Prevulcanized latex · Rheology · Viscosity modifiers

Rheological Behaviour of Prevulcanized Natural Rubber Latex

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The effect of viscosity modifiers on the flow properties of prevulcanized NR latex (PVL) was studied at different shear rates and temperatures.

PVL exhibited pseudoplastic flow pattern. The pseudoplasticity decreased on increasing temperature. The viscosity of PVL can be increased by the addition of viscosity modifiers such as casein, polyvinyl alcohol (PVA) and sodium carboxymethyl cellulose (NaCMC), the predominant effect being obtained by the addition of NaCMC.

Rheologisches Verhalten von vorvulkanisiertem [illegible]turkautschuk-Latex

Naturkautschuk-Latex, vorvulkanisiert · Rheologie · Viskositätsmodifikatoren

Der Einfluß von Viskositätsmodifikatoren auf die Fließeigenschaften von vorvulkanisiertem NR-Latex (PVL) wurde bei verschiedenen Schergeschwindigkeiten und Temperaturen untersucht. PVL zeigte ein pseudoplastisches Fließverhalten. Die Pseudoplastizität nahm mit steigender Temperatur ab. Die Viskosität von PVL kann durch Zusatz von Viskositätsadditiven erhöht werden, wie z. B. Casein, Polyvinyl-[illegible]ohol oder Na-carboxy-methyl-cellulose, wobei mit letzterer der größte Effekt erzielt wird.

Prevulcanized latex is a convenient form of latex for the latex goods manufacturing industry since it can be used directly for product manufacturing, eliminating latex compounding. During processing, latex is subjected to different forms of stress which may cause flow. Various techniques such as dipping, extrusion, casting, brushing, spraying etc. are employed for the manufacture of products from latex. Each technique involves a critical relation between temperature, stress and inherent fluid property such as viscosity of latex. A thorough evaluation and understanding of the rheological characteristics and of the factors that can be used to alter the flow behaviour of the latex are of vital importance for satisfactory operation. Viscosity of latex depends considerably on its solid content and particle size distribution [1]. Effect of dry rubber content and temperature on viscosity of NR latex was investigated [2]. The flow behaviour of latex can be modified by the incorporation of viscosity modifiers to suit the manufacturing process involved. The effect of surface active agents on the rheological properties of centrifuged and creamed latex have been reported [3]. The rheology of rubber solutions, suspensions, latex and latex compounds had been studied by *Leaman* [4]. Studies of *Gorton* [5] showed that the source of rubber will affect its molecular weight and distribution characteristics and this will thus influence the flow properties of rubber. According to *Collins* et al. [6] the important factors affecting rheological behaviour of latex are shear rate, particle size distribution and presence of electrolytes. Studies [7] on the rheological behaviour of natural and synthetic rubber latices in presence of surface active agents showed that addition of the surface active agents increased the viscosity of NR and SBR latices while they decreased it in the case of ENR latex. The rheological behaviour of blends of natural and SBR latices has also been reported [8].

This study reports the rheological behaviour of prevulcanized natural rubber latex (PVL) and the effect of viscosity modifiers on its flow properties under different shear rates and temperatures.

Experimental

Materials

Centrifuged NR latex (high ammonia) conforming to IS 5430-1981 was obtained from the Pilot Latex Processing Centre of the Rubber Board. Sulphur, zinc oxide and zinc diethyldithiocarbamate were of commercial grade and were used as dispersions in water, prepared by ball milling. Other chemicals were of laboratory grade and were used as solutions in water.

Prevulcanization

The latex compound was prepared in the formulation given in *Table 1*. Prevulcanization was carried out by heating the latex compound in a beaker immersed in a water bath set at 70 °C. The compound was subjected to continuous slow stirring and the beaker was kept covered to minimize loss of ammonia. After 2 h the latex was cooled and kept at room temperature. On the next day the latex was decanted and filtered through a 100 mesh sieve and the total solids content of the latex was adjusted to 58 %.

Table 1. Formulation of latex compound

Ingredients	Parts by weight (wet)
Centrifuged latex, 60 %	167.0
Potassium hydroxide solution, 10 %	2.5
Potassium laurate solution, 20 %	1.3
Sulphur dispersion, 50 %	3.0
Zinc diethyldithiocarbamate dispersion, 50 %	2.0
Zinc oxide dispersion, 50 %	0.4

Viscosity modifiers

The viscosity modifiers such as casein, polyvinyl alcohol and sodium carboxymethyl cellulose were prepared as 5 % solution in water. The dosage of viscosity modifiers used was 0.25 phr.

Rheological measurements

The flow behaviour of the prevulcanized latex and that containing viscosity modifiers were studied using Haake Viscotester VT550. Sensor system NV was used for the measurements. The study was conducted at three different temperatures, 25, 35 and 45 °C at shear rate from 1 to 150 s^{-1}.

Results and discussion

The rheological behaviour of latex has been analysed using Power Law equation.

$$\tau = K\dot{\gamma}^{n} \qquad (1)$$

where τ = shear stress (Pa), $\dot{\gamma}$ = shear rate (s^{-1}), K = viscosity index, n = flow index

By plotting log τ vs. log $\dot{\gamma}$ the values of K and n are obtained by regression analysis. The apparent viscosity, η is the ratio of shear stress to shear rate

$$(\eta = K\dot{\gamma}^{n-1}). \qquad (2)$$

Effect of shear rate on viscosity

Fig. 1 shows the effect of shear rate on viscosity of PVL at 25, 35 and 45 °C. On increasing the shear rate, viscosity of latex decreased which indicated its pseudoplastic behaviour. The effect is more pronounced at low shear rates, approaching near-Newtonian behaviour at high shear rates. NR latex is a non-Newtonian liquid which exhibits pseudoplastic flow pattern [9]. During prevulcanization, crosslinking takes place in each of the individual rubber particles without altering their state of dispersion appreciably. Thus the particles have the same shape, size and size distribution after prevulcanization [10]. At rest the particles are extensively entangled and/or randomly oriented. Under shear the particles become oriented in the direction of flow and the points of entanglements are reduced which causes the observed reduction in viscosity on increasing shear rate [11]. At high shear rate orientation may be maximum exhibiting near-Newtonian behaviour.

Effect of viscosity modifiers and shear rate on viscosity

Fig. 2 shows the effect of shear rate on viscosity of PVL in the presence of viscosity modifiers casein, polyvinyl alcohol (PVA) and sodium carboxymethyl cellulose (NaCMC). Viscosity modifiers are hydrocolloids and give viscous solutions in water which display the properties of a typical lyophilic colloid. They find their principal application in latex technology as modifiers of bulk flow behaviour and produce thickening effects when added to latex. Fig. 2 shows that all the viscosity modifiers increased the viscosity of PVL both at low and high shear rates. Among these the most significant effect is obtained by the addition of NaCMC. PVA offers a higher viscosity than casein at low shear rates, but as shear rate increases (20 to 150 s^{-1}) PVA offers a marginally lower viscosity than casein. This may be due to the easier displacement of the adsorbed layer of PVA from the surface of rubber particles at high shear rates. The increase of viscosity by the addition of viscosity modifiers is more pronounced at low shear rate and narrows down as shear rate increases. Generally the viscosity modifiers are distributed along the interphase and the aqueous phase. A network will be formed between molecules of the viscosity modifiers absorbed on the surface of the rubber particles and those present in the aqueous phase. This partially restricts the Brownian movement of the rubber particles. This will lead to agglomeration of rubber particles which causes an increase in particle size and thereby increase in viscosity.

Compared to raw PVL, that containing viscosity modifiers exhibited more pseudoplasticity as evidenced from the rapid decrease in viscosity with increase in shear rate (Fig. 2). When shear rate increases the viscosity modifiers are easily displaced from the rubber particles, the network becomes loose and the tendency of the rubber particles to slide past each other will be enhanced.

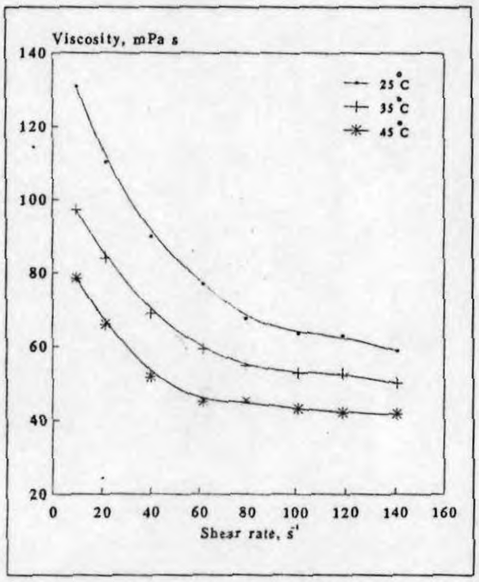

Fig. 1. Effect of shear rate on viscosity of PVL at different temperatures

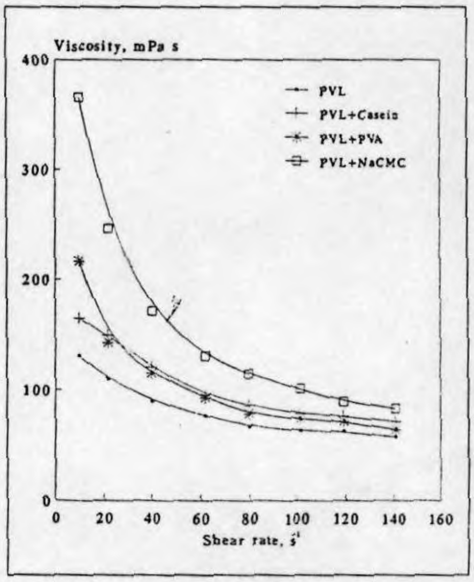

Fig. 2. Effect of shear rate on viscosity of PVL containing viscosity modifiers at 25 °C

Table 2. Flow index values at different temperatures

Samples	Flow index (n)		
	25 °C	35 °C	45 °C
PVL	0.7660	0.7744	0.7811
PVL + casein	0.6008	0.7360	0.7378
PVL + PVA	0.5618	0.6189	0.6734
PVL + NaCMC	0.4379	0.4546	0.4564

Table 3. Zero shear viscosity at 25 °C

Sample	Zero shear viscosity (mpa s)
PVL	154.8
PVL + casein	179.2
PVL + PVA	228.6
PVL + NaCMC	616.0

The higher pseudoplastic nature of the system containing viscosity modifiers is also evident from the flow index (n) values shown in *Table* 2. The value of n for a real fluid gives a relative measure of how its behaviour deviates from that of an ideal (Newtonian) fluid characterized by an n value of unity. The flow index can be considered as an inherent property of the fluid. A value of $n > 1$ indicates dilatant behaviour while $n < 1$ indicates pseudoplastic behaviour. A low value of n reveals more pseudoplastic nature. Table 2 shows that compared to raw PVL, viscosity modifiers impart lower values of n which indicates more pseudoplastic nature. Among the three viscosity modifiers NaCMC provides the maximum effect. The effectiveness of the viscosity modifiers in increasing the pseudoplasticity of PVL decreases in the order, NaCMC > PVA > casein.

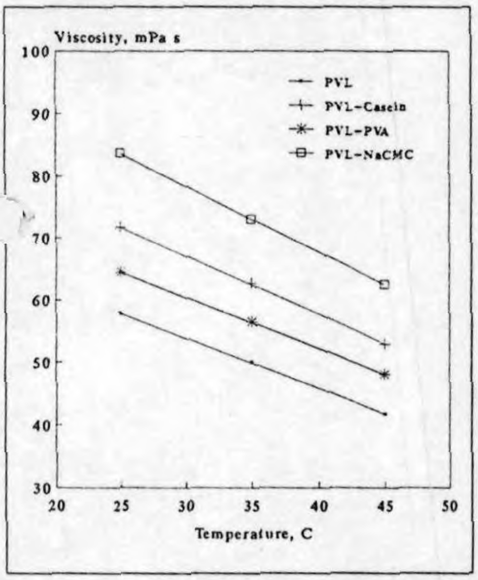

Fig. 3. Effect of temperature on viscosity of PVL containing viscosity modifiers (shear rate, 140.7 s^{-1})

Effect of temperature on viscosity

As with an increase in shear rate, increase of temperature also decreased the viscosity of PVL and those containing viscosity modifiers as can be seen in *Fig. 3*. It is also clear from Table 2 that the value of n increased as the temperature is increased from 25 to 45 °C indicating that an increase of temperature, decreased the pseudoplasticity of PVL and that containing viscosity modifiers. Latex contains two distinct flow units, a Newtonian solvent (water) and polymer particle (rubber). As temperature is increased, free volume increases and as a result the flow units become less restricted, more highly energized and less organized, thus resulting in decreased viscosity [12].

Zero shear viscosity

The zero shear viscosity of PVL and that containing viscosity modifiers are given in *Table* 3. Among the viscosity modifiers, the highest zero shear viscosity was exhibited by the system containing NaCMC followed by PVA and casein. The system with highest zero shear viscosity exhibited more pseudoplastic behaviour.

Conclusions

Prevulcanized natural rubber latex exhibited pseudoplastic flow patterns. The pseudoplasticity decreased on increasing temperature. The viscosity of PVL can be increased by the addition of viscosity modifiers such as casein, polyvinyl alcohol (PVA) and sodium carboxymethyl cellulose (NaCMC), the predominant effect being obtained by the addition of NaCMC. The pseudoplasticity of PVL is also increased by the addition of viscosity modifiers. The behaviour of PVL towards temperature remains unaffected by the addition of viscosity modifiers.

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