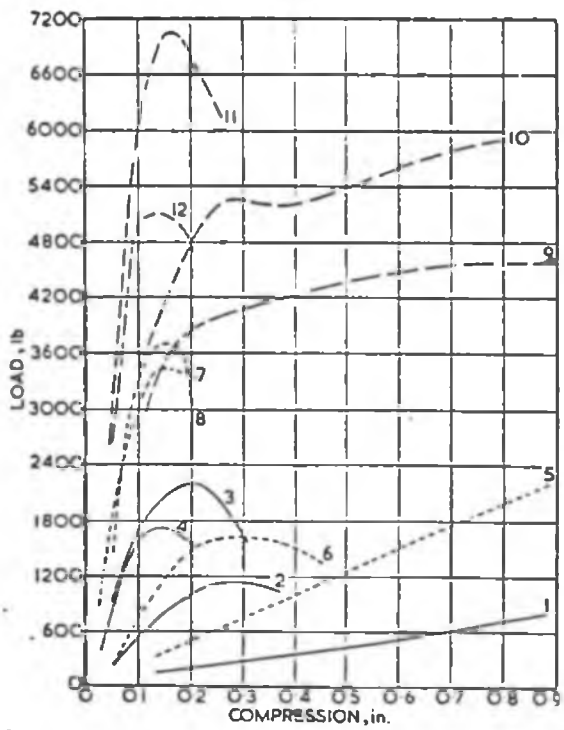


FIG. 5. *Unconfined Compression test: load/deformation curves of B.S. 594 compositions at 45°*

Nos. 1–4 Sand asphalt 75 pen. bitumen
5–8 25% stone-filled asphalt 45 pen. bitumen
9–12 55% stone-filled asphalt 45 pen. bitumen
Rate of strain 0·05 in./min.

From Fig. , where the mean values of the maxim. n load have been plotted as a f ction of composition number, it will be seen that this test has given fairly good accord with the predicted order of stability, but the test results have poor repeatability. This test, incidentally, shows very little difference in the stabilities of the rich sand asphalts 1 and 2. It may also be noted that, because of the high stress concentration in the region of the extrusion ring, some crushing of the stone occurred, so that the stability of stone-filled mixes is derived in some measure from the crushing strength of the aggregate.

Increasing the consistency of the residual bitumen from 75 pen. to 45 pen. has given rge increase in the stability of all four sand asphalts, probably as a result of the high rate of d na-tion employed.

Hveem Stabilometer.—In the present work, the Hveem Stabilometer, a form of triax... test, was used in the manner described by Hveem,[6] i.e. a cylindrical test specimen, 4 in. in diameter by 2·5 in. high was compressed axially at a constant rate of 0·05 in./min. and the lateral pressures measured which corresponded to incremental axial loads.

During a test the lateral pressure was determined at intervals of 1000 lb. for the axial load up to 6000 lb. The axial load was then reduced to 1000 lb., the press locked and the number of turns of the displacement pump required to increase the lateral pressure from 5 to 100 lb./sq. in. was noted.

From a graph of lateral pressure against vertical load, the lateral pressure at a vertical load of 5000 lb. was determined and used to express the ' relative stability ' in the form

$$S = \frac{100\,(P_v - P_h)}{P_v - P_h\,(1 - D_2/0{\cdot}222)}$$

where S = relative stability, %

P_v, P_h = corresponding vertical and lateral pressures, respectively, lb./sq. in.

D_2 = number of turns of the displacement pump handle for an increase of P_h from 5 to 100 lb./sq. in. for P_v = 80 lb./sq. in. (1000 lb. vertical load).

The mean relative stabilities are given as a function of composition number in Fig. 3, from which it will be seen that the dependence of the relative stability on binder content is substantially that predicted in each of the groups 1–4, 5–8 and 9–12. There is little difference in the stability between the last pair in each group. The over-all order of relative stability for the mixtures 1–12 is very definitely different from the predicted order, e.g. 5 and 6 have relative stabilities approximately equal to 1 and 2 respectively, and 9 and 10 are less stable than 3 and 4. The increase in stability for the sand asphalts when the 75 pen. bitumen is replaced by a 45 pen. bitumen is very small except for the richest mixture, a result contrary to that expected from road experience.

The use of an increased compactive effort of 50 blows on the Marshall compaction apparatus followed by a levelling load, with the driest mixtures 4, 8 and 12, increased their relative stabilities by a factor of from 1·2 to 1·3. As this increase is of the same order for the three different types of composition, it seems probable that the comparison between compositions established here for 15 blows plus a levelling load would remain largely valid for a compaction method employing 50 blows plus a levelling load.

For wearing-course compositions with penetration-grade bitumens, Hveem supplements the Stabilometer with a cohesion test. The conclusions expressed in this paper relate to the Stabilometer only.

Triaxial test.—All the tests described so far are empirical, the stress distribution in the specimen being non-homogeneous and largely unknown, from the very beginning of the load application. The triaxial test sets out to give information of a more fundamental nature. It has been used in the present work to determine the conditions of stress for which a large cylindrical bituminous specimen is just in equilibrium, the major principal stress being applied axially and the two minor equal principal stresses being developed by the small deformation of the specimen compressing the water in a cell enclosing the cylindrical surface of the test specimen.

The triaxial cell used was patterned on one used by Nijboer.[7] The size of the specimen tested, 10 in. by 3¾ in. diameter, is rather smaller than that used by Nijboer for stone-filled mixes and is closer to that given by the U.S. Asphalt Institute[5] which is 10 in. by 4 in. in diameter. The test machine used applied a hanging load through an 11 to 1 lever system, a correction being made for friction.

...ach of the compositions ... were carried out at ... as follows: the protective ... was mounted ... cell and the specimen inserted. The space between the sleeve and the cell ... with the Bourdon pressure gauges, was evacuated and filled with fresh... water whose temperature had dropped to 30°. The system was then sealed. Normal loads were applied to the specimen by a steel piston, the pressure on the top of the specimen being increased by increments of 50 lb./sq. in. until a nominal maximum of 500 lb./sq. in. was reached.

For each given load, lateral pressure was developed in the water cell as a consequence of the deformation of the specimen. When the rate of movement of the top of the specimen was less than 0·001 in./min. (specified by the U.S. Asphalt Institute), this lateral pressure was recorded as the equilibrium pressure. For some specimens measurements were repeated.

The results obtained with compositions 9 and 12 with 55% coarse aggregate have been plotted in the form of Mohr circle diagrams in Fig. 6. The failure envelope over the stress range investigated is not a straight line, except approximately over the region where the major principal stress is 300–500 lb./sq. in.

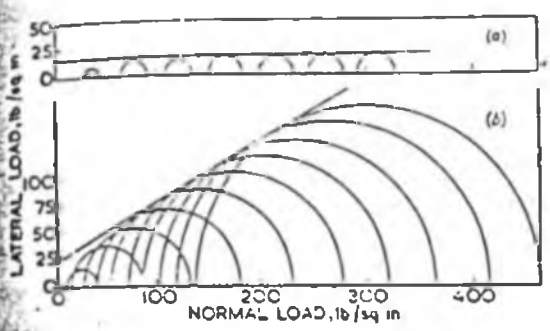


FIG. 6. *Triaxial test results on D.S. 594 55% stone-filled asphalts (45 pen. residual bitumen) at 30°*

(*a*) *Composition* 9 — $\varphi = 1°$ (2); C = 15 lb./sq. in. (11)

(*b*) *Composition* 12 — $\varphi = 26.3°$ (28·8); C = 23 lb./sq. in. (22)

Figures in brackets are repeat tests on the same specimen

Materials that have a straight-line envelope obey a Coulomb law of failure, i.e. flow or failure occurs in a plane of the material when the

shear stress in the plane $\geqslant c + \sigma_n \tan \varphi$

where c = cohesion, equal to the intercept of the straight line envelope on the ordinate in Fig. 6;

φ = the angle of internal friction, equal to the angle between the straight line envelope and the abscissa;

and σ_n = the normal component of stress across the plane of the material that is being considered.

From the point of view of the road engineer, a measurement of the stability under pressures equal to the inflation pressure of tyres 50–80 lb./sq. in., is of the greatest value. The lowest normal load used in the test is 50 lb./sq. in. and the triaxial apparatus used for this investigation would need modification to enable the shape of the failure envelope to be determined accurately in the region of 5–80 lb./sq. in. Since the Mohr envelopes are curved near the origin, values of the angle of internal friction and cohesion for the twelve compositions have been determined for the straight-line envelope at 300–500 lb./sq. in. and are given in Table IV. The use of these values in this region probably over-estimates the stability to be expected in the more practical region of stress, i.e. 25–80 lb./sq. in.

Results from repeat tests carried out on the same specimens are given in the same Table together with Prandtl bearing capacities calculated from the formula

$$\text{Prandtl bearing capacity} = \frac{c}{\tan \varphi}\left\{\frac{1 + \sin \varphi}{1 - \sin \varphi} \cdot \exp(\pi \tan \varphi) - 1\right\}$$

It will be seen from Table IV that the dry mixtures have angles of internal friction of about 26–28°, the internal friction decreasing with increase in binder content and becoming virtually zero for the rich stone-filled mixes 5 and 9. The values for the cohesion do not show any systematic trend with binder content though the cohesion is increased by the inclusion of stone in the mixtures. Repeating the test on the same specimen scarcely changes the internal friction but significantly increases the cohesion.

Table IV

Angle of internal friction, cohesion and Prandtl bearing capacity determined on B.S.594 compositions using a Triaxial test at 30

Composition No.	Angle of internal friction, degrees		c, Cohesion, lb./sq. in.		Bearing capacity, lb./sq. in.	
	First loading	Second loading	First loading	Second loading	First loading	Second loading
1	18·4	—	21	—	284	—
2	25·0	25·5	7	11	145	254
3	24·2	24·0	0	15	0	289
4	28·0	—	8	—	206	—
5	0·0	—	8	—	41	—
6	13·0	—	5	—	49	—
7	26·6	28·0	12	16·5	276	542
8	26·0	26·5	17	21	378	484
9	1·0	2·0	15	11	81	62
10	21·5	21·5	30	42	488	684
11	28·0	27·0	20	31	516	743
12	26·3	28·6	25	22	523	603

The Prandtl bearing capacity for repeat tests made on the same specimens appears higher for all specimens except 9. The ordering of these compositions by their Prandtl bearing capacities would seem to bear very little relation to the predicted order of these compositions (compare 9 with 1). A comparison of the dry mixtures 3, 4, 7, 8, 11 and 12 on the basis of the Prandtl bearing capacity, shows that the triaxial test does differentiate between these compositions in the expected manner. The fact that repeat tests can give widely differing results is probably attributable to the poor repeatability of the determination of the cohesion to which the Prandtl bearing capacity is simply proportional. This difficulty is emphasized when the envelope to the circles is drawn at lower pressures of 100–200 lb./sq. in. as recommended in the Asphalt Institute procedure, when for some mixtures apparent negative cohesions would be determined. The existence of negative values for the cohesion may be attributed to experimental error, but it is probable that the general departure from the simple Coulomb failure criterion exhibited by many mixtures, is a real one.

Summarized test results

The compositions investigated cover a very wide range of stability and each test has its own scale on which the stability has been expressed. An attempt has been made in Fig. 7 to facilitate comparison of the results for compositions 1–12 on seven of the tests by using a reduced stability value defined as

$$\frac{\text{stability value} - \text{minimum stability value}}{\text{maximum stability value} - \text{minimum stability value}}$$

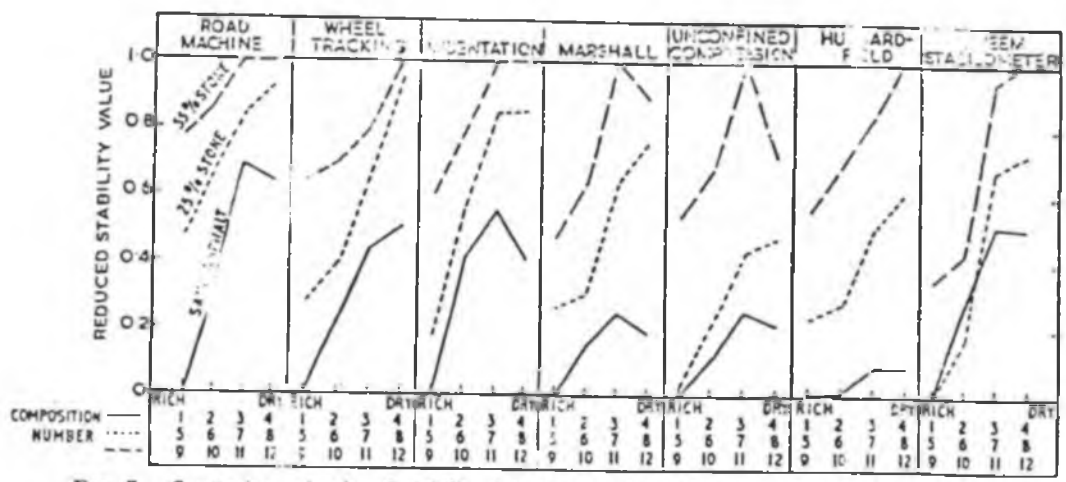


FIG. 7. *Comparison of reduced stability data from mechanical tests on B.S. 594 compositions*

For example, the reduced stability value for composition 7 on the Marshall test is obtained in the following manner.

The minimum Marshall stability is 800 lb. for composition 1 and the maximum is 3850 lb. for composition 11. The Marshall stability for composition 7 is 2700 lb. and therefore the reduced stability value for 7 is given by

$$\frac{2700 - 800}{3850 - 800} = 0{\cdot}62$$

On nearly all tests, composition 1 has the minimum stability value of 0, and 12 the maximum of 1.

Further comparison of the tests, particularly as to repeatability and simplicity, can be obtained from Table V, which is based upon all the experimental results and not only on those given in Fig. 7.

Discussion

Relation of test results to predicted order

(a) *Mean test order.*—For the purpose of this work a series of compositions, 1–12, was taken and placed in an approximate order of resistance to deformation in the light of general experience. Some uncertainty is necessarily attached to this estimate, because in practice, the opportunity to compare the behaviour of two or more surfacings under identical conditions very seldom occurs. Three facts have emerged from this investigation which indicate the direction in which this tentative order should be amended. These facts are:

(i) In Fig. 7 it will be seen that all seven tests, with the exception of the Hubbard–Field, show an overlap in the stabilities of the three main groups of compositions. Combining the mean values of all seven tests give the following mean numerical order for compositions 1–12:

Order No:	1	2	3	4	5	6	7	8	9	10	11	12
Sand asphalts	1	2		4		3						
25% stone-filled asphalts		5			6			7		8		
55% stone-filled asphalts							9		10		11	12

This mean numerical order is not put forward as the 'correct' order but shows the direction in which the predicted order may need amendment.

(ii) Compositions 5 and 9 are very rich mixes with low air voids. It is known that when the air voids are very low the risk of deformation is considerable.

(iii) On the Triaxial test, made at 30°, these same two compositions 5 and 9 have nearly no internal friction.

These three facts do make it seem likely that, at least in so far as the relative behaviour in the South of England is concerned, there is a real overlap in the practical stability of the three groups of B.S.594 compositions Nos. 1–12. The Hubbard–Field test is exceptional in not agreeing with this result. It must remain a matter for full-scale tests to determine the extent and significance of the overlap.

(b) *Individual test behaviour.*—The predicted continuous increase in stability with decrease in binder content within each group is in general borne out by the tests, although in the sand asphalts, 3 is often shown as slightly more stable than 4. The Unconfined Compression test and the Marshall test are the only tests giving a stability value to 12 lower than that of composition 11. In contrast, the Wheel-tracking test gives very high stabilities to the driest mixture in each group.

All tests except the Hveem Stabilometer and perhaps the Unconfined Compression test show the marked increase in stability on increase of viscosity of binder that is expected from a knowledge of road behaviour of B.S.594 rolled asphalts.

Finally, a comparison can be made in Fig. 7 between the stability of the dry sand asphalts 1–4 and the rich high-stone-content mixtures 9–12. It will be seen that for these compositions the Hveem Stabilometer and, from Table IV, the Triaxial tests, show an overlap in stability. The Road machine, Unconfined Compression and Hubbard–Field tests show the rich high-stone-content mix 9 as definitely more stable than the dry sand asphalt 4. The Wheel-tracking and Indentation tests are indecisive in this respect; for short loading times the dry sand asphalt appears more stable than the rich high-stone-content mixture, but for long loading times the reverse is the case.

A comparison of compositions 4 and 9 by means of the Marshall stability value alone cannot fairly be made because account needs to be taken of both stability and flow values and, because there is no agreed way in which this may be done, the relative order of 4 and 9 in the Marshall test must, as in the Wheel-tracking test, remain uncertain.

Relation of tests to practice

(a) *Correlation with deformation on the road.*—The fact that eight mechanical tests have given very different results with the same series of mixtures makes it essential to relate stability test results with practical road experience. Mixtures conforming to B.S.594 normally give a good margin of safety with regard to deformation. This will, however, depend on the traffic conditions which may be divided into three broad types for which different stability limits may be necessary. On straight roads with traffic of substantially constant speed, compositions having quite low stability do not deform even under very heavy traffic. Possible reasons for this are that the time of load application is short and that the traffic is not sharply canalized so that the deformation due to one vehicle may be ' ironed out ' by subsequent vehicles. Where traffic is turning, the net horizontal traction may, according to Nijboer,[4] be as much as 0·4 times the inflation pressure of the tyre. Further, the deformation is cumulative. A rather more severe requirement for stability is, therefore, demanded at junctions and bends than for straight roads. Standing loads constitute the third main cause of deformation which, although it may be severe, is localized.

It is not certain that a range of B.S.594 rolled asphalts of very different composition and of complex flow-behaviour would have the same order of ' resistance to deformation ' in these three different conditions of use. If they do not, an empirical test can only be a rough guide to road behaviour.

(b) *Durability and resistance to deformation.*—Lack of durability of a dense composition, affecting as it does the whole area of the surfacing, is a more serious form of failure than deformation. High binder contents can be used to give good durability though the resistance to deformation is thereby decreased. This decrease in resistance to deformation is offset by the use of a high viscosity binder. This fact underlies the design of B.S.594 compositions, experience having shown that relatively rich mixtures of this type are necessary to be certain of high durability in the conditions prevailing in some areas of the United Kingdom.

(c) *The use of B.S.594 compositions and its relation to mechanical test results.*—The relation of the mechanical test results to the successful application of B.S.594 mixtures employing 45 penetration bitumen is given in Table VI. It will be seen from this Table that Schedule 3 and Schedule 2 mixtures are successfully used in Scotland and the North of England, although on some of the tests they give unsatisfactory results. This is particularly true of the Marshall test in which most B.S.594 compositions have flow values (at 45°) higher than are specified for this test. The compositions used in city streets in Scotland have very little internal friction and yet prove suitable for these traffic conditions. In fact, in Scotland a 60/70 pen. bitumen is frequently used, which would give compositions having lower stability than that shown for the laboratory-prepared compositions containing 45 pen. bitumen.

(d) *The Marshall test.*—This test finds most favour in the United States and has been used to some extent in this country for airfields. Much of the American literature on the Marshall test really relates to aerodromes and not to roads. Some American engineers admit that stability has been overstressed in connexion with road surfacing work and that this has led to the laying of mixtures deficient in bitumen. The position on aerodromes, however, is materially different and, where heavy aircraft have to land at high speeds, it is held that the risk of deformation is so great that very high stability must be achieved even at the risk of some reduction in the life of the surfacing.

For such aerodrome surfacing work, the Americans generally call for:

(i)	Stability	Not less than 1500 lb.
(ii)	Flow value	Not more than 16 (in 0·01-in. units)
(iii)	Voids	3–5%
(iv)	Voids filled with bitumen	75–82%

Table V

Comparative performance of mechanical tests on B.S.594 compositions at 45°

		Road Machine test		Wheel-tracking	Indentation	Marshall (stability)	Unconfined Compression	Hubbard–Field	Hveem Stabilometer	Triaxial (30°)
		30°	45°							
Agreement of test stability figure with *predicted* order	Binder content in individual series. 1–4	F	F	G	P	P	F	P	F	P
	5–8	G	G	G	G	G	G	G	G	G
	9–12	F*	F*	G	G	P	P	G	G	G
	Overlap of group 1–4 with 9–12	G	G	Classification depends on time for which load acts		G	G	G	P	P
Dependence of test stability on viscosity	Sand asphalts (75 pen. replaced by 45 pen. bitumen)	High	High	High	Moderate	High	Moderate	High	Low	NT
Repeatability	Sand asphalts	F	NT	NT	NT	F	G	F	G	NT
	25% stone	G	NT	NT	NT	F	G	P	F	NT
	55% stone	G	NT	NT	NT	P	P	P	P	NT
	Over-all	FG	NT	NT	NT	F	FG	P	F	NT
Simplicity	Scale 1–5 in order of increasing simplicity	2		3	3	5	2	2	3	1
Average number of compositions manufactured and tested by one man in a fortnight		15		15†	15†	40	15	10	35	5–10

Scale: G = good
F = fair
P = poor
NT = not tested

*The poor discrimination shown on the Road Machine for the two lowest binder contents is due to the fact that there is negligible deformation.
†Allows for two tests of each composition.

Table VI

Relation of mechanical test results at 45° to the known successful application of B.S.594 mixes

Area of application	B.S. 594 schedule No. and % of stone	Road Machine Total deformation after 12 min.,* in.	Wheel-tracking Minimum rate of track depth, in. × 10^{-3}/min.	Indentation Minimum rate of indentation, in. × 10^{-3}/min.	Marshall		Unconfined Compression	Hubbard–Field	Hveem Stabilometer	Triaxial (30°c)
					Maximum load, lb.	Flow value, in.	Maximum load, tons	Maximum load, tons	Relative stability, %	Prandtl bearing capacity, lb./sq. in.
Scotland	3, 25%	0·9–0·7	50–26	150–5	1600–1800	0·5–0·3	0·15–0·8	1·8–2·0	2·0– 8·5	40–50
Scotland (seldom used)	3, 55%	0·55–0·45	6·5–4·5	3·5–0·5	2200–2700	0·5–0·3	1·9–2·4	3·2–3·8	14·0–16·5	80–490
North of England	2, 25%	0·7–0·45	26–5·5	4·5–0·5	1800–2700	0·3–0·2	0·8–1·5	2·0–3·0	8·5–24·5	50–280
North of England	2, 55%	0·45–0·25	4·5–2·5	0·5–0·1	2700–3800	0·3–0·2	2·4–3·5	3·8–4·3	16·5–33·5	490–520
South of England	1, 25%	0·45–0·35	5·5–1·0	0·5	2700–3100	0·2–0·15	1·5–1·7	3·0–3·4	24·5–26·0	280–380
South of England	1, 55%	0·25	2·5–1·0	0·1	3600–3800	0·2–0·12	2·5–3·5	4·3–5·0	33·5–35·0	520

*The specimens were prepared by a modified Marshall compaction procedure instead of the kneading compactor specified for this apparatus.

equal importance in the assessment of a mixture, the These design requirements are give design method. The requirements are, in practice, very stability value being only partons within the agreed specification give considerable differences stringent and even minor v: in the properties listed. *macadams and other surfacings.*—Many mixtures known to possess

(c) *Mastic a*- practice can scarcely be expected to show high stability when tested in the adequate sta- one of the methods described. For example, mastic asphalt can give poor results laborato- ory yet be very stable on the road. It is frequently the practice to lay an ' insert ' in th- ble grade of mastic asphalt at bus halts in the most heavily trafficked streets in central ; these have been most successful. Again, mixtures based on cut-back bitumen or emul- on in the form of bitumen macadam, fine cold asphalt, etc. can be very stable. All of these would be condemned if reliance were placed solely on certain laboratory stability tests.

(f) *Value of mechanical tests.*—A simple mechanical test that assisted in the design of dense surfacings could be of value to the asphalt industry. Although the Marshall test sets out to do this and may indeed prove suitable for certain climatic and traffic conditions, it must be remembered that B.S.594 compositions would never have been evolved from Marshall test criteria.

It is clear that the greatest care must be taken in employing any of these stability tests and in the interpretation of the results. Stability is only one factor affecting the behaviour of a surfacing, and over-emphasizing it may lead to a reduction in the life of a bituminous surfacing.

There are problems, however, such as the development of surfacings with local aggregates and the design of roads for other climatic conditions where a body of systematised experience, such as is summarized in B.S.594, is not available. Mechanical tests may well play a useful role in the investigation of these problems provided it is remembered that durability is usually more important than stability.

Mechanical tests are of value, therefore

(*a*) for supplying information on the resistance to deformation of otherwise satisfactory compositions,

(*b*) to give guidance on the likely resistance to deformation of new materials,

(*c*) to provide information on the effect of the constituents on the flow or mechanical properties of the asphalt.

For fundamental studies, tests employing a uniform distribution of stress are to be preferred. For an engineering comparison of stability it is likely that the most suitable method would be to employ an apparatus such as the Road Machine or the Wheel-tracking machine where an assessment can be made on the rate of flow under various applied loads. Because of the complex flow-behaviour of bituminous materials, information of this kind cannot be inferred from equilibrium or constant-rate-of-strain tests.

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Use Of Rubber In Road Surfacing Materials

P. D. Thompson.

Use of Rubber in Road Surfacing Materials

By P. D. Thompson, B.Sc.*

ICCRI Class No: 3626R27

At a conference on "Rubbers in the Building and Construction Industries" organised by the London Section of the Institution of Rubber Industry, held at the Institution of Electrical Engineers, London, on 1st November, 1963, the following paper was presented by the author.

In the hundred years or so since rubber was first mixed with bitumen, ideas have undergone a considerable change. Originally, the object was to modify the rubber by adding bitumen, but more recently the emphasis has been on altering the properties of bitumen by the addition of small quantities of rubber.

The use of rubber for road surfacing has undergone a similar change of emphasis. The earliest rubber road surfacings consisted of solid rubber blocks laid to form a road surface. For modern conditions this type of surfacing is far too expensive and extremely slippery when wet. The practice now is to blend small quantities of rubber with the tar or bitumen binder used in the manufacture of road surfacing materials. The amount of rubber used is only 1 to 2 oz. per sq. yd. of road, and may even be less than ½ oz. per sq. yd.

Forms of Rubber Used in Road Materials.

Rubber is usually used in the following forms:

(i) *Latex.*—This has concentrations of rubber of from 60 to 73 per cent. (D.R.C.).

(ii) *Unvulcanised rubber powder.*—The powder is specially made for use in road binders. It contains 40 per cent. of inert filler to prevent the rubber particles sticking together, and is about as fine as household flour.

(iii) *Vulcanised rubber powder.*—This is available in two slightly different forms. One is a coarse crumb containing just over 2 per cent. of combined sulphur; the other is a powder slightly coarser than unvulcanised powder and contains about 0·3 per cent. of combined sulphur and 24 per cent. of filler.

(iv) *Smoked sheet.*—This has to be milled and dissolved in oil, such as kerosene, before being dispersed in the road binder. Rubber in this form has only, so far, been used in Australia in a process specially developed for the site conditions existing there.

* Natural Rubber Producers' Research Association, in association with The Road Research Laboratory, Harmondsworth, West Drayton, Middlesex.

(v) *Ground scrap rubber.*—Rubber in this form is not generally recommended as its composition cannot normally be guaranteed.

Types of Road Surfacing in which Rubber is Used.

The road surfacings in which rubber is normally incorporated fall broadly into two types:—

(i) *Surface-dressing*, where the binder (tar or bitumen) is sprayed on to the road by a mechanical binder distributor (see Plate I). A single layer of stone chippings is then spread on top of the binder. This is nearly always a maintenance treatment, giving a fresh running surface for the traffic. Tar is sprayed at about 130° C. and bitumen at 150° to 160° C.

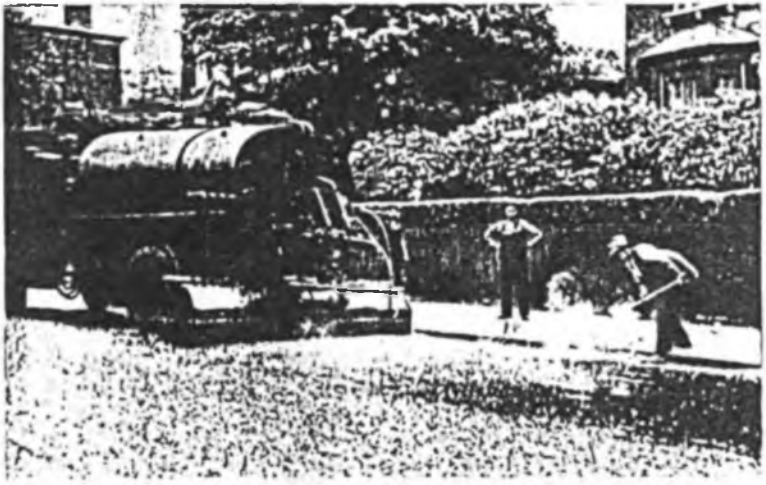


PLATE I. Binder being sprayed using a mechanical binder distributor.

(ii) *Mixed materials*, which consist of mixtures of coarsely graded aggregate, sand, filler and binder. These materials are put down in layers up to about 2 in. thick as shown in Plate II. The types of mixed materials in which rubber is used may be sub-divided into:—

(*a*) rolled asphalt;

(*b*) bitumen macadam;

(*c*) mastic asphalt.

There are certain differences in the methods of preparing these materials which lead to differences in the techniques for blending rubber with them.

In the preparation of rolled asphalt, the dry materials are mixed in a batch mixer, and the binder is sprayed in during the mixing cycle at

about 160° C. Mixing normally takes 1 to 2 minutes. The mixing plant is usually static and the mixed asphalt is transported to the road by lorry for anything up to 50 miles.

Bitumen macadam is mixed in a similar manner to rolled asphalt, but the binder temperature is much lower—around 100° C.

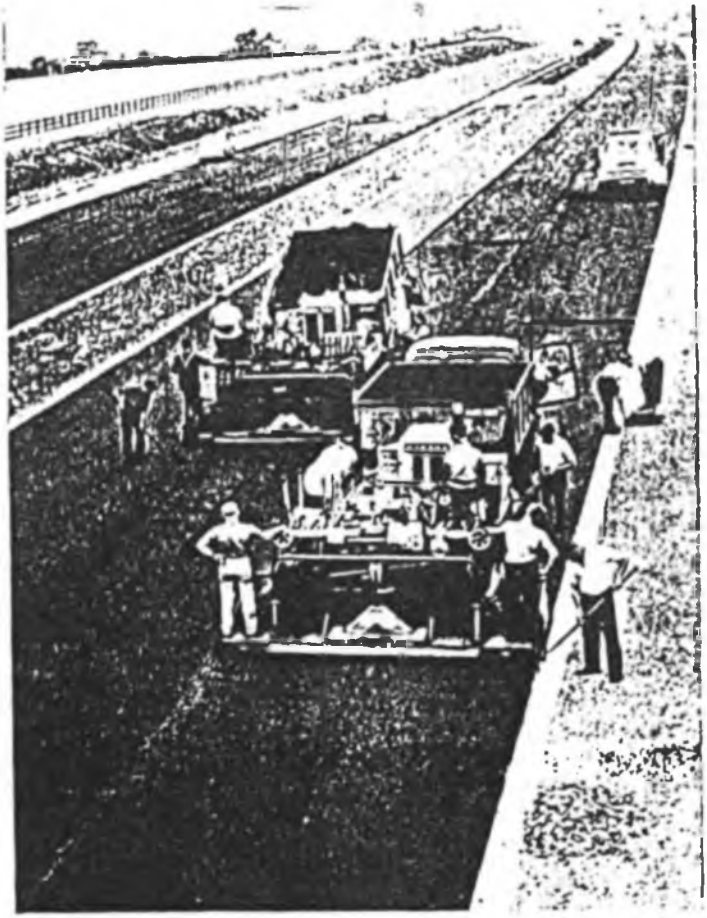


PLATE II. Laying mixed materials using mechanical asphalt spreaders.

Mastic asphalt is made by blending finely ground aggregate and bitumen, the resulting mastic mortar being cast into blocks. At the road site, the blocks are remelted in a mastic cooker and coarse aggregate is added. The resulting mastic asphalt is heated in the cooker to around 200° C. for up to about 8 hours before the material is laid (by hand).

Methods of Blending Rubber and the Proportions Used.

The methods of blending rubber into road binders, and the amounts of rubber used differ for the various types of road materials, and also to a certain extent depend on the form of rubber used. The important underlying principle is, however, the same for all materials: the rubber must be dissolved in the road binder at some stage before the material is laid on the road.

For surface-dressing, the rubber must be pre-blended into the tar or bitumen before spraying. For mixed materials, however, a pre-blended binder may be used or the rubber may be added during the process of mixing the aggregate, filler and binder. The method of addition will depend on the temperatures at which the materials are mixed and the convenience of the addition. For example, rolled asphalt is mixed at 160° C., and generally at least ½ hour elapses between mixing and laying. It is therefore convenient to add the rubber during mixing because there is ample time for dissolution into the bitumen and no need to store large quantities of pre-blended binder. Mastic asphalt, on the other hand, has to be heated at 200° C. for long periods. As rubber is subject to serious degradation when heated, it can only be added to the material in the mastic cooker immediately before laying.

The various methods of blending are fully described in literature issued by the Road Research Laboratory[1] and the Natural Rubber Producers' Research Association[2,3] and are not therefore described in detail in the present paper.

The proportions of rubber used are expressed as a percentage of the weight of soluble binder in the road material, because the object of adding rubber is to modify the properties of the binder.

The amounts for the different types of materials are given in Table 1.

TABLE 1

AMOUNT OF RUBBER USED IN ROAD MATERIALS

Type of surfacing	Percentage of rubber on binder (by weight)	
	Rubber powder	Latex
Surface dressing	1½–2	1–1½
Rolled asphalt	4–6	2–4
Bitumen macadam ..	4	2–3
Mastic asphalt	12–18	

The amounts of rubber recommended are governed by the minimum quantities required to give the desirable properties; at the same time they are limited to amounts which will enable the rubberised materials to be laid.

Analysis of Rubberised Binders.

As is well known, rubber is subject to degradation when heated, and at the temperatures at which road materials are mixed and laid, i.e. up to 200° C., the degree of degradation can be serious. Two methods of

analysing rubberised binders have been developed to assess the amount and state of rubber in the binders. These are illustrated in Figure 1. The binder is first dissolved in benzene and the acetone-insoluble fraction precipitated by addition of acetone. The acetone-soluble fraction is

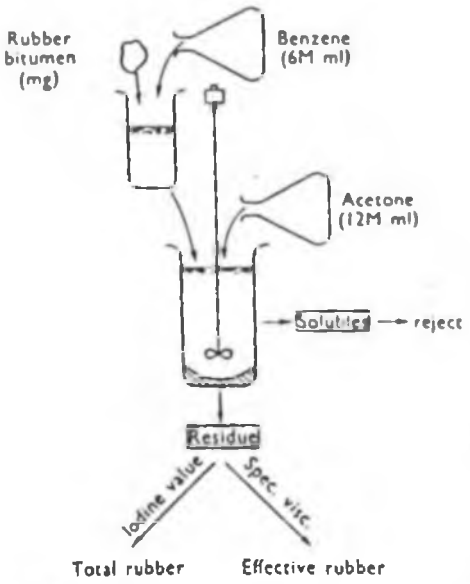


FIG. 1. Determination of the total and effective rubber contents of bitumen.

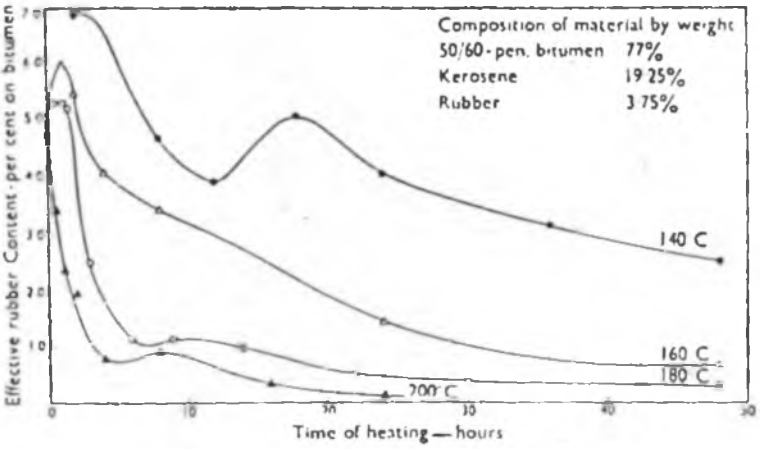


FIG. 2. The variation of effective rubber content of rubber-bitumen with heating.

rejected and the analysis is made on the insoluble fraction. This eliminates the acetone-soluble rubber which does not contribute to the alteration in the properties of bitumen and also 65 to 75 per cent. of the bitumen. Briefly, the iodine value is estimated and the specific viscosity of a 5 per cent. solution in benzene is measured. From the iodine value, which measures the number of double-bonds the total rubber content is estimated with sufficient accuracy for practical purposes (the iodine value of the acetone-insoluble fraction of most bitumens is remarkably constant); from the specific viscosity an "effective rubber content" is obtained. The specific viscosity of a solution of rubber in benzene enables an estimate of the average molecular weight to be obtained.[3] The bitumen has little effect on this measurement but is allowed for. The effective rubber content is defined as the concentration of a standard undegraded rubber which must be added to bitumen to give the same specific viscosity in benzene as the test sample. The method has been described in a Road Research Laboratory publication.[4] The variation of effective rubber content with heating is shown in Figure 2.

Properties of Rubber-modified Bitumens.

The properties of bitumen are altered by rubber in the following ways:—

A marked elasticity is imparted to the bitumen.
The viscosity is increased.
Deviation from Newtonian flow is increased.
The temperature sensitivity is reduced.
Brittleness at low temperatures is reduced.

Table 2 shows the change in some of these properties as measured by standard tests used in the road industry when 2 or 4 per cent. of rubber is added to bitumen.

TABLE 2

CHANGES IN PROPERTIES OF BITUMEN BY THE ADDITION OF 2 AND 4 PER CENT. OF NATURAL RUBBER LATEX

Standard test	Added rubber: per cent. by weight of bitumen		
	0	2	4
Penetration at 25° C.	101	86	66
Softening point R and B. (° C.) ..	43	50	58
Penetration index	−1·3	+0·2	+1·5

A 100 pen bitumen has a viscosity of about $7{\cdot}6 \times 10^5$ poises; the viscosity of an 86 pen bitumen is about $1{\cdot}1 \times 10^6$ poises and that of a 66 pen bitumen is about $1{\cdot}8 \times 10^6$ poises.

The degree of change in properties will vary with the amount of heating to which the rubberised binders have been subjected and, in general, it varies proportionately with the effective rubber content. Thus, limits must be placed on the amount of heating to which a rubberised binder may be subjected. Since the change in effectiveness of the rubber is gradual, an arbitrary figure has been chosen, i.e. the time at any given

temperature at which the effective rubber content drops to half the total added rubber content.

Full-scale Road Experiments.

The proof that any modification to normal road materials gives an improved result must lie in a comparison of the behaviour of the new material with that of the normal material. Laboratory work alone cannot prove that the new material will give better results. A series of

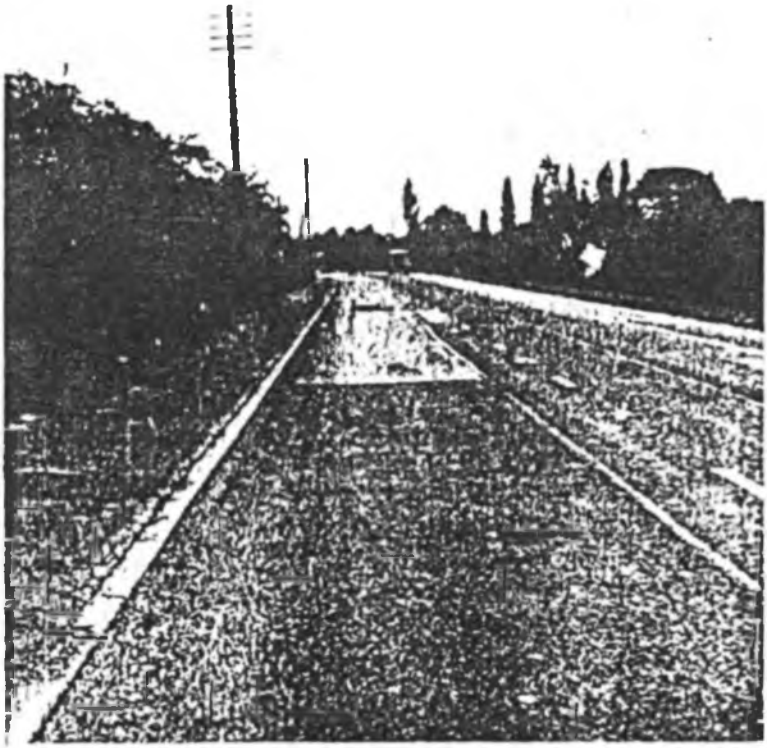


PLATE III. Damage caused by a spell of hot weather on A.61. Cut-back bitumen (background) at 4½ yd.²/gal. fatted up, rubberised bitumen (foreground) at 4½ yd.², gal. remained fairly good; the centre lane (under light traffic) was unaffected.

full-scale road experiments with rubberised materials has therefore been carried out to assess the wearing qualities of these materials under normal traffic.

In surface-dressing, for example, normal bitumen binders "fat-up" under heavy traffic in hot weather, that is, the binder is pushed to the

surface, covering the layer of stone. As shown in Plate III, the addition of rubber prevents fatting up, owing to the reduced temperature susceptibility of the rubber-modified binder resulting from the non-Newtonian flow characteristics of the binder. It has also been found during the

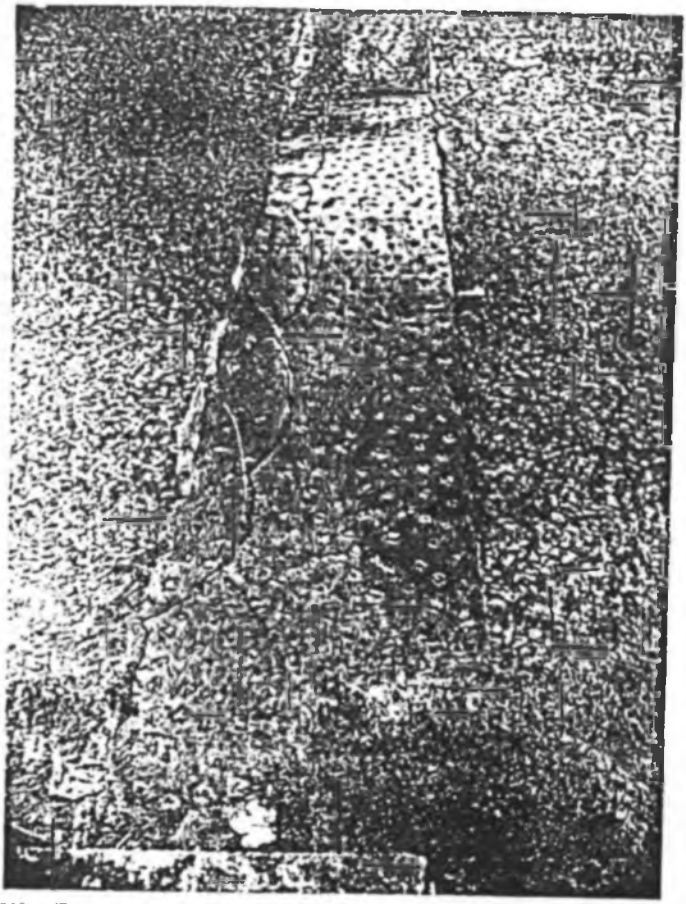


PLATE IV. Treatment of cracked asphalt over concrete, showing cracking of unrubberised mastic asphalt after three years.

laying of rubberised surface-dressings that the stone sticks more tenaciously to the binder; this property is especially valuable during bad weather immediately after laying.

When mixed materials are used, one of the most important results of adding rubber is the resistance to cracking which is obtained. A number of experiments have been carried out with rubberised mastic

Surface-dressing using rubberised bitumen is generally about 20 per cent. more costly than normal surface-dressing. The cost of using rubberised mastic asphalt for the replacement of cracked asphalt, as described in the paper, works out at about 12 to 15 per cent. more than that using normal mastic asphalt when all the site work is taken into consideration.

No actual costs are available for the commercial use of rubberised bitumen-macadam, but it is estimated that, if the rubber were added to the material during mixing, the rubberised macadam would cost between 5 and 20 per cent. more than the normal material laid (depending on the form of rubber used) and probably 25 to 40 per cent. more if the rubberised binder were pre-blended.

TABLE 4

INTERIM RESULTS AFTER 5 YEARS OF AN EXPERIMENT WITH RUBBERISED BITUMEN MACADAM ON TRUNK ROAD A.15 AT YAXLEY, HUNTS.

Binder		With rubber		Without rubber	
Cut back bitumen 100 secs. at 40° C	4·75%	9	F — R	5	P R
	3·0%	7	F R	4	F – t R
	3·5%	10	FG —	3	F – t R
	3·75%	8	FG—	2	FG—t
	4·25%	6	FGvt	1	F— R
300 pen bitumen	2·75%	11	FG—	19	FG—
	3·0%	12	G	17	FG —
	3·5%	15	G	20	FG —
	3·75%	13	G	18	FG —
	4·25%	11	G	16	FG—

Notes: Numbers refer to section numbers.
R = written off for replacement
G = good
F = fair
FG = fairly good
P = poor
— = disintegrating
v = variable
t = transverse variation due to traffic laning

Latex is cheaper than the rubber powders available, but its 30 to 40 per cent. water content necessitates a greater control during blending with hot bituminous materials and the use of powder is often more convenient, especially where the blender has a limited experience of using rubber.

Acknowledgements. – This paper is published with the permission of the Director of Road Research, Road Research Laboratory, D.S.I.R. and the Director of the Natural Rubber Producers' Research Association.

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2 Natural Rubber Producers' Research Association, "Rubber in Roads Information Sheets," Revised, August, 1961, London.
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[*Received 6th February*, 1964]

asphalt over concrete joints. When asphalt is laid over concrete, it cracks over the joints between the concrete slabs owing to the relative movement of adjoining slabs. To test the effectiveness of the rubberised material, the cracked asphalt is cut away as shown in Plate IV, and replaced with normal or rubberised mastic asphalt. The normal material cracks as shown in Plate IV. The rubberised material, however, withstands the movement without cracking as shown in Table 3 which gives the results of a full-scale experiment carried out in Middlesex on Boston Manor Road.

TABLE 3

CRACKS IN ASPHALT OVER CONCRETE-EFFECT OF ADDING RUBBER OR STONE TO MASTIC ASPHALT

Type of mastic asphalt	Binder consistency	Number of joints	Number cracked after 7 years
Plain (no stone)	65 pen	9	7
	40 pen	18	15
Plain, with expanded metal ..	40 pen	8	7
Stone filled	40 pen	9	3
Rubberised (no stone) (2½ per cent. rubber)	25 pen	8	0

In a similar experiment with rolled asphalt, it was found that the rubber considerably reduced the number and severity of cracks, although cracking was not eliminated entirely.

In an experiment where bitumen macadam and a similar rubberised material were laid on a weak base, it was found that an increase in life of at least 40 per cent. was obtained by the addition of rubber. When the experiment was concluded owing to the start of a road improvement scheme at the site of the experiment, two of the rubberised bitumen macadam sections were still serviceable and the increased life of these sections compared with that of the comparable normal materials would probably have been at least 50 per cent. Table 4 shows the results of the experiment after 5 years and also illustrates how the sections are assessed during an experiment of this type.

In the time available, it is not possible to cover the details of all the experiments carried out. Those experiments that have been mentioned are among those that have shown that the addition of rubber to road binders produces materials which overcome some of the limitations of normal road materials.

Costs.

It is difficult to give accurate costs of the materials mentioned in this paper. The costs incurred during full-scale experiments bear no relation to normal commercial costs. The work with experimental materials takes a lot longer and often only small quantities of these materials are used. The surfacing of a length of road experimentally may therefore be many times more expensive than the surfacing carried out commercially, using any one material. However, the following figures may be taken as a guide to commercial costs.

(16)

(21)

USE OF NATURAL RUBBER LATEX IN ROAD CONSTRUCTION

By

M.J. FERNANDO

&

M. NADARAJAH

J. Rubb. Res. Inst. Malaya, 22(5), 430–440 (1969)

Use of Natural Rubber Latex in Road Construction

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Latex is the most effective form of natural rubber for road construction, both centrifuged latex and Revertex being used. The authors found creamed skim latex most effective for road-making. Because of its easy availability, however, field latex is more suitable for road-making in the natural rubber producing countries.

Results of laboratory studies on cationically stabilised, compounded and peroxide-vulcanised field latex are reported. The studies concerned the dispersion of rubber particles, temperature-dependent and rheological properties, ageing and stripping of rubberised bitumen and uses of rubber in mix designs.

Experimental stretches of road surfacing have been laid with bitumen containing up to 4% field latex. Further test stretches are being laid with rubber-modified pre-mix using field and creamed skim latices.

The improvement of bitumen by the addition of rubber was attempted even a century ago, but only recently it has become possible on a scale large enough to be of commercial interest (SINCLAIR AND BRISTOL, 1967). A fifteen-year co-operative programme of research on rubberised road materials has established conclusively the advantages of rubberised road materials for certain applications (THOMPSON, 1967). Rubber has been added to bitumen as powders, cements and latex. Unvulcanised rubber in latex form is more effective than others (SMITH, 1960), though the powder form has the advantage of convenience of addition. There is thus a steady drift away from the use of the Mealorub-type of semi-vulcanised powder and Rodorub, a slightly vulcanised powder to Pulvatex, an unvulcanised powder and to latex (MULLINS, 1963). Further, latex is considerably cheaper.

Natural rubber latices commercially used for road making are centrifuged latex and Revertex, the latter (STONE, 1963) giving better results. THOMPSON (1964) has recommended the use of concentrated latex at 1–1½% for surface dressings, 2–4% for rolled asphalt and 2–3% for bitumen-macadam. In the natural rubber producing countries, the simplest form of latex to be used is preserved field latex and its modifications.

Latices Used in Experiments

Latices used in the study were: *(a) Low ammonia field latex* — field latex was treated with 0.35% ammonia and diammonium hydrogen phosphate to precipitate and separate the magnesium and preserved with 0.3% sodium pentachlorophenate; *(b) Revertex; (c) Centrifuged latex; (d) Creamed skim latex* — skim latex was ammoniated to 0.7% and creamed for 48 hours with a 2.5% solution of carboxy methyl cellulose or hydroxyethyl cellulose at 0.25% on the latex and the ammonia content of the creamed skim latex brought up to 1%; *(e) High ammonia field latex* — field latex was treated with 0.35% ammonia and diammonium hydrogen phosphate to precipitate and separate the magnesium and the ammonia content was brought up to 1%; *(f) Compounded latex* — tetramethylthiuram disulphide, zinc oxide and zinc diethyldithiocarbamate as 50% dispersions and thiourea

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as an aqueous solution were added to low ammonia field latex; *(g) Cationically stabilised latex*—field latex was stabilised at 2 or 5% with a non-ionic stabiliser (Vulcastab LW), with cetyl trimethyl ammonium bromide (3% on latex) and concentrated HCl was added to bring the pH to 4; and *(h) Peroxide-vulcanised latex*—high ammonia field latex was treated with cumene hydroperoxide and tetraethylene pentamine.

Test Methods

The laboratory test methods used were as follows: A.S.T.M. D-5-52 (100 g, 5 seconds, 77°F) for penetration; A.S.T.M. D-36-26 for softening point (ring and ball); A.S.T.M. D-113-44 (25°C, 5 cm/min) for ductility and elasticity, toughness and tenacity for rheological properties. The triaxial machine applying a constant rate of deformation (0.1 in. per min) on samples 2½ in. high and 1 in. diameter prepared from rubberised bitumen, sand and quarry dust and mixed as shown in *Table 1* was used.

TABLE 1. GRADATION OF AGGREGATES FOR RHEOLOGICAL PROPERTIES

A.S.T.M. sieve number	Passing by wt (%)
4	100.0
8	71.0
16	50.0
30	35.2
50	25.0
100	17.7
200	12.5

Stripping tests were the boil test, the water immersion test, and the test to assess the stripping action of rubberised bitumen on limestone (FERNANDO, 1967). This quantitative test is based on the action of HCl on limestone, after stripping is carried out by boiling in water for 15 minutes. The mix designs were:

Hubbard field test. This test is used to help design sand bitumen mixes. These mix designs were carried out with different percentages of rubber, for various types of latices. The gradations of the sand and filler were controlled within the theoretical Fuller's curve to obtain minimum voids. This was done by blending different fractions of various sizes of aggregates according to *Table 1* (ASPHALT INSTITUTE, 1956).

Marshall test. This is an essential test for designing asphalt concrete (pre-mix). The aggregate mix was prepared by blending various fractions of aggregate sizes according to Fuller's curve as given in *Table 2*.

TABLE 2. GRADATION OF AGGREGATES FOR THE MARSHALL TEST

A.S.T.M. sieve number	Passing by wt (%)
¾"	100.00
½"	81.5
⅜"	71.0
4	50.0
8	35.2
16	25.0
30	17.7
50	12.5
100	8.8
200	6.2

MIXING OF LATEX WITH BITUMEN

Latex was mixed with bitumen by adopting a slight modification to the method given by the NATURAL RUBBER PRODUCERS' RESEARCH ASSOCIATION (1964): "Bitumen is heated to a temperature 300–325°C in a boiler, the capacity of which will allow for at least a 50% increase in binder volume. An anti-foaming agent may be added. With efficient hand stirring, a small quantity of latex is sprayed slowly using a garden watering-can. After allowing the latex to be on the surface for 20 seconds it is stirred into the binder carefully. Stirring should be continued for a minimum period of 20 minutes after the addition of rubber, the temperature being maintained between 300 and 325 F."

PROPERTIES OF BITUMEN RUBBERISED WITH LATEX

In field latex, the particle size ranges from less than 0.04 μ to about 2 μ, the maximum in the size frequency curve occurring at approximately 0.6 μ (VAN DEN TEMPEL, 1952). When latex is concentrated by centrifuging, the distribution curve

is shifted towards larger diameters since most of the smaller particles are left in the skim. Thus skim latex would have most of the small particles, and centrifuged latex most of the large particles, present in field latex. The smaller the size of the latex particles, the less the heat required to disperse them in a homogeneous mixture and the less degradation caused by heat. In this respect, creamed skim latex and, to some extent field latex would be superior to centrifuged latex.

Figure 1 shows the particle distribution of rubber in bitumen as field latex, centrifuged latex and Revertex. In these curves, obtained by means of microphotography, it is clear that field latex in bitumen gives the highest percentage of small particles (size under) at any particle size.

The properties of bitumen with different percentages of rubber for various types of raw latices are given in *Table 3*.

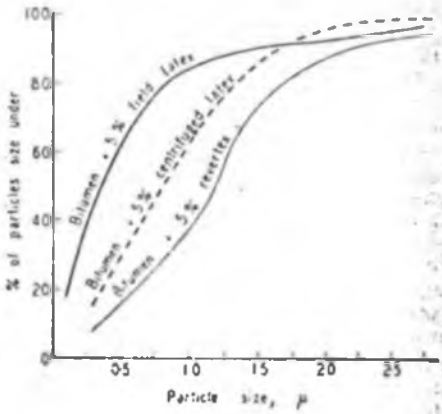


Figure 1. Particle distribution of rubber in bitumen.

TABLE 3. PROPERTIES OF BITUMEN RUBBERISED WITH LATEX

Property	Rubber (%)	Type of latex					
		L.A. field latex	H.A. field latex	L.A. centrifuged latex	Revertex	Creamed skim latex	
						C.M.C.	H.E.C.
Penetration	0	90	90	90	90	90	90
	2	74	69	71	73	70	68
	3	68	60	65	63	62	64
	4	62	58	60	53	52	60
Softening point	0	49	49	49	49	49	49
	2	53	58	54	54	58	57
	3	56	62	58	61	59	59
	4	60	63	61	67	64	62
Ductility	0	150+	150+	150+	150+	150+	150+
	2	72	55	54	72	73	58
	3	61	40	48	60	60	51
	4	54	34	43	35	45	34
Stripping on limestone	0	6.2	6.2	6.2	6.2	6.2	6.2
	2.5	2.6	4.3	2.0	1.3	1.0	2.4
Percentage increase in toughness	2.5	68	108	93	39	125	–
Percentage increase in tenacity	2.5	186	260	303	220	136	140

From these results it is clear that rubber in the form of raw latices, even when used in small quantities, is highly effective in modifying the physical properties of bitumen. The field latex (H.A.) and creamed skim latex are just as good as, if not superior to, Revertex in respect of penetration, softening point and ductility.

Figures 2 and *3* show the variation of the Hubbard field design with different percentages of rubber for creamed skim latex and field latex respectively. *Figures 4* and *5* illustrate the variation of Hubbard field stability for different types of latices with 80/100 bitumen as the control. It is clear that there is a distinct increase in the stability on the addition of rubber, keeping the percentage of air voids and the percentage filled with asphalt within specified

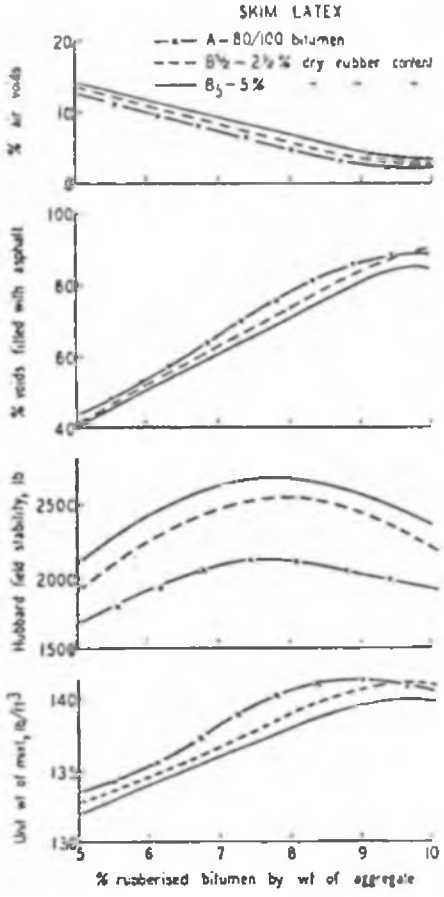


Figure 2. Hubbard field designs obtained with rubberised bitumen.

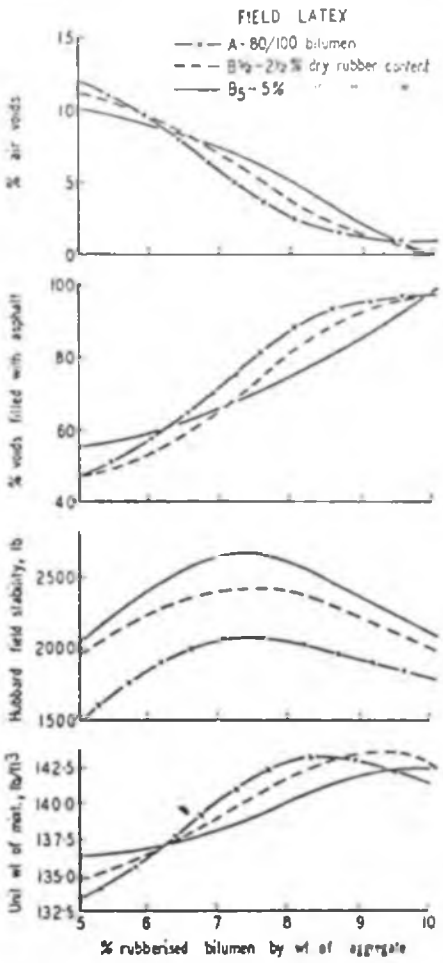


Figure 3. Hubbard field designs obtained with rubberised bitumen.

limits. With 2½% rubber, creamed skim latex showed the maximum Hubbard field stability (24% over the control), while field latex gave an increase of 18%. Field latex as well as creamed skim latex showed a maximum Hubbard field stability of 30% increase for 5% dry rubber content (d.r.c.).

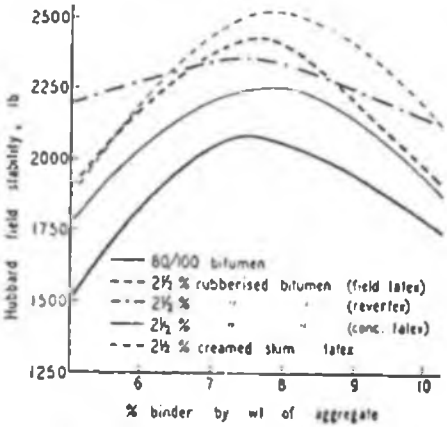


Figure 4. Hubbard field stability for different latices with 2½% d.r.c.

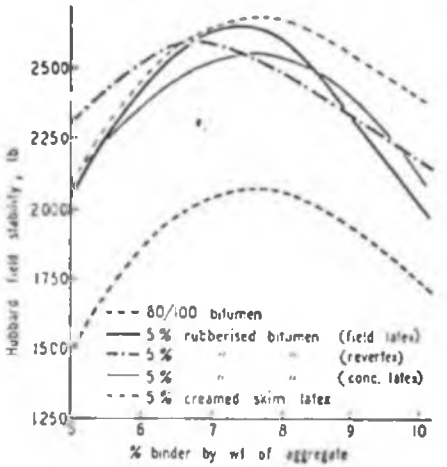


Figure 5. Hubbard field stability for different latices with 5% d.r.c.

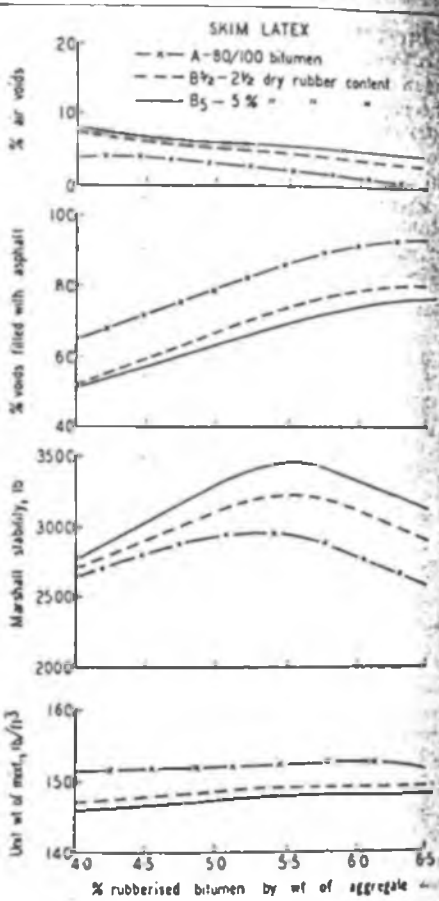


Figure 6. Marshall designs obtained with rubberised bitumen (skim latex).

Figures 6 and *7* show the variation of the Marshall design for asphalt concrete (pre-mix) with different percentages of rubber for creamed skim latex and field latex respectively. Variation of the maximum Marshall stability for different types of latices is illustrated in *Figures 8* and *9* with 80/100 bitumen as the control. A maximum increase of 12% in the stability was observed with creamed skim latex for 2½% d.r.c., whereas field latex gave an in-

crease of 8%. With 5% d.r.c., a maximum increase in stability of 19% was observed for creamed skim latex and 11% for field latex.

As field latex is the most easily available form of latex in the natural rubber producing countries, further work was done on it. Results on the use of rubber as field latex, on loss on heat ageing, and decrease in penetration on ageing

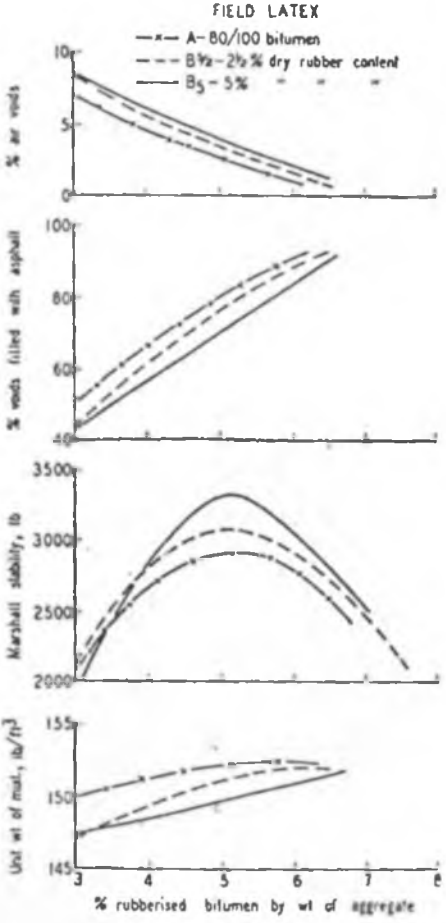


Figure 7. Marshall designs obtained with rubberised bitumen (field latex).

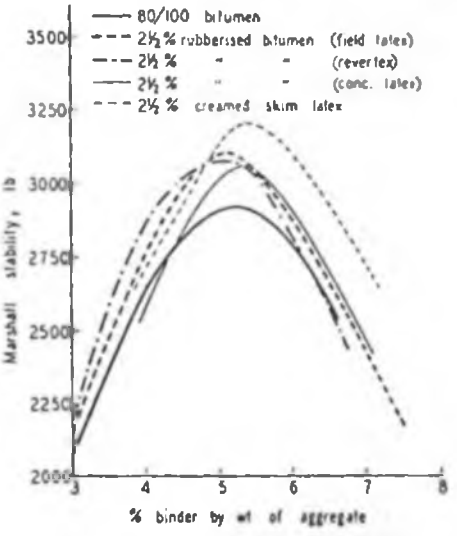


Figure 8. Marshall stability for different latices with 2½% d.r.c.

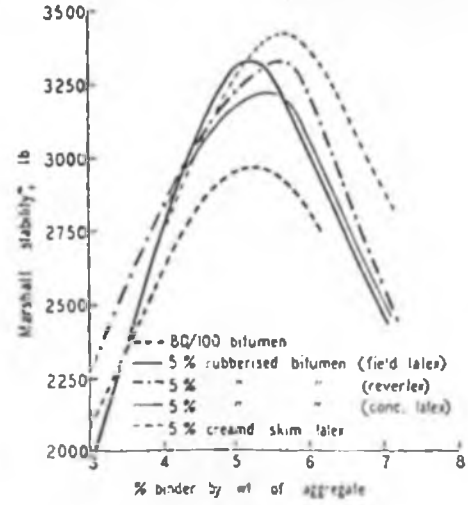


Figure 9. Marshall stability for different latices with 5% d.r.c.

TABLE 4. EFFECT ON PHYSICAL PROPERTIES OF BITUMEN RUBBERISED WITH FIELD LATEX (L.A.)

Type	Ageing		Penetration at			Percentage stripped			
						Boil test		Water immersion test	
	Loss on heat ageing (%)	Decrease in penetration (%)	25 C	30 C	35°C	Granite	Charnakite	Granite	Charnakite
80/100 Bitumen	0.33	20	90	130	200	12	11	5	10
2% Rubberised bitumen	–	–	–	–	–	5	1	0	1
2½% Rubberised bitumen	0.11	12	60	81	120	–	–	–	–
5% Rubberised bitumen	0.10	5	54	77	112	–	–	–	–

given in *Table 4* confirm previous findings (LEWIS AND WELBORN, 1954) that rubber enhances the ageing properties and resistance to subsequent cracking due to brittleness of bitumen.

The results obtained on the variation of penetration with temperature, of bitumen rubberised with field latex and on stripping immersion test *(Table 4)* show the effectiveness of rubber.

EFFECT ON BITUMEN OF FIELD LATEX MODIFIED WITH ADDITIVES

Compounded Latex

It has been shown by DE MERLIER *et al.* (1964) that smoked sheet in which the rubber has a molecular weight of less than 400 000 exerts a negligible influence on the elasticity of the bitumen; above this value, the elastic recovery increases rapidly and attains 100% for a molecular weight value of about 900 000. Rubber is subject to degradation when heated and at the temperatures at which road materials are mixed and laid, *i.e.*, up to 200°C, the degree of degradation can be serious. The formula used for making compound C *(Table 5)* was that recommended by the NATURAL RUBBER PRODUCERS' RESEARCH ASSOCIATION (1961) for compounding natural rubber latex for heat resistance: natural rubber as latex 100, zinc oxide 1, tetramethylthiuram disulphide (TMTD) 3, zinc diethyldithiocarbamate (ZDC) 1, and thiourea* (TU) 1, vulcanised for 2–3 hours at 70°C. Compounds A and B were prepared by adding 25% and 50% respectively of the compounding ingredients as in C. No pre-vulcanisation was done, since vulcanisation occurred when the compounded latex was mixed with hot bitumen.

The properties of bitumen with different percentages of rubber for compounds A, B and C are given in *Table 5*. Light vulcanisation (Compound A) gave the best all-round properties.

CATIONICALLY STABILISED FIELD LATEX

Preliminary trials on bitumen rubberised with cationic perbunan C latices by ESSER AND HOFMANN (1964) have been reported by them to be interesting, as cationic latices whose rubber particles have a positive charge would promote a particularly good adhesion of such

* According to *N.R.P.R.A. Technical Information Sheet No. 93*, an effective anti-oxidant for unvulcanised latex.

TABLE 5. EFFECT OF FIELD LATEX MODIFIED WITH ADDITIVES ON PROPERTIES OF BITUMEN

Property	Rubber (%)	Type of modified latex							
		Compounded latex				Cationically stabilised field latex	Peroxide-vulcanised field latex		
		Control	A	B	C		A	B	C
Penetration	0	90	90	90	90	90	90	90	90
	2	74	80	78	75	64	69	64	56
	3	68	70	72	70	59	60	62	52
	4	62	62	68	66	55	58	58	48
Softening point	0	49	49	49	49	49	49	49	49
	2	53	53	53	52	56	58	58	59
	3	56	57	55	53	58	62	63	62
	4	58	61	57	55	61	63	64	65
Ductility	0	150	150	150	150	150	150	150	150
	2	72	60	52	50	81	55	35	22
	3	61	58	49	45	58	40	30	20
	4	51	51	40	30	49	34	26	17
Stripping on limestone	0	6.2	6.2	6.2	6.2	6.2	6.2	6.2	6.2
	2.5	4.0	–	2.0	–	1.3	4.3	3.0	2.9

rubberised bitumen to other materials. The results obtained by us with cationically stabilised field latex, as given in *Table 5*, show an improvement as compared with the control in penetration, softening point and stripping. It would be expected that still better results on stripping would be obtained with an acidic stone such as granite.

PEROXIDE VULCANISED FIELD LATEX

Sekhar (1958) has stated that, during aeration of natural rubber latex, oxygen produces peroxidic centres in rubber and that while the production of these peroxidic centres causes the rubber to degrade on heat ageing, the presence of reduction activators altered the course of reaction to one of cross-linking. It may be expected that blowing of air over the surface of heated field latex in the preparation of Revertex may give rise to peroxidic cross-linking due to reduction activators present in the latex serum. Bloomfield (1952) has shown that cumene hydroperoxide (CHP) and tetraethylene pentamine (TEP) can cross-link rubber molecules in latex. CHP at 0, 0.4 and 0.8% and TEP at 0, 0.1 and 0.2% were added to H.A. field latex respectively. The properties of the bitumen with different percentages of rubber and with different concentrations of CHP, *i.e.*, A having 0%, B having 0.4% and C having 0.8% CHP are given in *Table 5*. It will be seen that peroxide vulcanisation gives some improvement in the properties of bitumen over that of the control.

CHEMICAL INTERACTION OF NATURAL RUBBER WITH BITUMEN

Elastomer and bitumen technologists have generally held the view that the effect of rubber on a bituminous material is physical rather than chemical. Kalin (1967) investigated the use of SBR (styrene 23%, butadiene 77%) latex

in rubberised asphalt and is of the view that the effect of the rubber in bitumen is purely physical.

However, this may not be so in the case of natural rubber latex. SEKHAR (1961 and 1963) has shown the presence of abnormal groups in rubber namely about 9 to 35 aldehydic groups and about 100 to 420 aldehyde condensing groups per polyisoprene molecule, assuming a molecular weight of 1 000 000. Since bitumen has also highly polar atoms such as nitrogen, sulphur and oxygen and would be expected to contain aldehyde and aldehyde condensing groups, it is reasonable to expect some chemical interaction, when mixing natural rubber latex with bitumen. This may explain the somewhat varying results obtained in the properties of bitumen rubberised with field latex. Thus if there is a long interval between tappings because of rain interference, if the latices are from different clones or if the tapping intensity varies, then all these factors may affect the amount of abnormal groups in rubber and hence the properties of the bitumen rubberised with field latex. The results obtained for the properties of bitumen rubberised with (a) high ammonia field latex from clone Tjir 1, and (b) high ammonia field latex from clone RRIM 501, given in *Table 6*, confirms this view.

Further it is known that hydroxylamine condenses with the aldehyde groups present in the natural rubber molecules and renders them inactive. The H.A. latex from RRIM 501 was treated with hydroxylamine at 0.34% on the latex and the properties of bitumen rubberised with this latex are also given in *Table 6*. It will be seen that the properties of the hydroxylamine-treated latex are inferior to that of the non-treated H.A. latex from RRIM 501 in penetration and softening point. Hence the aldehyde groups in natural rubber latex in the unreacted state have a chemical influence in improving the properties of the bitumen.

TABLE 6. CHEMICAL INTERACTION OF NATURAL RUBBER LATEX AND BITUMEN

Property	Rubber (%)	Type of latex		
		Tjir 1 H.A. latex	RRIM 501 H.A. latex	RRIM 501 latex treated with ammonia (0.5%) and then with NH_2OH (0.34%)
Penetration	0	96	90	96
	2	77	70	80
	3	74	67	76
	4	70	62	67
Softening point	0	48	49	48
	2	56	56	54
	3	60	58	55
	4	60	61	57
Ductility	0	150+	150+	150+
	2	46	76	60
	3	41	58	56
	4	36	43	49

FIELD EXPERIMENTS

An experimental seal coat was laid on one mile of road with rubberised bitumen at the 9th mile, Nagoda–Matugama–Agalawatta road about two years ago. The work consisted of sections of single seal coat using 1, 2, 3 and 4% rubberised bitumen. A short section was also given a double seal coat using $\frac{1}{2}$" metal for the first seal coat. Some sections were treated with plain rubberised bitumen containing 2 and 3% dry rubber content and blinded with sand.

The control and the 1% rubberised bitumen single seal coat section have shown some cracks already. However, the 2% rubberised bitumen single seal coat section is behaving well. Therefore a rubber content of 2% should be the minimum to be used for road work.

The section dressed with plain bitumen and blinded with sand has already started pitting up, while the rubberised bitumen sections blinded with sand has as yet shown no signs of pitting at all.

Half a mile of road is being laid with rubber modified pre-mix (4% d.r.c. on bitumen), the rubber being in the form of field latex (L.A.), field latex (H.A.) and creamed skim latex.

More and more field trials must be carried out to study the potentialities of rubberised bitumen in other forms of construction such as asphalt concrete and sand asphalt carpets where little work has been done.

For convenience in field work, a 16% rubberised bitumen masterbatch is recommended.

DISCUSSION

To improve the stability of field latex, it was treated with diammonium hydrogen phosphate, to precipitate the magnesium. According to *N.R.P.R.A. Technical Information Sheet No. 93*, diammonium hydrogen orthophosphate is an effective inhibitor in oxidative breakdown of unvulcanised latex rubber. Hence it would be advantageous if an excess of diammonium hydrogen phosphate is added so that after being used for precipitating the magnesium up to 1 p.p.h.r. of it is left in the field latex. It is during the process of dissolving the rubber in bitumen that it is liable to get degraded. Once the rubberised bitumen is laid, the rubber is protected by the surrounding mass of bitumen and further oxidation of the rubber is unlikely to occur to any significant extent.

The use of a non-volatile preservative may be an advantage, as it is less likely to be affected by heat during the mixing process; hence our experiments with L.A. field latex. According to de Merlier *et al.* (1964), rubber in the form of latex takes several weeks to swell and distribute itself uniformly throughout the bitumen. It is therefore necessary that a certain waiting period should be allowed for the elastic properties of the bitumen to reach a maximum. This period may vary with various types of latices and may be why L.A. field latex behaves less efficiently in laboratory experiments than H. A. field latex and Revertex in rubberised bitumen *(Table 3)*. According to Thompson (1967), it has been established conclusively that the rubber must be dissolved in the binder since undissolved rubber makes no contribution to the improvement of surfacings.

It is well known that skim rubber because of its high protein content shows some undesirable properties when compounded in the normal way. An alternative use of skim latex would be the use of creamed skim latex with bitumen in roads.

The observations made by the authors on the experimental roads laid recently confirm the view that the temperature-dependent properties, elastic properties and stripping action due to monsoon rains and traffic are improved considerably.

At the present prices for rubber, the cost (in Ceylon) of a single seal coat increases by 2½%, double seal coat by 3%, asphalt concrete (pre-mix) by 4½%, and sand asphalt carpet by 6% for rubberised bitumen using field latex or creamed skim latex for road work. Other countries have claimed large savings by using rubber in roads, with the life of the road increased by 25–40%. In effect, it is not the initial cost of the road but the cost per square yard per year of its total life including repairs and renewal that decides the economy of road construction. Thus, the additional cost of using rubber in road work is negligible in view of the longer life it gives to the roads.

The natural rubber producing countries are now faced with the problem of obtaining reasonable prices for their rubber. Wide-scale use of it in roads in the natural rubber producing countries themselves would not only help increase rubber consumption but also give them better roads. Bitumen imports could also be reduced considerably.

There seems to be a bright future for the use of rubber in roads in Ceylon. Certainly rubber will play a very important part in all the desired properties of a binder for a road engineer to give more durable, better and cheaper roads.

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DISCUSSION

Chairman: Dr. J-P. Poliniere

Mr. K.M. Philip asked if the authors had tried 'reclaimed rubber' in roads. Mr. Fernando replied this had not been done yet. Mr. R.A. Billett noted the use of anti-foaming ingredients in some trials and enquired if these decreased the surface tension of the bitumen, leading to reduced adhesion and greater stripping. Mr. Fernando said no stripping had been observed. In reply to Mr. Billett's further question, he said the cost of the rubber required was 2% of the cost of the bitumen and aggregate used in the top surface; it was not 2% of the total cost of road construction.

Mr. J.E.A. Slootman asked about safety on roads incorporating rubber, especially when wet. Mr. Fernando said that many countries had reported improved resistance to skidding. He had investigated the index of retained strength under wet conditions (which is the ratio of these values expressed as a percentage of control) by preparing specimens of pre-mix cured in the oven and duplicates cured in water; the tests indicated improved strength even in the wet. Mr.R.W.J. Gouldbourn said his experience in England was that rubber gave a rather bad skid surface. Compounds of nitrogen influenced the adhesion of bitumen with certain types of aggregates. He enquired if latex had been mixed with emulsions of bitumen especially with a view to protecting the sides of canals. Mr. Fernando said most work had been done with penetrating types of bitumen, but emulsions of bitumen had been found very useful on a small scale to patch pot-holes, when it was necessary to have a small supply with good storage properties for occasional use.

Dr. B. Saville drew attention to the temperature of 325°C at which the latex was added to the molten bitumen and asked if there was any hazard from the steam evolved. Mr. Fernando said it was necessary to take precautions, but the workers had been trained to add the latex carefully in very thin streams and small quantities and to allow time for dispersion; anti-foaming agents should be used when necessary. Mr.A.D.T.Gorton asked if the rubber dissolved in the bitumen, what the role of the aldehydic groups was and how this was affected by the use of peroxide-cured rubber or of vulcanised rubber powder. Although the rubber must be dissolved in the bitumen, Mr. Fernando thought that it was broken down to some extent by the heating; therefore, moderate vulcanisation to raise the initial molecular weight was beneficial. According to their theoretical model, the aldehyde groups at intervals along the hydrocarbon chains gave points of anchorage for the bitumen and for cross-links and this resulted in flexibility.

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Compounding Natural Rubber Latex for Improved Performance

M.W. PHILPOTT

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Undergraded natural rubber as it occurs in latex is characterised by exceptionally high strength and elasticity. Improvements in the performance of latex products are therefore to be sought not so much in enhancing their already excellent elastomeric qualities as in conserving these qualities under increasingly severe conditions. The scope for improving manufactured latex products lies chiefly, though not exclusively, in the direction of increasing their resistance to oxidative deterioration.

Although most manufactured latex products are vulcanised, there are important industrial uses for latex in which the vulcanisation process is omitted. Therefore, the ageing resistance not only of vulcanisates but also of unvulcanised latex deposits is discussed here.

A large proportion, possibly as much as one-third, of the latex currently produced is consumed in areas where the latex plays an *adhesive* role. For example, reconstituted leathers, fibreboards, bonded hair, non-woven fabrics, tufted carpets and self-sealing envelopes are all composite manufactures in which rubber latex is the binder or sticking component.

Many of the products in which latex is thus employed as a binding medium are not vulcanised. Consequently natural rubber is often the elastomer of choice because, more than most synthetic materials, it combines the qualities of adhesiveness, flexibility and strength in the unvulcanised state.

Provided service conditions are not too severe many of the articles manufactured from unvulcanised natural latex age satisfactorily. This is largely due to the anti-oxidants naturally present in *Hevea* latex. The protective power of the latter can be readily demonstrated by contrasting the ageing behaviour of ordinary NR latex films with that of films deposited from partially purified (multiple creamed) NR latex, or from synthetic polyisoprene latex *(Figure 1)*.

Under severe ageing conditions, or in the presence of deleterious metals, even whole latex rubber (*i.e.*, rubber containing all the non-rubber constituents originally present in the latex) is liable to degrade rapidly. It is then sometimes necessary or desirable to supplement the natural inhibitors with other protective agents. Selected anti-oxidants of the conventional radical chain-breaking type are often

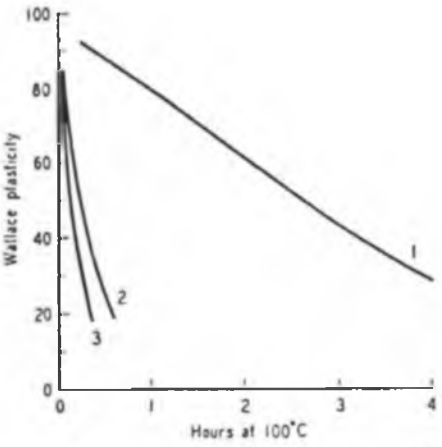


Figure 1. Rate of degradation of latex films in air at 100°C. 1—NR latex; 2—partially purified (four times creamed) NR latex; and 3—synthetic cis-polyisoprene latex.

Why runways should be rubberised

K S Gopalakrishnan

Rubberisation of runways in airports is becoming popular in the West. It is because flexible pavements in airports are showing increased signs of premature failures probably resulting from heavier aircraft, higher tyre pressures, increased traffic, etc. and these defects can be overcome by rubberisation of pavements.

It is very important from the safety angle that early detection of the distresses in the pavements is made and appropriate measures taken so that safe operation of aircraft is ensured. Distresses normally occur in the bituminous pavements owing mainly to surface weathering, fatigue and poor drainage. Differential movement of the sub-base over a period of time also contributes to the distress. The major distresses observed in bituminous pavements are high-temperature permanent deformation, low temperature cracking and load associated fatigue.

As these defects are mainly related to the basic nature of the binder, namely the thermoplastic property of bitumen, for overcoming the defects appropriate treatment of bitumen is required. Many additives have been tried in the past for modifying the thermoplastic nature of bitumen and also for improving its stripping resistance. Most successful among the additives tried for improving the performance of bitumen is the class of compounds called polymers. The types of polymer modifiers tried can be grouped as bloc co-polymers, natural and synthetic rubbers and others (reclaimed rubbers, ground tyre waste, etc.).

Quite small quantities of polymer produce significant changes in the properties of bitumen. The apparent viscosity of bitumen is increased considerably by the incorporation of a few per cent by weight of polymer. Incorporation of polymer into bitumen produces the following changes:

Increases resistance of bitumen to flow at high temperature.

Improves resistance of bitumen to brittleness at lower temperature.

Enhances the binding power of bitumen with aggregates.

Imparts resilience, toughness and elastic nature to bitumen.

The first major experiment with rubberised bitumen was made at Essendon airport in Melbourne in 1954. The success of the experiment gave impetus to further rubberisation of runways

Choice of the polymer to be used for modifying the properties of bitumen as a binder in pavement construction depends on a number of factors such as: easy availability at affordable price; capability of polymer to confer the desired qualities to bitumen at low concentrations and easy incorporation of the polymer into bitumen.

Based on several studies conducted in different parts of the world it has been found that natural as well as synthetic rubber-modified bitumen produces the best results when applied to roads. For application in runway construction also the same result is expected.

Basically, rubberised bitumen consists of a bituminous compound into which rubber in a suitable form and proportion is incorporated, using an appropriate technique. Rubberised bitumen is then used in constructing pavements using conventional road building techniques. Following the incorporation and uniform distribution of rubber, bitumen undergoes radical changes in its properties depending to a large extent on the type and grade of rubber; ratio of rubber to bitumen, and method of incorporation of rubber into bitumen.

It has been clearly established that for maximum effectiveness, the rubber must dissolve in the binder (bitumen).

A systematic study comparing the effects of natural and synthetic rubber modified bitumen for application in airport pavements has not been made so far. However, such a study has been carried out by Smith L.M. for roads and the results of the trials indicated that natural rubber performed better than styrene-butadiene rubber (SBR). Natural rubber is an unsaturated polymer which will be

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degraded on prolonged heating, especially at high temperature. The mechanical properties of degraded rubber are poor. As such, the effect of time and temperature of heating when natural rubber is added to bitumen is very much important.

Considering the great success of the use of natural rubber for modifying bitumen for road surfacing, the same technology was tried also for rubberising runways. The first major attempt with rubberised bitumen was made in January 1954 at Essendon airport on the outskirts of Melbourne. The runway with fine cracks was surface-dressed using bitumen modified by natural rubber. Report on the performance showed convincing advantage of rubberised bitumen in preventing crazing on the surface of the pavement. The success of the trial gave impetus to further rubberisation of runways. Natural rubber was used in forms like latex, powdered rubber and rubber solution. However, in most trials, natural rubber was used as latex. The following are the names of a few airports the runways of which have been rubberised using natural rubber.

Guildford near Perth, Western Australia; Essendon Airport, Melbourne; Salisbury, South Rhodesia, Western Junction Airport, Launceston, Tasmania, Australia; Dunedin's New Momona Airport, New Zealand; and East Sale Airport, Melbourne.

Durability criteria

The US Department of Transportation of the Federal Aviation Administration sponsored a study on the 'Durability criteria for airport pavements' and the report on the study was published in 1994. The report reveals that, of the 45 airports which tried synthetic rubber as bituminous additives, 29 used styrene-buta rubber latex and three use polychloroprene.

The report indicates that the prominent reason for using bi nous additives in U.S airport p ments is to prevent or deter the cracking in the asphalt concrete report also reveals that most bituminous additive users are p with the performance of the als.

In India, though natural and thetic rubber are available in for modifying bitumen for use i port pavements, rubberisation ways is yet to be experiment technique of incorporation of into bitumen is readily availabl the Rubber Board. It is high time the airport authorities turned attention to the cost-effective and formance-oriented technique rubberising airport pavements.

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