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Rheological and Extrudate Behaviour of Natural Rubber/Latex Reclaim Blends

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ABSTRACT: The rheological and extrudate behaviour of natural rubber/latex reclaim blends were evaluated using a capillary viscometer. The study shows that the viscosity of natural rubber decreases marginally on the addition of latex reclaim while the variation of viscosity with shear rate is not affected. The temperature sensitivity of the blends is not affected significantly with the addition of latex reclaim. The extrudates of natural rubber/latex reclaim blends are smooth up to the addition of about 50 wt. percent latex reclaim in filled natural rubber compounds.

KEY WORDS: natural rubber, latex reclaim, rheological properties.

INTRODUCTION

THE KNOWLEDGE OF the rheological behaviour of rubber compounds is of considerable importance in mixing, extrusion, calendering and moulding operations. The appropriate classification of raw materials and the prediction of their processibility play an important role in the control of manufacturing processes [1–7]. One of the commonly used

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raw materials in rubber compounds is reclaimed rubber. The addition of the reclaimed rubber to a rubber compound improves its mould flow and reduces its cost [8–11]. Further, the incorporation of reclaim rubber to a rubber compound offers processing advantages such as better surface finish, higher rate of extrusion, better dimensional stability and lower die swell [12–15].

In contrast to dry rubber reclaim, latex reclaim contains rubber hydrocarbon of very high quality which is only lightly crosslinked. The mechanical properties of the natural rubber/latex reclaim blends have been reported [16–17]. These studies show that the mechanical properties of the rubber compounds are not affected seriously on the addition of latex reclaim up to about fifty weight per cent of virgin rubber. The present study was undertaken to investigate the rheological behaviour of such blends. In this paper, we report the rheological and die swell behaviour of natural rubber and natural rubber (NR)/latex reclaim (LR) filled rubber compounds.

EXPERIMENTAL

Materials

Natural rubber: ISNR-5 (supplied by Rubber Research Institute of India, Kottayam), Mooney viscosity (ML(1 + 4) 100°C)–85.3.

Latex reclaim: Prepared from waste latex gloves (waste gloves were supplied by AVT Rubber Products Ltd., Kakkanad), Volatile matter–0.12%, Ash content–3.98%, Acetone extract–4.86%, Rubber hydrocarbon content–91.04%, P_o–40, Mooney viscosity (ML(1 + 4) 100°C)–54.

Additives: Zinc oxide, stearic acid, benzothiazyl disulphide, tetramethyl thiuram disulphide, sulphur, Accinox ZC (N-1,3 dimethyl N′phenyl P-phenylene diamine), carbon black (HAF N 330), Aromatic oil used were all commercial grade.

Preparation of Compounds

Natural rubber was masticated on a laboratory mixing mill and the latex reclaim in the form of a sheet was added at different percentages. The blends were prepared as per the formulations given in Table 1 according to ASTM D 3182-1982.

Rheological Measurement

Rheological studies were carried out using a capillary rheometer, attached to a Zwick Universal Testing Machine, model 1474. The extru-

Table 1. Formulations.

Materials	A	B	C	D
NR	100	75	50	25
LR	0	25	50	75
ZnO	5	5	5	5
Stearic acid	2	2	2	2
MBTS	0.6	0.45	0.3	0.15
TMTD	0.2	0.15	0.1	0.05
Sulphur	2.5	1.875	1.25	0.625
Carbon black	40	40	40	40
Aromatic oil	5	5	5	5
Accinox ZC	1	1	1	1

sion assembly consisted of a hardened steel barrel underneath the moving crosshead of the machine. A hardened steel plunger which was accurately ground to fit inside the barrel was held to the load cell by a latch assembly. The barrel was thermally insulated from the rest of the machine. The capillary used was made of tungsten carbide steel. It had a length to diameter (l_c/d_c) ratio of 40, with an angle of entry of 180°. The temperature inside the barrel and capillary was varied between 80 and 110°C, with an accuracy of 1°C. The barrel was electrically heated and accurately controlled. The crosshead speed could be varied in the range 0.5–500 mm/min.

Eight grams of the test sample was put into the barrel of the capillary rheometer and forced down to the capillary by the plunger attached to the moving crosshead. After a warm-up period of 3 min. the sample was extruded through the capillary at 10 different speeds. Forces corresponding to specific plunger speeds could be measured by the pressure transducer attached to the plunger and were recorded using a strip chart recorder assembly.

The force and crosshead speed were converted into apparent shear stress (τ_w) and shear rate ($\dot{\gamma}_w$) at the wall, respectively, using the following equations involving the geometry of the capillary and plunger:

$$\tau_w = \frac{F}{4A_p(lc/dc)}$$

$$\dot{\gamma}_w = \frac{3n' + 1}{4n'} \times \frac{32Q}{\pi d_c^3}$$

where F is the force applied at a particular shear rate, A_p is the crosssectional area of the plunger, l_c is the length of the capillary, d_c is the diameter of the capillary, Q is the volume flow rate (calculated from the velocity of the crosshead and the diameter of the plunger) and n' is the flow behaviour index, defined as,

$$n' = \frac{d(\log \tau_w)}{d(\log \dot{\gamma}_{wa})}$$

and determined by regression analysis of the values of τ_w and $\dot{\gamma}_{wa}$ obtained from the experimental data. $\dot{\gamma}_{wa}$ is the apparent wall shear rate, calculated as $32Q/\pi d_c^3$. The shear viscosity, η, was calculated as,

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

Extrudate Swelling

The extrudates were carefully collected as they emerged from the capillary die, taking care to avoid any deformation. The diameter of the extrudate was measured at several points after 24 h of extrusion using a binocular stereo-microscope. The average value of five readings was taken as the diameter of the extrudate (d_e). The extrudate swelling was calculated as the ratio of the diameter of extrudate to that of the capillary (d_e/d_c).

RESULTS AND DISCUSSION

Figure 1 shows the variation in shear viscosity of the blends with shear rate. It is found that the viscosity of the natural rubber/latex reclaim blends is lower than that of the natural rubber compound. Further, the viscosity of the blends decreases with increase in shear rate, as expected. Table 2 shows the flow behaviour index (n') of the blends. These data reveal the strong pseudoplastic nature of the blends.

Figure 2 shows the variation in viscosity with temperature at three different shear rates, viz., $16.6S^{-1}$, $166.6S^{-1}$ and $1666.6S^{-1}$. It can be seen that the viscosity decreases with temperature at all three shear rates. But this effect is more pronounced at higher shear rate as seen from the increased slope of the corresponding curves.

The dependence of melt viscosity on temperature was determined by an Arrhenius type equation

$$\eta = Ae^{E/RT}$$

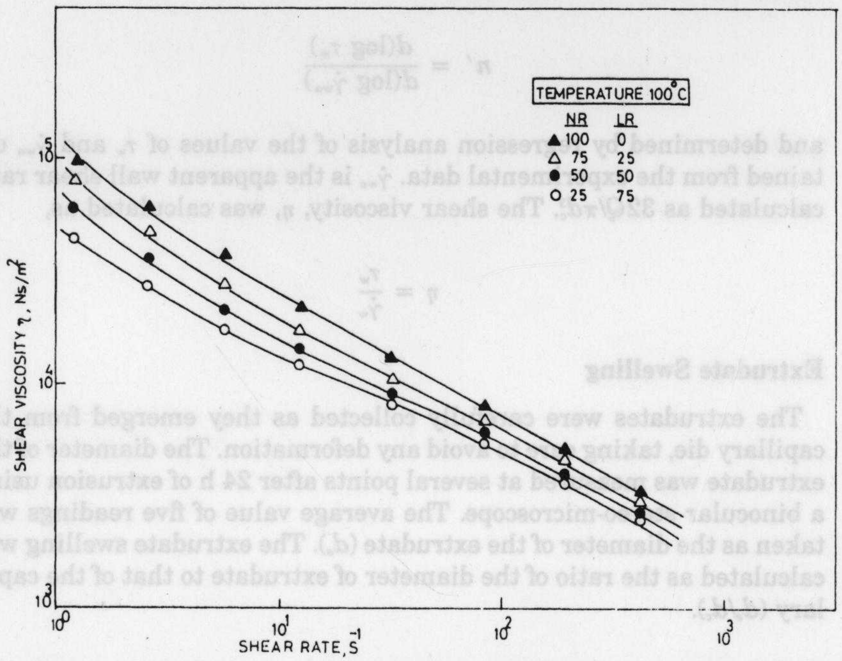

FIGURE 1. Variation in shear viscosity with shear rate of NR and NR/LR blends.

where A is a constant, E the activation energy and R the universal gas constant. From the slope of the plots, E values were calculated and are given in Table 3. The magnitude of the activation energy provides valuable information on the sensitivity of the material towards the change in temperature. From Table 3, it is clear that the heat sensitivity of the raw natural rubber is not affected significantly on the addition of latex reclaim.

Table 4 gives the die swell ratio (d_e/d_c) of the raw natural rubber and

Table 2. Flow behaviour index (n′) of NR/LR filled blends.

Compound (NR/LR)	Temperature (°C)		
	90	100	110
100/0	0.27	0.24	0.23
75/25	0.25	0.23	0.22
50/50	0.24	0.23	0.21
25/75	0.23	0.22	0.21

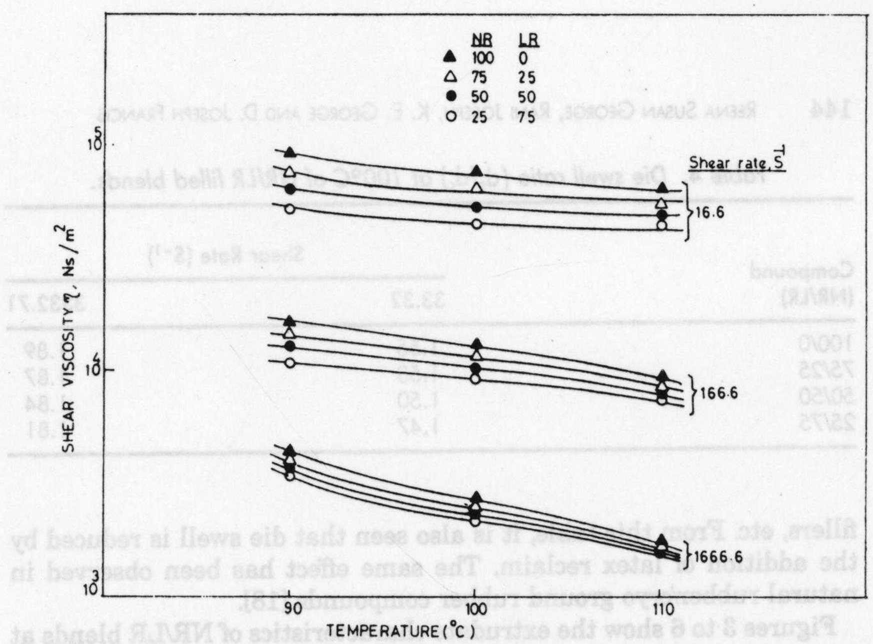

FIGURE 2. Variation in shear viscosity with temperature of NR and NR/LR blends.

NR/LR filled compounds at 90, 100 and 110°C at the two shear rates of 33.32 and 3332.71S^{-1}. In general, die swell increases with increase in shear rate, which is a common phenomenon exhibited by almost all rubber compounds. Die swell is a relaxation phenomenon since when the molten polymer flows through the capillary, shearing tends to maintain the molecular orientation of polymer chains and when the melt emerges from the die, the molecules tend to recoil, leading to the phenomenon of die swell. The elastic recovery of the polymer chain is influenced by such factors as stress relaxation, crosslinking, presence of

Table 3. Activation energy of flow (kJ mol⁻¹) of NR/LR filled blends.

Compound	Shear Rate (S^{-1})		
(NR/LR)	16.6	166.6	1666.6
100/0	4.0	3.4	2.8
75/25	3.6	3.3	2.7
50/50	3.4	3.1	2.5
25/75	3.2	2.9	2.2

Table 4. Die swell ratio (d_e/d_c) at 100°C of NR/LR filled blends.

Compound (NR/LR)	Shear Rate (S^{-1})	
	33.32	3332.71
100/0	1.55	1.89
75/25	1.53	1.87
50/50	1.50	1.84
25/75	1.47	1.81

fillers, etc. From this table, it is also seen that die swell is reduced by the addition of latex reclaim. The same effect has been observed in natural rubber/cryo ground rubber compounds [18].

Figures 3 to 6 show the extrudate characteristics of NR/LR blends at two shear rates at different temperatures. It is seen that the extrudates are smooth up to about 50 wt. percent latex reclaim in filled natural rubber compounds. This shows that there is good interparticle bonding between the latex reclaim and natural rubber. The compound containing about 75 wt. percent of latex reclaim gives extrudates with rough

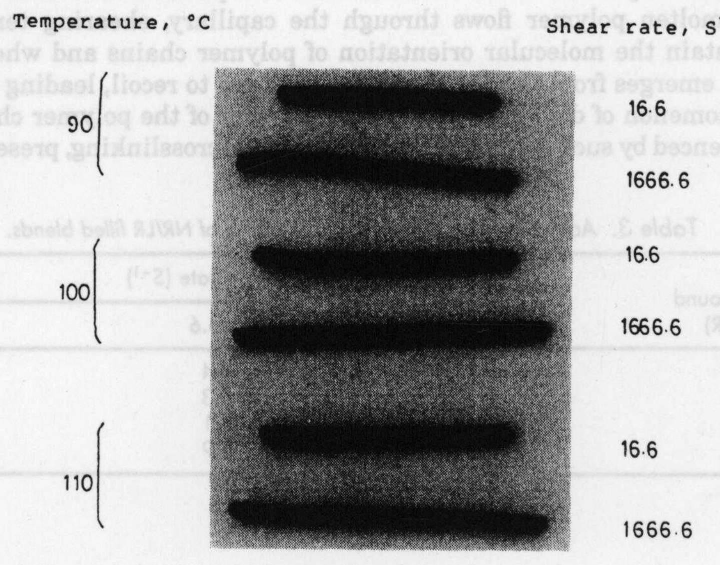

FIGURE 3. Extrudate photograph of NR at two shear rates at different temperatures.

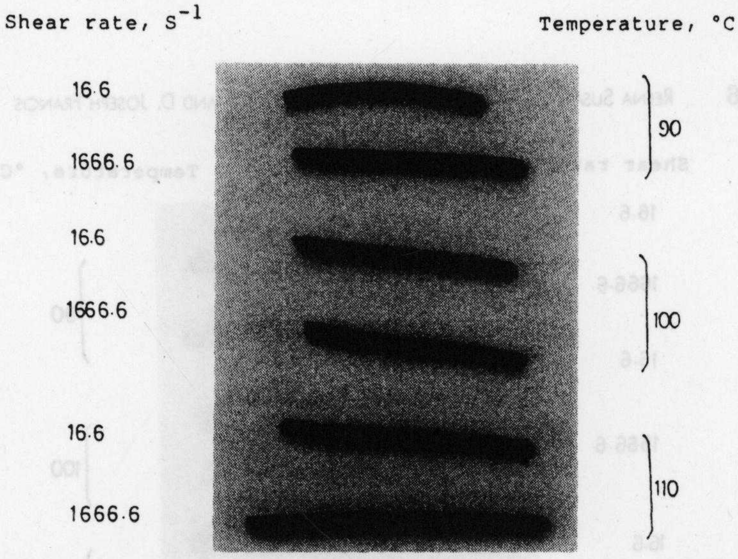

FIGURE 4. Extrudate photograph of NR/LR (75/25) blend at two shear rates at different temperatures.

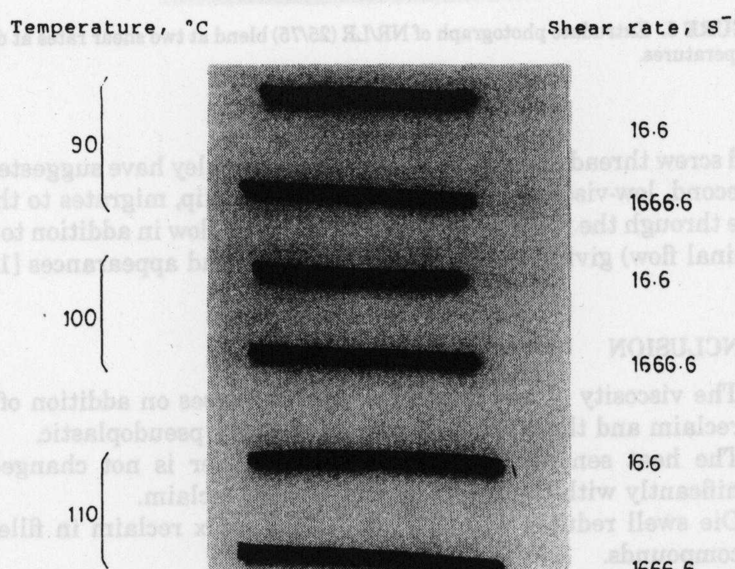

FIGURE 5. Extrudate photograph of NR/LR (50/50) blend at two shear rates at different temperatures.

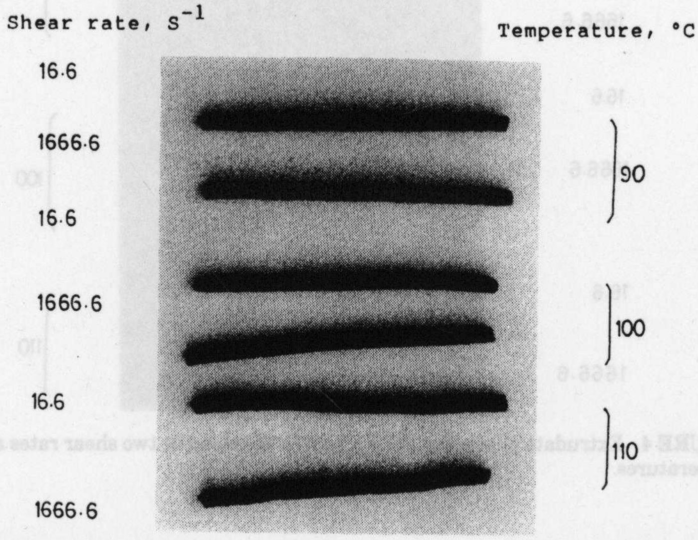

FIGURE 6. Extrudate photograph of NR/LR (25/75) blend at two shear rates at different temperatures.

and screw thread appearances. Turner and Bickley have suggested that a second, low-viscosity phase, which causes a slip, migrates to the surface through the roll mechanism action (radial flow in addition to longitudinal flow) giving the extrudates screw thread appearances [19].

CONCLUSION

1. The viscosity of raw natural rubber decreases on addition of latex reclaim and the NR/LR blends are strongly pseudoplastic.
2. The heat sensitivity of raw natural rubber is not changed significantly with the incorporation of latex reclaim.
3. Die swell reduces with the addition of latex reclaim in filled NR compounds.
4. The extrudates of NR/LR blends are smooth upto about 50 wt. percent LR.

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