RUBBERIZED BITUMEN AND ITS APPLICATIONS

AN ANNOTATED BIBLIOGRAPHY

Compiled by

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ABOUT THE COMPILATION

This bibliography "RUBBERIZED BITUMEN AND ITS APPLICATIONS: AN ANNOTATED BIBLIOGRAPHY" consists of literature on rubberized bitumen, rubberized roads, asphalt pavements, etc. available in the RRII library. The bibliography covers publications from 1931 and this volume is compiled using CDS/ISIS software package developed by UNESCO.

The compilation consists of two sections; the Bibliography Section, arranged alphabetically by the title followed by the author(s), citation, abstract and key words, and the Key Word Index Section, comprising all the key words from the respective article.

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BIBLIOGRAPHY

01- ADOT's use of crumb rubber in asphalt pavements
Way, George B and Arizona, P E
Rubber India, Jan: 1998. 9-11.

The Arizona Department of Transportation (ADOT) has used crumb rubber from ground worn out tires, since the late 1960's to primarily reduce reflective cracking. In 1988, ADOT started using crumb rubber mixed with hot asphalt, commonly referred to as asphalt rubber, as a binder in hot-mix asphalt. Typically, these mixes are either open-graded or gap-graded and from 12.5 mm to 25 mm or 25 mm to 50 mm in thickness respectively. Open-graded mixes generally contain 9 to 10% asphalt rubber binder whereas the gap-graded ones contain generally 7.5 to 8.5%. To date, field performance has been very good with very little reflective cracking. Ground tire rubber from over four million tires in Arizona has been recycled since 1988, in the making of hot-mix asphalt with asphalt rubber.

Key words: Asphalt rubber; Binders; Tyre crumb; Asphalt pavements

02- Application of crumb rubber modifiers (CRM) in asphaltic materials
Rouse, Michael Wm
Meeting of the Rubber Division, American Chemical Society, 1994, Chicago, Illinois.

The paper presents a general overview of crumb rubber modifiers in asphalt used in pavements. The use of rubber and modifiers in asphalt pavements relative to highway traffic and environmental condition, crumb rubber modifiers and CRM Technology, testing methods presently used for asphalt composites and field trials and effect of the Intermodal Surface Transportation Efficiency Act (ISTEA) mandates on scrap tyre availability in relationship to the implementation of the Federal Highway Administration (FHWA) superpave™ binder mixture specifications for determining road pavement performances. The use of scrap tyre rubber in highway applications is rapidly gaining attention and can emerge as a viable market for the rubber waste stream and provide improvement to roads.

Key words: Crumb rubber modifier; Asphalt; Pavement performance

03- The application of latex to highway and floor surfacing
Wren, W G
Journal of R.R.I.M Communication, No. 245: 1940, pp.1-15.

Latex-cement mixtures hold promise in Malaysia as a flooring material. The paper gives an outline of (1) microscopic investigations of these mixtures whereby information can be obtained on the nature of the crystalline and amorphous products formed by the interaction of cement and latex and the manner in which these are dispersed in the matrix, (2) effects of different stabilizers, which are essential to these mixtures, on the hydration of the cement, by means of the chemical determination of free and combined water, (3) principles of compounding, whereby variation may be produced in the physical properties of the resultant products, (4) type of apparatus most suitable for making these mixtures, (5) physical tests evolved in association with building research stations, (6) utilization of these tests in order to make a comparison of the properties of latex-cement mixtures with other flooring materials and finally a summary of other uses to which latex-cement materials may be put.

Key words: Latex cement mixtures; Flooring materials; Hydration

04- Asphalt rubber mixtures in road building
Plaizier, J A
Transactions, IRI, 15(1): 1939. 23-50.

Addition of small quantities of rubber to bitumen changes the properties of asphalt materials considerably. Rubber is added as vulcanized powder, latex or rubber as solution in liquid hydrocarbon. In this study the use of unvulcanized rubber as dry rubber in finely divided form was chosen for investigation. Raw rubber could be distributed homogeneously in the melted bitumen without difficulty. Incorporation of unvulcanized rubber powder to bitumen may be a good solution but if the temperature of dissolution is very high, or if prolonged heating is practised binder properties of bitumen-rubber mixture will deteriorate and road performance will be poor. The application of bitumen- rubber powder composites for road construction revealed that many favourable changes of the properties of bitumen were imparted by the addition of rubber when mixed at optimum temperature. Use of above mixtures are promising in other areas were repair work, as joint fillers, wood paving work as an adhesive etc. Addition of latex to the bitumen is difficult due to the foaming problem and later studies were successful in perfecting the technology and reducing the problems of fretting and destabilisation. Hence it is advisable that for small capacity utilization of rubberized bitumen, latex can be used where as for large capacity application NR powder with suitable machinery for mixing is the technically feasible method.

Key words: Asphalt rubber; Bitumen-rubber powder mixtures; Road construction; Asphalt-mastic carpets

05- Asphalt-rubber systems in road rehabilitation
Joe Cano, P E
Rubber India, 49(10): 1997. 9-13.

Method of preparation, application processes and advantages of asphalt-rubber are described. Applications of asphalt-cement as Stress absorbing membrane (SAM), Stress absorbing membrane interlayer (SAMI), binder for asphalt concrete open-graded friction courses (OGFC) and for gap-graded mixes are indicated. Use of asphalt-rubber concrete is strongly recommended to optimize the performance and serviceable life of asphalt concrete pavements in three layer and two layer systems.

Key words: Asphalt rubber concrete; Stress absorbing membranes; Road rehabilitation

06- Australian experience in the use of rubberized bitumen
Billet,R A
Rubber Developments, 18(4): 1965. 153-156.

Rubberized bitumen possesses certain physical and mechanical properties like higher softening point, lower brittle point, lower penetration, better toughness and tenacity, higher ductility and elasticity which distinguishes it from normal bitumen or bitumen modified by other additives. The use of rubber appears to be of advantage for pavements but rubberized bitumen is regarded as speciality material. In New Zealand, another area which has had considerable success with rubberized bitumen is Revertex. Snowy mountain roads and accesses which experiences temperature ranges from 85°F to 100°F are good illustration of the versatility of rubber bitumen.

Key words: Rubberized bitumen; Surface dressings; Australia

07- Bituminous thermoplastic elastomer
Roy, T K; Mallik, A and Mukhopadhyay, D
Proceedings of the International Conference on Rubber, 12-14 December 1997, Calcutta, Volume II, pp.152-155.

Elastomeric bitumen results from oxyconversion, and does not possess true elasticity. It requires modification by polymers for having reversible strain upon large deformation. Combination of thermoplastic elastomer with bitumen results in inherent resistance to permanent deformation. Polymer - bitumen gel resulted from phase inversion of blend manifests the desired properties for improving bitumen to the level of useful applications including against large deformations. It also

serves the purpose of having low cost thermoplastic elastomer based on bitumen.

Key words: Deformation; Polymer bitumen gel; Bituminous thermoplastic elastomer

08- Case histories of modified bitumen membranes
Darling, B; Fishman, H B; Goodwillie, J; Winchell, K and Wooten, J
Meeting of the Rubber Division, American Chemical Society, 29 May-1 June 1990, Las Vegas, Nevada.

Polymer modified bituminous membranes are durable and strong and are resistant to environmental factors such as sunlight, rain and wind. They find use as roofing membranes. Composition and performance attributes of modified bituminous membranes are described in the paper. Polymer modifiers tried include atactic polypropylene (ATP), styrene butadiene styrene (SBS) and combinations of APP with SBS and SBS with styrene ethylene butadiene styrene (SEBS) rubber. It is reported from field experience that modified bituminous membranes provide excellent performance when selection, design, workmanship and maintenance are proper.

Key words: Bitumen membrane roofing; Polymer modifiers; Tensile strength

09- A cheaper rubber-bitumen using latex
Thompson, P D
Rubber Developments, 14(2): 1961. 61-64.

Natural rubber in the form of latex added to bitumen results in great improvement in properties and is the cheapest form of rubber additive. Foaming of the bitumen was a problem, which could be reduced by using antifoaming agents. At temperatures of 140°C or below, the deterioration of rubber is very gradual. Thus if the blending temperature of latex and bitumen is maintained below 120-130°C rubber remains in its most effective form. The effective rubber content practised is 2% on the mass of base bitumen. Details of the process, equipment and procedures for the manufactures of rubberized bitumen with latex is given and this is patented by Natural Rubber Producers Research Association.

Key words: Rubberized bitumen; Binders; Effective rubber content

10- Correlation between laboratory and road rubber wear tests
Krishnan, V; Ramakrishnan, R and Donovan, J A
Rubber Chemistry and Technology, 68(5): 1995. 804-814.

The wear resistance ranking of three rubber compounds A, G and K measured in the laboratory at medium to high slip on sharp silicon carbide (SiC) grinding wheels was similar to that determined by road tests at Pecos, Texas. The wear resistance ranking of the three compounds changed on blunt alumina grinding wheels compared to wear resistance rankings on sharp SiC grinding wheels. The change was most probably due to a change of mechanism from mainly cutting on sharp surfaces to predominantly fatigue on blunt surfaces. For these three compounds a change in the ambient temperature from 23 to 75°C during laboratory testing had no effect on the wear resistance ranking. The wear of the rubber compounds on the abrasive grinding wheels and during road tests followed Zapp's relation in which the wear is proportional to the ratio of dynamic modulus to rupture energy.

Key words: Wear resistance; Road test; Rubber compounds

11- Development of flexible pavement design method for roads and parking area of LPG plant complexes
Arya, I R; Jain, P K and Vermani, N D
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. III.63-III. 76.

The paper gives details of development of design procedure for flexible pavement catering to heavy duty LPG tankers. The suggested design procedure is applicable to roads and parking areas of LPG separation plants and LPG bottling plants. It is reported that roads and parking areas of LPG plant complexes, which are designed, based on conventional method develop premature distress. The specifications of various flexible pavement component layers are also suggested. Thick bituminous surfacings are recommended in view of high tyre pressure and heavier loads using a harder grade bitumen or polymer modified bitumen. The CBR and pavement thickness relationship curve has been developed to design flexible pavement of roads and parking area of various LPG plant complexes for 37.2 tonne LPG tanker.

Key words: Flexible pavement design; LPG plant complex; Asphalt surfacings

12- Dynamic shear rheological properties of polymer-modified asphalt binders
Newman, J Kent
Journal of Elastomers and Plastics, 30(3): 1998. 245-263.

Rheological characteristics were measured using DSR (dynamic shear rheometry) for two asphalts (A and B, conventional AC-20 viscosity grades) from different crude sources modified with 5% SBR, 5.5% LDPE, 5% SB and a crumb rubber (5%)/SBS (2%) mixture. Master curves were constructed from DSR frequency sweeps at temperatures ranging from -20 to 80°C. The master curves were constructed using the method of reduced variables, similar to the WLF equation and described all binders well except for the A-LDPE binder. Polymer network formation is suggested in the B-SB binders based on the tendency of the tan d master curve to exhibit a local minimum and the lack of observable phase separated polymer domains within the resolution of the fluorescence microscope. The morphology of the SBR polymer in the asphalt was observed to be dependent on the specific asphalt source. Initiation of polymer network formation is postulated for B-SBR based on the behaviour of tan d and the asphalt swollen phase separated polymer domains as observed by fluorescence reflection microscopy. For B-LDPE, A-CR + SBS, and B-CR + SBS the response of tan d suggests networking but is postulated to be a contribution of the clearly observable phase separated polymer domains. The overall response of B-LDPE and the CR + SBS binders are a sum of the contributions of each phase with the polymer acting more as a filler, dominating the rheological response at intermediate frequencies.

Key words: Polymer modifiers; Rheology; Compatibility; Complex modulus; Dynamic shear rheometry; Asphalt binders

13- Economics of rubberised road
Haridasan, V and Gopalakrishnan, K S
Rubber News, May:1980. 37-38.

Development of roads in general and that of rubberized road in particular is briefly discussed. Technique of rubberization of bitumen is presented. Rubberized roads are more durable compared to neat bitumen roads and the service life increases by 50% or more. Moreover, the surface bears heavy traffic, provides skid resistance and withstands both cold and hot weather conditions. The additional cost for seal coats using 2% rubber in bitumen is 12-15% and that for rolled asphalt with 4% rubber 16%. Some of the other uses of rubberized bitumen are also mentioned.

Key words: Rubberization; Bituminous pavements

14- The effect of network formation on the rheological properties of SBR modified asphalt binders
Yong-Joon Lee; Lawrence; France, M and Hawley, Martin C
Rubber India, 49 (December): 1997. 17-23.

Styrene-butadiene rubber (SBR) was used to modify asphalt binders. The rheological and thermo-mechanical properties of the binders were investigated using rotational viscometry, dynamic shear rheometry and thermal mechanical analysis. The optimum SBR content and mixing procedure were determined based on the rheological properties of the asphalt/SBR blends. Addition of 3-5% (w/w) SBR resulted in enhanced high temperature performance of the binders. The SBR progressed from a dispersed polymer to local networks to a global network with increasing SBR content. This phenomenon was exhibited in rheological properties such as complex modulus and melt viscosity. It was also verified visually by using a laser scanning confocal microscope. Because of this network formation, the binders showed a large increase in the complex modulus, which indicates resistance to rutting.

Key words: Asphalt binders; Rheology; Polymer network

15- Effect of polymer modified binder on durability of asphalt concrete mixes
Sreedhar, M and Mazumdar, Mayajit
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I.135-I. 138.

The results of modifying asphalt by ethyl vinyl acetate (EVA) with respect to durability against wetting at ambient and elevated temperatures, freezing and freeze-thaw cycles are described. EVA increases the durability against wetting. However EVA does not significantly improve the stability of bitumen during freezing and freeze-thaw cycles. Increasing the polymer content above 2.5% on the weight of bitumen does not have much improvement over the results obtained at 2.5%.

Key words: Polymer modified bitumen; Asphalt concrete; Ethylene vinyl acetate

16- The Elasticity of rubber-bitumen binders for use in roads
De Merlier, Jacqueline; Leveque, J and Curchod, J
Rubber Chemistry and Technology, 37(2):1964. 457-476.

To effect maximum improvement in the elasticity of elastomer-bituminous binders, an elastomer must (1) swell in oils and

disperse homogeneously within the binder (2) have a molecular weight at least equal to 6,00,000 and higher upto 9,00,000 (3) possess a linear structure and (4) be present in the binder in an amount at least equal to 10%. Natural rubber and synthetic polyisoprene may fulfil these conditions, but the latter appears to be less effective. Eventhough natural rubber appears to offer the highest elastic recoveries in the finished blend, it is probable that its more rapid degradation in the course of time will ultimately reduce these values below those maintained by certain synthetic rubbers, if not suitably protected.

Key words: Rubber bitumen binders; Elasticity; Rubberized roads

17- Enormous potential for road rubberisation
Gopalakrishnan, K S
Indian Rubber and Plastics Age, 35(5):1999. 7-9.

Possibility of increasing consumption of natural rubber (NR) for a non-conventional application is discussed. It is felt that the present situation of excess NR glutting the market and the declining trend in price can be rectified if NR is extensively used for road rubberization. Use of bitumen premixed with NR latex at the refinery level is recommended for ensuring uniformity in properties for the rubberized bitumen and for large-scale road rubberization programmes.

Key words: Rubberized bitumen; Road rubberization; India

18- Evaluation of rubberised limestone filler in asphalt paving mixtures
Bissada, Amir F and Anani, Ali A
Rubber Chemistry and Technology, 57(1): 1984. 1-18.

This paper presents the results of initial evaluation of rubberized limestone filler in asphalt paving mixtures and deals with (1) the physico-chemical properties of rubberized limestone filler, (2) effect of the rubberized filler on the physical properties of the asphalt fines binder system, (3) effect of rubberized filler on the Marshall design of asphalt paving mixtures and on tensile strength properties and (4) effect of rubberized filler on resistance of the mix to moisture damage. The study showed that asphalt cements can be modified by adding carboxylated butadiene rubber chemically bound to calcium carbonate to give a wide range of products of different compositions and consistencies. These rubberized fillers can disperse more rapidly in the hot asphalt.

Key words: Rubberized filler; Asphalt pavements; Asphalt binders

19- Experiences of Malanadu Development Society in rubberization of roads
Mathew, Vadakkemuriyil
Workshop on Rubberized Roads, 17 January 1998, Rubber Research Institute of India, Kottayam.

The paper highlights the experience of the Malanadu Development Society in the rubberization of roads in the Idukki, Kottayam and Pathanamthitta districts of Kerala state. Bitumen rubberized by incorporating 2% (w/w) of natural rubber and specially preserved field latex was used for the work. Short and comparatively long stretches of roads ranging in length from 0.2 km to 12 km were rubberized. The paper also describes the process of rubberization, evaluation of the rubberized roads and economics of process.

Key words: Rubberized bitumen; Road rubberization; Kerala

20- Field experiments with powdered rubber in bituminous road construction
Shelburne, T E and Sheppe, R L
Rubber Age, 66(5): 1950. 531-538.

Early results of the field experiments with powdered rubber by Virginia Department of Highway in 1949 are discussed. Powdered natural rubber (NR), reclaimed powdered rubber and cut black asphalt and NR powder were added to bitumen and used for construction of roads. All the constructions were carried out using machines like Adnun Paver, Barber Greemepaver and Power Distributor. Identical sectors were also constructed without rubber to study the performances. Visual observation, road roughness measurement and skid tests revealed that it is feasible to incorporate small percentage of NR or reclaim powder rubber into asphalt mixes. However, several years will be required to decide the differences in performance of different sections and pavements with and without rubber.

Key words: Rubberized bitumen; Rubberized road; Rubber asphalt; Virginia

21- Full-scale road experiments using rubberized surfacing materials
Thompson, P D and Szatkowski, W S
Road Research Laboratory Report LR 370. 1971, pp. 1-42.

Addition of rubber to mastic asphalt prevents or markedly reduces cracking on bituminous surfacing laid over joints or cracks in concrete pavement. The best results have been obtained when the high-

est binder content consistent with resistance to deformation under traffic has been used. Addition of 4% of natural rubber to the binder of rolled asphalt considerably reduced the number and severity of cracks in the surfacing material laid over joints and cracks. A 50 % increase in life of bitumen macadam was obtained in one experiment when 4% of rubber was added to the binder. A second experiment with 2.5% of rubber was however inconclusive. A limited full-scale experiment has also suggested that the life of dense tar surfacing may be increased by the addition of rubber powder to the binder. A change in traffic distribution over the site has unfortunately made direct comparison of the experimental and control impossible. No significant advantage has been gained from the use of rubber or methacrylate-graft-rubber in tar surface dressing. A considerable reduction in the tendency of bitumen surface dressings to 'fat up' in hot weather under heavy traffic was shown when rubber has been blended with the binder. An increased initial holding power of the binders containing rubber was observed. Rubberized bitumen binders has shown no advantage on lightly-trafficked roads.

Key words: Rubberized bitumen; Surface dressings; Binders

22- A general system describing the visco-elastic properties of bitumens and its relation to routine test data
Van Der Poel, C
Journal of Applied Chemistry, May: 1954. 221-235.

After dynamic and static experiments on the mechanical behaviour of bitumens an attempt was made to incorporate all the essential factors into a simple system. This was found to be possible in the form of a nomograph, by means of which the deformation of bitumens can be calculated as a function of stress, time and temperature. Origin or method of manufacture proved to be of less importance than hardness and rheological type. For correlation with standard test-methods, the ring-and-ball temperature and the penetration index were found to be suitable parameters. The nomograph enables the average behaviour of a given grade to be calculated with an accuracy sufficient for engineering purposes. Another feature of the nomograph is that it creates the possibility of giving an interpretation of other routine tests. Both penetration and Fraas breaking test are discussed, with examples.

Key words: Bitumen; Viscoelasticity; Stiffness modulus

23- Improvement of asphalt by addition of rubber and latex
Esser, H
Rubber Chemistry and Technology, 37(4): 1964. 1049-1063.

This article reviews the improvement of asphalt by addition of rubber and latex. Brief description of the test methods for rubberized bitumen is given. Advantages of the use of rubberized bitumen, effective mechanism of rubber in bitumens, effect of the type and physical form of the rubber and methods of incorporation into bitumen are described.

Key words: Asphalt; Rubberized bitumen; Road pavements

24- The influence of rubber on the brittleness and viscosity of bituminous materials
Mason, P; Thrower, E N and Smith, L M
Journal of Applied Chemistry, Aug:1957. 451-459.

Brittleness and resistance to deformation of rubber bitumens and of sand asphalts made with rubber/bitumens have been investigated and compared with results obtained with similar materials not containing rubber. The brittleness tests were carried out by subjecting the materials to an imposed rate of tensile strain at 0°C, the stress and strain being measured throughout the test. The deformation characteristics were measured in a wide-gap concentric-cylinder apparatus, the tests on bitumens being conducted at 25°C and those on sand asphalts at 45°C. The results showed that the incorporation of rubber produces a material which displays, under the test conditions used, a marked increase in resistance to deformation, simultaneously with a reduced brittleness at low temperatures. Although some free rubber is clearly present as a separate phase, the modification of the normal bitumen properties is due at least in part to dispersion of the rubber on a molecular scale.

Key words: Rubberized bitumen; Brittleness; Viscosity

25- An insight into rubberised roads
Gopalakrishnan, K S
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I. 116-I. 125.

The paper outlines changes in the techniques of road building consequent to the introduction of automobiles and heavy vehicles in the early twentieth century. The history of the development of rubberized roads with the main objectives of increasing the service life and improving the performance is discussed. Information is presented on the technique of rubberization and the different types of rubbers that have been tried for improving the performance of bitumen. Details of the laboratory trials used for assuring the performance of rubber modified

bitumen are presented. It is reported that compared to styrene butadiene rubber (SBR), natural rubber (NR) imparted better properties to bitumen. Of the different types of NR tried, NR latex showed the most promising results. Effect of storage of rubberized bitumen under different temperatures is explained. Results of full scale paving experiments of rubberized bitumen are presented. It is reported that proper incorporations of adequate quantity of NR in appropriated forms into bitumen and use of such NR modified bitumen in pavings led to savings with safety. It is also reported that extra cost for rubberization may come to 15-20% of the cost of building bituminous roads.

Key words: Rubberized bitumen; Rubberized asphalt; Road rubberization; India

26- Laboratory performance of ASR modified asphalt binders

Dutta, Utpal; Ibadat, Imran; Klempner, Daniel and Keshawarz, Mohammad S

Journal of Elastomers and Plastics, 29(4):1997. 326-343.

Automobiles, when no longer useful, are flattened and shipped to automotive shredder facility. While shredded to recover the ferrous and non-ferrous metals for recycling, a huge quantity of non-metallic residue, commonly called automotive shredder residue (ASR), is generated. Since ASR mostly contains plastic and rubber related materials, and addition of plastic and scrap rubber from waste tires as a road material has been proven to be effective in solving existing pavement related problems, attempts were made to examine the feasibility of ASR as a road material additive. As a part of this effort, compatibility and mechanical properties of ASR modified asphalt were studied. The asphalt was mixed with a requisite amount of ASR for one hour at 375°F. Glass transition temperature (T_g) and microstructure of ASR, asphalt and ASR modified asphalt were examined to determine compatibility. Mechanical properties of ASR modified asphalt were studied by dynamic mechanical analysis. The photomicrographs and T_g of ASR modified asphalt demonstrated some compatibility between ASR and asphalt. Dynamic mechanical analysis indicated that rutting and ageing properties of asphalt could improve with the addition of ASR

Key words: Asphalt; ASR; Automotive shredder residue; Pavement performance; Aged binder

27- Long and short-term stability of straight and polymer modified asphalts
Collins, Jim H and Bouldin, Mark G
Meeting of the Rubber Division, American Chemical Society, 8-11 October 1991, Detroit, Michigan.

Both short and long-term ageing can have a significant influence on the performance of hot mix asphalt (HMA) pavements. This is true for polymer modified asphalts as well as for conventional asphalt cements (AC's). The latter can undergo significant age hardening during storage, mixing and in the field. This long-term ageing can be dramatic and lead to premature pavement failure. The effects of ageing can be exacerbated in the case of permeable pavements or in regions with extreme climatic conditions. Polymer modification is a viable route in overcoming these potential deficiencies by providing binders with well balanced property sets. This is generally achieved by modifying soft, compatible asphalt. Improvements are noted in both the binder's resistance to permanent deformation and its ability to mitigate thermal and fatigue cracking. However, unsaturated polymers are susceptible to thermal and oxidative degradation. Thus, it is imperative to avoid prolonged storage and excessive temperatures. This is especially important in hot mix plant operations. Gel permeation chromatography (GPC) and dynamic mechanical analysis are found to be excellent tools in evaluating the stability of modified asphalts. Likewise, rolling thin film oven (RTFO) ageing can be useful in indicating potentially unstable polymer/asphalt blends. Different asphalt chemistries can lead to varying degrees of polymer stability. In general, RTFO ageing is severe than actual field operations. With regard to long-term ageing the findings appear to support the notion that California tilt oven durability (CATOD) ageing is a reasonable simulation for field ageing in hot desert-like climates. In more moderate climates, only less than 20% polymer degradation occurs even after three to four years in the field. Improved thermal and oxidative stability can be achieved by modifying asphalts with saturated polymers. However, good handling practices are still imperative to preclude the consequences of serious asphalt age hardening. Rheological characterization, GPC and field data demonstrate superior performance of these blends even in severe climates.

Key words: Polymer modifiers; Asphalt age hardening; GPC

28- Low temperature dynamic properties of bitumin-rubber mixtures
Shim-Ton, J; Kennedy, K A; Piggott, M R and Woodhams, R T
Rubber Chemistry and Technology, 53(1): 1980. 88-106.

Influence of four commercial elastomeric materials, namely (1) powdered vulcanized tire reclaim rubber, (2) precipitated waste SBR latex from an effluent recovery system, (3) liquid carboxy-terminated butadiene acrylonitrile polymer (Hycar CTBN from Goodrich) and (4) liquid polybutadiene with terminal allylic bromine substituents (Polysar RTV), on the low temperature dynamic properties of an asphalt binder used in road paving was studied using a Rheovibron Viscoelastometer. The results indicate that liquid polybutadiene is the most efficient low temperature flexibilizer. Addition of rubber markedly reduces the temperature susceptibility. The thickening behaviour of bitumen-CTBN rubber mixtures after the addition of calcium chloride was also studied. The implications of the low temperature dynamic transitions, viscosity behaviour, penetration values and thickening behaviour of bitumen/rubber mixture with respect to road performance are discussed.

Key words: Rubberized bitumen; Dynamic property; Road performance

29 - Modification of asphalt by block polymers of butadiene and styrene
Kraus, Gerard
Rubber Chemistry and Technology, 55(5): 1982. 1389-1402.

Rubberized asphalt composition were prepared using two types of styrene/butadiene block copolymers, namely (1) 300000 weight average molecular weight containing 30% styrene and (2) 130000 weight average molecular weight containing 40% styrene. The basic morphological and mechanical properties of these were studied. Addition of 10-14% of these polymers to asphalt results in lower penetration values, greatly refused flow above noon temperature, increased softening temperature and superior low temperature flexibility. The blends are characterized by a unique morphology in which the block polymer, swollen with the lower molecular weight constituents of the asphalt, forms a continuous lacework in a bituminous phase enriched with asphaltenes. The polymer rich phase consists of two microphases derived from the block copolymer domain structure. This multiphase morphology accounts for the important features of their mechanical behaviour.

Key words: Rubberized ageing; Asphalt; Styrene butadiene block co polymers

30- Modified bitumens containing thermoplastic polymers
Piazza, S; Arcozzi, A and Verga, C.
Rubber Chemistry and Technology, 53(4): 1980. 994-1005.

Bitumens from different sources were modified by blending, at 200°C, with thermoplastic polymers SBS styrene butadiene block co polymer (Europrene AG) and atactic polypropylene, at different ratios and mixing times. Penetration grades, softening points, Frass breaking points, low temperature flexibility tests, tensile tests and creep torsion tests were carried out. Optical micrographs of some blends were also studied. The results indicate that the mechanical and viscoelastic behaviour of bitumen, both at high and low temperature, was noticeably improved by the addition of these polymers. Characteristics of bitumen-polymer blends depend heavily upon bitumen quality and mixing process.

Key words: Thermoplastic polymers; Bitumen; Viscosity

31- Natural rubber as an additive to road materials
Thompson, P D
Rubber Journal, 149(5): 1967. 135-138.

The article reports the research findings of the joint programme of the Natural Rubber Producers Research Association and Road Research Laboratory of UK. Extensive investigations in the laboratory and on full scale road experiments established the advantages of rubberized road materials for certain applications. The different composites for road work like surface dressings, rolled asphalt, macadam and mastic asphalt and their improvement in properties by the addition of natural rubber, which acts solely by modifying the properties of binder, are illustrated. In the surface dressings composites, rubber prevents or reduces the tendency of binder to fat up during hot weather. In rolled asphalt, resistance to cracking can be improved. Life of bitumen macadam can be increased and mastic asphalt is made more resistant to cracking by rubberization. Brief description of the construction process, with photographs, to illustrate why rubber is now accepted as an addition for road surfacing is given.

Key words: Asphalt; Surface dressings; Rubberized road materials

32- Natural rubber for the Forth Bridge
Smee, A R and Thompson, P D
Rubber Developments, 17(3): 1964. 71-73.

Forth Bridge in the United Kingdom, opened on September 4, 1964, is the largest suspension bridge in the world outside USA, with a total length of 6980 ft. A specially designed rubberized bituminous membrane of high durability and light weight, which could withstand weather conditions without crack formation and deterioration, was laid between the deck and final asphalt surfacings. Pulvatex (unvulcanized

rubber powder), 5% by weight of bitumen, was used as the bitumen modifier. The thickness of the membrane was 1½ inch and the load on the bridge could be reduced remarkably by using the thin membrane.

Keywords: Rubberized bitumen; Asphalt surfacings; Forth Bridge

33- Natural rubber in asphalt pavements
Mullins, L
NR Technology, 7: 1971. 1-17.

Although numerous pavement surfacings containing rubber (synthetic and natural) have been laid in many countries, the amount of really reliable evidence produced to show quantitative comparison between the performance of rubberized and non rubberized materials has been relatively small. Both outstanding and disappointing results were found in the field trials. Much evidences are obtained from the change of properties of asphalt pavement materials by the addition of rubber, which may be beneficial to improve the performances. The properties like susceptibility of asphalt to change in temperatures are reduced considerably. Softening point increased, brittleness at low temperature reduced, impact resistance and strength of the asphalt is increased. The details of the laboratory and field trials, method of incorporation of rubber, variation in properties with blending time, storage time, design of pavements for different matrix are given. The conclusion is that evidence to the merit of addition of rubber to asphalt materials can only come from road experiments. Lack of conclusive evidence is mainly due to the extremely difficult and complex control factors related with road experiments. On examination of the numerous rubberized roads, large number of countries agrees with this finding. Recent experiments conducted by NRPRA and Road Research Laboratory were designed to evolve meaningful conclusions and particular attention given to method of addition of rubber and design of type of road surfacings for different application with distinct advantages.

Key words: Natural rubber; Asphalt pavements; Binders

34- Natural rubber powder in roads: Tests and studies
Fisher, Harry K
Rubber Developments, 2(4):1949. 10-12.

Extensive studies were conducted in the use of natural rubber (NR) powder in asphalt paving. Initial results indicated that rubber added to asphalt paving mixtures will lower maintenance cost, increase elasticity of the pavement, raise coefficient of friction, protect the pavement at high and low temperatures and extend the life of the pavement. Observation during the field tests showed that a decrease in the pen-

etration of asphalt upon the addition of rubber powder depends on several factors like the grade and the source of the bitumen used and the percentage of rubber powder added. The changing consistency of the paving material is not great enough to be visibly seen in batch to batch mixing operations. Field trials are to be extensively carried before giving a final recommendation in the optimum percentage of NR powder and developments of machinery for quick and economical method of mixing of asphalt with rubberization to be continued.

Key words: Rubber asphalt; Asphalt pavements; USA

35- Performance based bitumen specification - the product of tripartite working group
Arya, I R; Jain, P K; Tyagi, B R and Himmat Singh
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I.57-I.69.

The paper briefly describes the principal features of performance- based specifications drafted by tripartite working group of scientists from Indian Institute of Petroleum (IIP), Central Road Research Institute(CRRI) and Indian Oil Corporation (IOC). Relationship between physico-chemical properties of bituminous binders and key pavement performance factors related to bitumen characteristics viz., thermal cracking, fatigue cracking, ageing, moisture sensitivity and deformation, besides aspects of constructability and safety are detailed. The paper also gives a brief review of SHRP performance-based specification, ODOT performance-based specification and bitumen qualagon by shell. The proposed draft performance-based specifications consist of two sets of tests. One covers nine tests and limits for quality control, the tests being specific gravity (for weight/volume conversion), water content, viscosity at 60°C (pavement deformation at high temperature), viscosity at 135°C (setting of mix and constructability), penetration (to check grade), softening point (to check bleeding), solubility in TCE (to check purity) and test on residue from thin film oven test (to check excessive age hardening). The other contains nine tests for initial qualification of crude. For study of moisture sensitivity, retained compressive strength tests have been incorporated. Fraas breaking point test has been included to check effect of wax and low temperature cracking. The measurement of asphaltene content and asphaltene flocculation ratio are recommended to control setting of mix as well as early cracking of surfacings.

Key words: Bitumen specification; Binders; Pavement performance

36- Performance of polymer modified bituminous premix carpet surfacing on Joshimath-Badrinath road in snow bound area
Jain, P K and Arya, I R
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I.83-I.95.

Polymer modified bituminous binders are known to (a) reduce thermal cracking at low temperature (b) better fatigue resistance (c) reduce rutting associated with high temperature and heavy loads and have the potential to the cost effective. The paper give details of field experiment conducted using conventional 80/100 bitumen, SBS modified bitumen and EVA modified bitumen on snow bound Joshimath-Badrinath road with over 1000 commercial vehicles in peak season. The road stretch is located at 2500m height from sea level and gets covered with heavy snow in winter. Details of blending, laying and performance of various test sections are discussed besides cost benefit analysis of using polymer modified road binders in snow bound climate. Binder specifications for snow bound climatic conditions are also described. On the basis of findings it can be concluded that life of premix carpet may be enhanced about 1.5 times resulting about 20% savings in road maintenance cost as a result of reduced frequency of overlays.

Key words : Polymer modified bitumen; Pavement performance; India

37- Performance of scrap tire rubber modified asphalt paving mixes
Coomarasamy, A and Hesp, S A M
Meeting of the Rubber Division, American Chemical Society, 21- 24 October 1997, Cleveland, Ohio.

Although scrap tire rubber has been used for asphalt modification for several years, the most effective way of utilizing scrap tire rubber for this application has not been thoroughly investigated. There is a need to determine the most suitable types (including the particle size) of tire crumb rubber, which would give the best performance. Tire rubber modified asphalt binders were prepared by mixing (under moderate shear) 30 and 80 mesh crumb rubber and partially devulcanized tire rubber, with two grades of paving asphalts. High shear mixing was used only to prepare a sample containing a fine dispersion of crumb rubber particles of 0.4 microns, from a 30 mesh crumb rubber and asphalt. Low temperature fracture toughness testing was performed using a new method based on ASTM E 399-90 procedure, at -20°C. SHRP binder tests, for high-temperature and low-temperature performance rating, were also performed. Rutting tests were conducted on a wheel tracking machine, at 60°C and the resistance to low temperature cracking was determined

by thermal restrained specimen test (TSRST). The results reveal that the high temperature performance of modified asphalt systems containing fine crumb rubber particles is significantly better when compared to the performance of the other samples. Moderate improvements in low temperature thermal cracking resistance were also achieved with these systems.

Key words: Asphalt binders; Fire crumb rubber; Rutting test

38- Physical and rheological characteristics of liquid natural rubber modified bitumen
Radhakrishnan Nair, N; Mathew, N M; Thomas, Sabu; Chatterjee, Prabha and Siddiqui, M A
Journal of Applied Polymer Science, 68(1): 1998. 53-61.

Polymer modification of commercially available bitumen has been attempted by the incorporation of liquid natural rubber (LNR) of medium viscosity. Both soft and blown bitumens have been studied. Physical and rheological characteristics of the samples were investigated. Improvement in physical properties such as shear strength and ductitlity in the case of blown bitumen and resistance to flow in the case of soft bitumen were observed. It was also found that as a result of addition of LNR, the activation energy of flow increases in the case of soft bitumen and decreases in blown bitumen.

Key words: Liquid natural rubber; Bitumen; Rheology; Polymer modification

39- Physico-chemical aspects of asphalt modification for road construction
Defoor, F
Meeting of the Rubber Division, American Chemical Society, 29 May – 1 June 1990, Las Vegas, Nevada.

Owing to unsatisfactory binder properties, performance of asphalt roads is adversely affected which necessitates the use of improved or modified binders. An attempt has been made to evaluate the different types of polymeric materials currently used as road bitumen modifiers. The objective of the study was to obtain insight, control and experience in the mechanism of improvement of compatibility of the polymer-binder mixtures developed. LPDE, EVA, EPDM, SBS and blends of these polymeric substances were evaluated. In all cases studied, the polymeric additives were found to produce better quality materials compared to ordinary bitumen.

Key words: Asphalt modifiers; Road construction; Blends

40- Polychloroprene-modified aqueous asphalt emulsion: Use in roofs and roads
Newaz, S S and Matner, M
Meeting of the Rubber Division, American Chemical Society, 29 May –1 June 1990, Las Vegas, Nevada.

Polymer modified asphaltic materials are used for roof covering as well as for providing better performance to asphalt roads. Polychloroprene latex was mixed with aqueous asphalt and the resulting elastic materials was found to be good for the above applications. Factors such as choice of asphalt and latex, choice of thickener and surfactant, choice of coagulant, choice of application techniques and high and low temperature behaviour of asphalt latex coagulation matrix were studied. Chloroprene modified asphalt gave better overall performance for the applications tried.

Key words: Asphalt latex; Polychloroprene latex; Roofing; Road repairs

41- Polyethylene- modified bitumen for paving applications
Jew, P; Shimizu, J A; Svazic, M and Woodhams, R T
Journal of Applied Polymer Science, 31(8):1986. 2685-2704.

In cold regions, transverse cracking of asphaltic paving materials is a serious problem. In this investigation, low temperature stress-strain properties of bitumen containing dispersed polyethylene were measured over the temperature range from -40 to 0°C and compared with unmodified bitumen in an attempt to develop a tougher, more ductile crack-resistant binder for paving materials. Several grades of polyethylene were individually dispersed in liquid, heated bitumen to produce therein colloidal suspensions of polyethylene. The viscosities of these suspensions were determined at various temperatures and concentrations for each grade of polyethylene. Despite rather large differences in composition, molecular weight and crystallinity of the polyethylenes, the differences in viscosity at the same concentration were relatively minor. However, the viscosity was very sensitive to the polyethylene concentration and the mixture became difficult to process at concentrations greater than 10% by weight. These hot mixtures were then cast into rectangular beams for flexural testing at temperatures below 0°C. Near the optimum polyethylene concentration, the bitumen mixture possessed increased flexural strength, increased flexural modulus, increased elongation and increased fracture energy at temperatures near -30°C. In one example the energy to fracture was increased ninefold compared to a standard 80/100 pen. bitumen control at -20°C. Mix design results are presented for a typical aggregate and compared with a MTC HLA hot-mix paving formulation which is used extensively throughout Ontario.

The polyethylene-modified asphalt concrete mix displayed a curious increase in both the Marshall flow and the Marshall stability values. Dynamic mechanical measurements confirmed the expected increase in resilient modulus at temperatures above 0°C. Marshall briquettes containing polyethylene also exhibited slightly greater wet strength retention after prolonged immersion in water. These observations are consistent with the published data for commercial Novophalt paving materials developed in Austria and predict that the use of polyethylene in asphaltic hot-mix paving materials can extend service temperature range at both high and low temperatures, thereby simultaneously reducing both pavement distortion (rutting) and low-temperature cracking, so that pavement life can be more than doubled. The cost of such modification can be substantially reduced if scrap or reclaim polyethylene is employed instead of virgin polyethylene. Dispersing agents, such as Shell Chemical Kraton G block copolymers were advantageously employed to control emulsion stability, particle size, and compatibility of the dispersed polyethylene phase.

Key words: Asphalt pavements; Polyethylene binder; Flexural testing; Novophalt paving

42- Polymer modification of paving asphalt binders
Lewandowski, L H
Rubber Chemistry and Technology, 67(3):1994. 447-480.

This review mainly addresses the use of polymer modifiers in dense-graded hot-mix asphalt concrete pavement applications. The group of polymers discussed are block copolymers, thermoplastics and synthetic and natural rubbers. An introductory background to asphalt chemistry, reasons for polymer modification of asphaltic binders and test used to grade asphalt binders are presented. Emphasis is placed on methods used to characterize the compatibility between polymer and asphalt. Morphology and rheological behaviour of storage stability and mechanical properties of polymer-modified asphalt binders are discussed.

Key words: Asphalt binders; Polymer modification; Rheology

43- Polymer modified bitumen and related properties
Srivastava, Anil
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I.41-I.55.

For pavement design there is a need for materials which show improved properties and possess the following characteristic features: (a) free from cracking at low temperature, (b) improved visco elastic recovery, (c) improved resistance to fatigue, (d) high flexibility and

impact resistance and (e) higher stability and resistance to permanent deformation at high temperatures. These properties can be achieved by modifying the bitumen using polymers. However, simply the addition of polymer into a compatible bitumen at high temperature will not produce the required properties, as experienced by various laboratories throughout the world. One has to cope with incompatibility of bitumen and polymer, phase separation in modified bitumen, storage stability problems, molecular weight distribution, 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.

Key words: Binders: Modified bitumen; Asphalt concrete

44- Polymeric additives and their role in asphaltic pavements. Part I: Effect of additive type on the fracture and fatigue behaviour
Aglan, H
Journal of Elastomers and Plastics, 25 (4): 1993. 307-321.

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) exhibited 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; Asphalt pavements; Fracture; Fatigue behaviour

45 - Preparation and evaluation of polymer-modified asphalt binders
King, G; King, H and Brule, B
Meeting of the Rubber Division, American Chemical Society, 29 May –1 June 1990, Las Vegas, Nevada

Addition of a polymer modifies the physical characteristics of asphalt. The physical characteristics of the polymer-modified asphalt (PMA) depend on factors such as the base asphalt, the type and percentage of polymers, compatibility of the constituents, blending technique etc. The paper describes the methods for the evaluation of PMAs by microstructure and physical property characterization. Microstructure of PMA can be evaluated by scanning electron microscopy by reaction of osmium tetroxide with PMA, followed by extraction of asphalt with a suitable solvent or by reflective fluorescence microscopy without extraction of asphalt. Maximum improvement in properties as a binder is obtained when it swells the polymer.

Key words: Polymer modified asphalt; Stability; Microstructure; Scanning electron microscopy; Reflective fluorescence microscopy

46- Properties of rubberised bitumen from reclaimed rubber
Azemi Bin Samsuri
Journal of Natural Rubber Research, 11(3): 1996. 166-182.

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

Key words: Rubberized bitumen; Reclaimed rubber; Glove crumbs; Road pavements

47- Recycled rubber with asphalt as a membrane for pavement rejuvenation: A progress report
Winters, Robert E (BOB)
112th meeting of the Rubber Division, American Chemical Society, 4-7 October 1977, Cleveland, Ohio, Paper No.56.

Ground vulcanized scrap rubber and paving grade asphalt are reacted at high temperature to attain a tough and elastic composition. Worn out tyres were subjected to size reduction by cryogenic grinding before addition to asphalt. This could be applied to highways, city streets, airports and other paved surfaces as a membrane for correction of flexural cracking and is very economical compared to a complete reconstruction with a new base. The material can be used as a water barrier on bridge decks, ponds and canal linings and roofing.

Key words: Asphalt; Recycled rubber; Pavement performance; Cryogenic grinding

48- Reinforcement of asphalt and tar by elastomer addition
Sinclair, E A and Bristol, K E
Rubber World, 161(3): 1969. 67-71.

Asphalts and tar are used extensively in highway paving, roofing, paper lamination and other industrial applications. By chemically or physically modifying these materials, their behaviour and usefulness can be considerably improved. Paving grade bitumens are blended with different forms of rubber such as crumb, powder, solution, latex and liquid. Mixing time and temperature affect blend properties. Temperature susceptibility, ductility at low temperature, toughness and tenacity, softening point, impact resistance, adhesion and cohesion, recovery and bleeding resistance of the bitumen are improved by the addition of rubber. A high-Mooney, low-gel SBR gives the best combination of property improvements. It is observed that there is no significant difference in property improvements between the latex and powder form of a polymer, provided they are both well dispersed.

Key words: Rubberized bitumen; Asphalt; Reinforcement; Tar-rubber blend

49- Reinforcement of asphalt and tar by elastomer addition. II.
Sinclair, E A and Bristol, K E
Rubber World, 161(4): 1970. 66-69.

The properties of penetration grade asphalts for highway application are improved by the addition of SBR polymer. Effect of concentration of SBR on properties of both high and low viscosity types of

asphalt are studied. Softening point, ductility at low temperature, toughness and temperature susceptibility are improved considerably by 3% dry weight of SBR polymer from latex. Blends of tar and nitrile rubber (NBR) provide a binder resistant to the solvent action of fuel and is being used to overcome major maintenance problem in military and domestic air fields. Time and temperature of mixing, type and concentration of rubber and tar source influence the final properties.

Key words: Asphalt reinforcement; Rubber bitumen

50- Rheological properties of rubber-modified asphalt.
Zaman, A A; Fricke, A L and Beatty, C L
Journal of Transportation Engineering, Nov-Dec 1995. 461-467.

The performance of rubber from used tires as an asphalt cement modifier was evaluated for shear-flow properties and creep-rupture behaviour of modified asphalt cements. Results indicate that various asphalt/rubber samples exhibit shear-thickening, the Newtonian and shear-thinning behaviour being dependent on the shear rate. Shear viscosity, linear viscoelastic function, elasticity and creep resistance of asphalt cement increased with the addition of rubber, indicating that 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 road cycle.

Key words: Modified asphalt; Rheology; Ground rubber

51 - Rheology and microstructure of polymer/asphalt blends
Bouldin, M G; Collins, J H and Berker, A
Rubber Chemistry and Technology, 64(4):1991. 577-600.

This paper, primarily devoted to the fundamental rheological properties of polymer modified binders, demonstrates the effectiveness of polymers in improving especially the high temperature properties of asphalt. Addition of polymer to the asphalt improves the end-use properties such as reduced creep at high temperatures, less brittleness at low temperatures and better impact properties at intermediate temperatures. For optimal performance at elevated temperature it is essential that a network be present. Choice of the asphalt and powder, polymer concentration and the method of incorporation determine the extent of network formation.. Suitably modified asphalts show a comparatively lower modulus at low temperatures and a higher modulus in the ambient temperature as compared to unmodified asphalt.

Key words: Polymer asphalt blends; Rheology; Binders

52 - Road performance studies and an investigation of some problems associated with rubberised bitumen road construction
Weeraratne, A and Nadarajah, M
Quarterly Journal of Rubber Research Institute of Ceylon, 47:1971. 37-49.

This work deals with various laboratory investigation and field experiments to determine the properties of bitumen with and without rubber. The resistance of rubberized bitumen to cracking, deformation and stopping was assumed to be due to chemical and physical interaction of bitumen with rubber. It is assumed that aldehyde condensing groups present in bitumen react with aldehyde groups present in NR. The presence of ammonia in latex brings about temporary deactivation of aldehyde groups at normal temperatures. At the high temperatures of processing rubberized bitumen, ammonia volatilises leaving the aldehyde groups free to react with the bitumen. The reaction of aldehydes to form condensation product with bitumen is accelerated by sodium hydroxide. A combination of sodium hydroxide and ammonia is hence a better preservation system for latex to be used for blending with bitumen. It was found that the viscosity and workability problems associated with rubberized bitumen could be overcome by introducing kerosene oil into the bitumen to the extent of 5-10% before addition of the required quantity of rubber. The use of rubber asphalt masterbatches, which were bitumen rubber composites that contained 12-16% dry rubber, further speeded up the blending of rubber. This masterbatch dissolved at high temperature and enabled the dilution with further quantity of bitumen. Addition of rubber to bitumen improved its properties. Rubberized bitumen showed better bonding and less bleeding. The initial cost was seen to be increased by 10%. However, the technical advantages outweigh the marginally higher cost.

Key words: Rubberized bitumen; Road performance; Road construction

53- Rubber could give the 100 year old road surface
Dempster, David
European Rubber Journal, May:1978. 47-48.

The results of research at the University of Toronto suggest that if granulated rubber is added to conventional asphalt for road surfacing, the road life can be increased by at least 50%. Addition of ground tyre scrap rubber produces measurable improvements in road performance. Apart from greater durability, the other advantages are increased pavement flexibility (fewer potholes), greater skid resistance and improved adhesion of the topping to the base.

Key words: Rubberized asphalt; Skid resistance

54- Rubber for road-making and building materials.
Shaw, K
Rubber Journal, 149(10): 1967. 8-13, 36.

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. Addition of rubber to bitumen increases the elasticity of the composite which imparts resistance to deformation and increases road life. It also acts as a vibration absorber.

closer look at bitumasti

Key words: Rubberized bitumen; Surface coating

55- Rubber in asphalt pavements: A method for utilising all of our rubber waste
Huff, Bobby J
111th meeting of Rubber Division, American Chemical Society, 1977, Illinois, Paper No.35.

The value of scrap rubber in highways and recreational surfaces have been established making it a valuable commodity rather than a problematic solid waste. As this usage continues to grow, it is foreseeable that the entire scrap pile would be required and that it might even be necessary to create new material of similar composition for this purpose. The addition of scrap rubber considerably improves the quality of asphalt surfaces mainly by improving their resistance to cracking. Powdered devulcanized or reclaim rubber have the advantage over latex in that they contain chemicals that resist weathering eventhough it is a little more difficult to disperse in bitumen as compared to latex. Powdered rubber is reacted with asphalt at high temperatures and afterwards kerosene is added to reduce the viscosity. On evaporation of kerosene a highly resilient membrane of rubberized asphalt is obtained which has excellent adhesion to existing bitumen surfaces. Such a membrane act as a sealant for water and hence can waterproof bridge decks and clay soils.

Key words: Rubberized asphalt; Binders; Rubber waste

56 - Rubber in low cost roads
Beagle, Charles W
Rubber Developments, 10(2): 1957. 44-47.

The article describes a method of making low cost roads

which is of special interest to overseas territories undergoing rapid development. Such areas undergoing rapid development are often confronted with the problem of building adequate roads or streets. The relatively small amount of traffic does not justify construction of very expensive type of pavements. This situation required a low cost type of construction. That type of construction was experimented in South Plainfield, New Jersey. They used natural rubber latex added emulsified bitumen to surface the road laid with crushed stone. This improves the adhesive properties and result in better retention of the stone. Emulsified bitumen used for this work was a low-viscosity rapid-setting type with 0.25-1% of natural rubber latex by weight. The performance of such roads improved tremendously and the cost for construction was very low.

Key words: Rubberized bitumen; Rubberized roads; USA

57 - Rubber in road and airport construction in the United States
Lockwood, Warren S
Rubber Developments, 2(3): 1949. 7-11.

The article describes the use of rubber powder in the construction of roads in Virginia, Ohio, Minnesota and Texas. Rubber powder was used at 6% on the weight of asphalt. Proposal to rubberizing an airport is also discussed in this article. On addition of rubber to asphalt, rubber absorbs a portion of asphalt and road surfaces laid with rubberized asphalt has improved road life. The road foundation is protected better and roads become dust free.

Key words: Rubberized roads; Natural rubber; Airfields; Asphalt; USA

58- Rubber in road construction
Duriez, M M
Rubber Developments, 4: 1951. 62-63.

From rubber development organisations viz. Rubber Stitching in Holland, Institut Francais du Caoutchouc in France, the British Rubber Development Board in Britain and their American office, the Natural Rubber Bureau in U.S.A. have played significant roles in promoting use of rubber in road construction. Incorporation of small quantity of rubber in bitumen makes it more plastic at room temperature, with reduced flow at high temperature and improved adhesion to aggregates. The addition of bitumen also confers skid resistance to the pavement surface. When rubber is added to bitumen it absorbs a part of hydrocarbon constituting the maltness, resulting in a material with greater hardness. Rubber can be added as a powder or latex. Powdered rubber is

added in a way similar to the addition of filler. It is easier to incorporate rubber in latex form. Stabilised NR latex has a pH similar to that of bitumen and since particle size of latex is much smaller (about one sixth) than that of bitumen, it gets occluded by the bitumen with the result that it is finely dispersed throughout the bitumen better than that in the case where rubber is added in the powdered form.

Key words: Natural rubber; Rubberized roads; Road construction

59- Rubber roadways: A review
Hastings, J D
Journal of the Rubber Research Institute of Malaya, 4(1&2): 1932. 65-75.

Rubber Roadways Ltd., is a company formed under the auspices of the Rubber Growers' Association in 1915 to faster the use of rubber for roadways. Though various methods were envisaged for the use of rubber in road making, only in the case of block paving has a satisfactory material developed. But the initial cost of laying is too high. Therefore, attention has recently been focussed on use of wet mixes prepared from latex. It should be cheaper to lay material which can be poured or spread.

Key words: Bitumen emulsion; Rubberized roads

60 Rubber roadways: Their advisability and practicability
Cox, W F V
I.R.I. Transactions, 8: 1931. 345-363.

The progress that has been made in the use of rubber for road surfacing is reviewed and the steps to be taken to expedite the adoption of rubber for pavements are indicated. Performance of seven experimental stretches of roadways laid with vulcanized rubber blocks were satisfactory with regard to the parameters such as absorption of vibration and migration of noise, evenness, dustlessness, cleanliness, ease of maintenance, non slippery surface, appearance and longer service life. The advisability of using rubber paving for bridges, for foot paths and for traffic lines is also examined. The cost factor is also discussed.

Key words: Natural rubber; Rubber roadways; Rubber paving

61- Rubberised bitumen from rubber-bitumen masterbatch
Narusawa, S; Kunisawa, S and Asao, M
Proceedings of the Natural Rubber Research Conference, 1960, Kuala Lumpur, pp. 960-970.

A rubber-bitumen masterbatch was prepared by mixing 80 parts of premasticated flat bark with 20 parts of straight-run bitumen 40/60 and 5 parts of oxalic acid on an open mill and the mixture was used as a rubber-bitumen masterbatch for rubberizing bitumen. The properties of the bituminous cement rubberized with this masterbatch were studied. The effect of sulphur on the ductility and tenacity of the material was also discussed. It was found 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.

Key words: Rubberized bitumen; Rubber-bitumen masterbatch

62- Rubberized roads
Kaliin, Donald A
Rubber Age, 99(10): 1967. 75-82.

The history of rubber in paving, improvements in the physical property of asphalt achieved by the incorporation of rubber, mixing of rubber, both pre-blending and plug mill mixing and advantage of use of rubber in mixes are covered in this paper. Rubber added to asphalt results in an increase in adhesion and cohesion, 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, results in an improved asphaltic pavement.

Key words: Rubberized roads; Asphalt pavements; Viscosity

63- Rubberised roads for Indian conditions
Gopalakrishnan , K S
Workshop on Rubberized Roads, 17 January 1998, Rubber Research Institute of India, Kottayam.

The paper points out the predominant shift in the share of freight and passenger traffic from rail to road which has taken place during the period from 1950-51 to 1992-93. It is emphasised that in the wake of the tremendous growth in the number of vehicles during the past five decades, the length of good quality roads has to be increased significantly. One way to improve the performance of the bituminous roads, it is suggested in the paper, is by the use of natural rubber modified bitumen. The paper describes the road rubberization process, its advantages and also touches upon the field trials conducted in Kerala.

Key words: Rubberized roads; Modified bitumen; Kerala

64- Rubberised roads for superior performance
Gopalakrishnan, K S
Rubber Asia, 8(4): 1994. 57-58.

The results of laboratory studies and several road experiments conducted in many parts of the world clearly indicate that use of rubberized bituminous pavements will undoubtedly lead to saving and safety. Addition of rubber to bitumen increases the viscosity, reduces the susceptibility to temperature and improves the strength. It also improves the resistance to cracking, flatting up, deformation or flow and resistance to stripping. The additional cost of rubberization will be more than compensated by the advantages accruing by the use of natural rubber.

Key words: Rubberized bitumen; Road rubberization; India

65- Rubberized roads on the continent
Wildeboer, A F W
Rubber Developments, 10(1): 1957. 12-14.

This paper describes the development of the rubberized roads in Germany, Switzerland, Denmark, Austria, Sweden, Finland etc. The good behaviour of rubberized asphalt constructions are due to better cohesion and lower heat sensitiveness due to addition of rubber to bitumen.

Key words: Rubberized asphalt; Rubberized roads

66- Rubberized bituminous materials and their use in road construction
Parker, W D and Walker, W D C
Journal of Applied Chemistry, Sep: 1957. 481-491.

The compatibility of natural and synthetic rubbers and polymers such as polyvinyl chloride with coal tar pitches and bitumen 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.

Key words: Rubberized bitumen; Road rubberization

67- Rubberized roads in Queensland
Douglas, Neil
Rubber Developments, 12(1): 1959. 23-26.

This report describes the work in Queensland. The four centres selected for the trials were Bristane, Mackay, Ayr and Cairns. In each case 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 confirm to minor movements of road base. Unvulcanized rubber powder was used for the preparation of rubberized bitumen.

Key words: Rubberized roads; Rubberized bitumen; Queensland

68- Some viscous and elastic properties of rubberised bitumens
Smith, L M
Journal of Applied Chemistry, July:1960. 296-305.

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, mainly 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 vulcanized rubber, causes a rapid breakdown of the rubber when heated with bitumen. An equi-viscous basis is suggested for characterisation of rubberized bitumens

Key words: Rubberized bitumen; Viscosity; Elastic strain recovery

69- Speciality polymers in road applications: Some noval technological advances
Jain, P K
Proceedings of the International Conference on Rubbers, 7-12 December 1997, Calcutta, V 2, pp.135-138.

Laboratory and field studies conducted at the Central Road Research Institute, India confirm that ethylene vinyl acetate copolymer with vinyl acetate content ranging from 18 to 28%, when added to bituminous binders to the extent of 2.5 to 5.0% improves flexibility at low temperature, prevents permanent deformation of road surfacings at high

temperature and improves 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 recorded superior performance under heavy loading.

Key words: Ethylene vinyl acetate copolymer; Binders; Road surfacings; India

70- Surface dressing with rubberized bitumen in Hornsey
Pentecost, G A
Rubber Developments, 11(4): 1958. 119-122.

The article describes the laying of short stretches of surface dressing with rubberized bitumen in U.K. Natural rubber in powder form was blended at 2% level with bitumen and fluxed to a spraying viscosity with about 20% of flux oils. The paper reports that substantial improvement in skid resistance of the roads was experienced.

Key words: Rubberized bitumen; Surface dressings; UK

71- A Survey on rubberised asphalt for road surfacing
Anonymous
Rubber International Magazine, 2 (16): 2000. 83-86.

This survey indicates that rubberized road surfacing has been widely studied and is becoming more popular due to the advantages over the conventional asphalt roads. 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. There are two processes 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. Some of the NR producing countries have carried out successful trials on rubberized 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. One of the main obstacles for rapid and wide application of rubberized road surfacing is that it costs more than the conventional asphalt road, despite its longer life and lower maintenance cost. The social and economic impact of the technologies are quite encouraging . Rubberized road surfacing would also result in more comfortable driving, reduce traffic noise and absorb light and protect the driver's eyes.

Key words: Rubberized asphalt; Road surfacings; Rubber modified bitumen

72- A Survey on the use of rubber in bituminous pavements: 1945-1951
Clinebell, Bety J O and Straka, Leora E
Rubber Age, 70: 1951. 69-73.

This survey on the use of rubber in bituminous pavements during the 15 year period 1945-1951 reviews the various investigations carried out on (1) the different forms in which rubber has been used in pavement constructions, (2) properties of rubber added, (3) method of mixing and laying and (4) the action of rubber in asphaltic bitumen. Advantages of rubber incorporation to road surfacing compositions and cost considerations are also discussed.

Key words: Rubberized bitumen; Asphalt pavements

73- The technical merits of rubber as an additive to road binders: The present position
Mullins, L
Proceedings of the Natural Rubber Research Conference, 1960, Kuala Lumpur, pp. 978-986.

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, close control of variables such as the state of the rubberized binder, temperature and time of mixing and spreading technique. The results obtained from these trials and their implications are described.

Key words: Rubberized roads; Rubberized bitumen; UK

74- Techno-economic feasibility of using natural rubber modified bitumens for maintenance of flexible pavements
Jain, P K and Sood, V K
Workshop on Rubberized Roads, 17 January 1998, Rubber Research Institute of India, Kottayam.

The need for increasing the effective service life of bituminous pavements is highlighted. Modification of bitumen by incorporating 2-4% natural rubber is reported to be very much effective for the purpose. Problems encountered while blending bitumen with rubber and

methods for overcoming the difficulties are explained. Properties of rubber modified bitumen are also discussed and specifications of rubberized binders indicated. Use of natural rubber modified bitumen is reported to provide a 35% saving in periodic maintenance cost. For economic reasons and to achieve better quality, blending of natural rubber at the refinery itself is suggested.

Key words: Rubber modified bitumen; Flexible pavements; Road rubberization; India

75- Thermoplastic elastomers as bitumen modifiers for the roads and airfields surfacings
Mahapatra, Partap K
Indian Road Congress, Seminar on Bituminous Roads: Design and Construction Aspects, 25-26 August 1994, New Delhi, India, pp. I.127-I.134.

Evaluation of thermoplastic elastomers of the type SBS as a modifier for bitumen for road and airfield surfacings is presented. Thermoplastic elastomers modify bitumen by increasing the resistance of the latter to permanent deformation at high road temperatures without affecting the properties of the bitumen at other temperatures. The process of blending SBS with bitumen, effect of SBS on properties of bitumen, penetration- temperature and viscosity-temperature relations, stability and stiffness of mixes, etc. are described. Reference is also made to some field trials.

Key words: Modified bitumen; Road surfacings; Airfields

76- Those amazing rubber roads. Part 1
Allison, Kenneth
Rubber World, 155(6): 1967. 47-52.

Early developments on the concept of rubberized roads are reviewed. The Asphalt Institute and the National Asphalt Pavement Association did not encourage the idea of binding rubber to asphalt. Later the International Institute of Synthetic Rubber Producers (IISRP), the National Rubber Producers' Research Association (NRPRA) and the Road Research Laboratory(RRL) of the U.K reported the advantages of rubberized roads. Various problems associated with this development are also discussed and the size of the market indicated.

Key words: Rubberized roads; Asphalt; History

77- Those amazing rubber roads. Part. II
Allison, Kenneth
Rubber World, 156(1): 1967. 91-106.

Road rubberization offers a potentially huge market for rubber. The present rubber roads situation in regard to technology, economics, product differences and highway safety are discussed. Four of the common methods of incorporating rubber into the final asphalt road mixture are mentioned. Problems relating to ageing of rubber asphalts and the effect of molecular weight are also studied. A few experimental projects and new developments are also described.

Key words: Rubberized roads; Asphalt; History

78- Torsional braid analysis of bitumen-liquid rubber mixtures
Kortschot, M and Woodhams, R T
Polymer Engineering and Science, 24(4): 1984. 252-258.

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 behaviour using a modified Fraas 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 m. 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% 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.

Key words: Torsional braid analysis; Asphalt rubber

79- The use of mechanical tests in the design of bituminous road surfacing mixtures. II. Stability tests on rolled asphalt
Broome, D C and Please, A
Journal of Applied Chemistry, 8: 1958. 121-135.

A comparison of resistance to deformation of rolled asphalt has been made at 45°C 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,

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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.

Key words: Road surfacings; Bituminous mixtures; Rolled asphalt; Stability

80- Use of natural rubber in road surfacing materials
Thompson, P D
Proceedings of the Institution of the Rubber Industry, 11: 1964. 94-103.

The paper reports that the earliest road surfacings were using solid rubber blocks. Such surfacings were too expensive and caused the roads to be slippery when wet. Later, the technique of modifying the bitumen by blending with rubber was successfully tried. Rubber was used as latex, unvulcanized rubber powder, vulcanized rubber powder, smoked sheets and ground scrap rubber. Rubberized bitumen was tried in surface dressing, bitumen macadam, rolled asphalt and mastic asphalt. Technique of blending rubber with bitumen was standardised and properties of rubber modified bitumen were evaluated. Full scale field trials were conducted and economics of rubberized roads was reported.

Key words: Road surfacings; Rubber bitumen; Asphalt

81- Use of natural rubber latex in road construction
Fernando, M J and Nadarajah, M
Journal of Rubber Research Institute of Malaya, 22(5):1969. 430-440.

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-vulcanized field latex are reported. The studies covered the dispersion of rubber particles, temperature-dependent and rheological properties, ageing and stripping of rubberized 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.

Key words: Rubberized bitumen; Road rubberization; Rheology

82- Why runways should be rubberised
Gopalakrishnan, K S
Rubber Asia, 9(5): 1995. 69-71.

Bituminous runways in airports shows increased signs of failure resulting from heavier aircrafts, higher tyre pressures, increased air traffic, etc., and these defects can be overcome by rubberization. Distresses in bituminous runways normally occur owing mainly to surface weathering fatigue differential movement of sub-base over time, etc., which are mainly related to the nature of the binder. By suitably modifying the binder by incorporation of a small proportion of rubber, the situation can be improved considerably. The paper narrates that since the success of the first major experiment with rubberized bitumen at Essendon airport in Melbourne in 1954, rubberization is becoming popular.

Key words: Modified bitumen; Airport pavements

KEYWORD INDEX