Original Article

Compatibilization of natural rubber (NR) and chlorosulfonated polyethylene (CSM) blends with zinc salts of sulfonated natural rubber

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Abstract

A rubbery ionomer of zinc salt of sulfonated natural rubbers (Zn-SNR) was synthesized and used as a new compatibilizer for the blends of natural rubber (NR) and chlorosulfonated polyethylene (CSM). Epoxidized natural rubber (ENR) was also used for the preparation of NR/CSM blends. The effect of ionomer concentration on melt viscosity of the 50/50 (%wt/wt) NR/CSM blends at different constant shear rates was characterized. It was found that the incorporation of ionomer increased shear viscosity of the blends, indicating an increase in interfacial interaction between the NR and CSM. The maximum shear viscosity was observed when the ionomer of 10% by weight of NR was added into the blends. The tensile, tear, oil resistant properties and morphology of the various 20/80 NR/CSM blends with and without the Zn-SNR and ENR at the 10% wt of NR were examined. The 100% modulus, tensile strength, tear strength and oil resistance of the compatibilized blends improved over those of the uncompatibilized blends. The blends compatibilized with the Zn-SNR showed higher levels of improvement in modulus, tensile and tear strength than those of ENR. The tensile strength of 20/80 blends with the Zn-SNR and ENR compatibilizers increased by 38 and 30% over the corresponding neat blends. Furthermore, the addition of ionomer and ENR resulted in decreased domain of dispersed NR phase size and improved interfacial adhesion between the NR and CSM, indicating enhanced blend compatibility. These results suggest that the Zn-SNR is a new effective compatibilizer for NR and CSM blends.

Keywords: natural rubber (NR), chlorosulfonated polyethylene (CSM), blend, zinc sulfonated natural rubber (Zn-SNR),
compatibilizers

1. Introduction

Natural rubber (NR) is an important elastomer which exhibits excellent mechanical properties, and it has been increasingly used in a wide range of industrial applications. However, the resistance of natural rubber to oil and aging on exposure to oxygen, ozone and heat is poor because of its non-polar nature and reactive double bonds in the structure. This makes NR unsuitable for many high performance applications. A number of recent investigations have reported that blending of NR with other oil, ozone/oxygen and heat resis-

tant elastomers could improve the degree of oil, ozone and heat resistance. Basically, the performance of rubber blends is largely governed by various factors including the nature of rubbers (Stephen *et al.*, 2006; Sirqueira *et al.*, 2003; Sirisinha *et al.*, 2004), blend compositions (Naskar *et al.*, 1994; 2001), phase morphology of rubber blends (Sirisinha, *et al.* 2003) and interfacial cross-linking in rubber blends (Naskar *et al.*, 1994). For example, improved oil and thermal aging resistance were observed when NR was blended with chlorinated polyethylene (CPE) (Sirisinha *et al.*, 2004). Blends of NR with carboxylated styrene butadiene rubber (XSBR) (Stephen *et al.*, 2006) and EPDM (Sirqueira *et al.*, 2003) were reported to have better aging and ozone resistance. Sirisinha *et al.* (2003) have demonstrated that

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improved phase morphology in blends of NR and nitrile rubber (NBR) resulted in an increased oil resistant property of the blends. Naskar *et al.* (1994; 2001) studied blends of NR and carboxylated nitrile rubber (XNBR). They found that oil resistance and mechanical properties of NR/XNBR blends strongly depended on blend ratios and the degree of interfacial crosslinking between NR and XNBR components.

It is well known that chlorosulfonated polyethylene (CSM) is an important elastomer which has been frequently used in many applications such as sheeting cable and geo-membrane due to its outstanding resistance to deterioration by heat, oils, ozone and oxidation. Recently, blends of CSM with NR have been studied by Tanrattanakul and Petchkaew (2006). They reported that blends of NR and CSM were immisicible, except for NR rich blends (70-80%wt of NR), and that oil and ozone resistant properties of the blends increased with respect to CSM content. Further improvement in mechanical properties and compatibility of the blends could be obtained when a suitable compatibilizer, such as epoxidized natural rubber (ENR), was added to the blends.

Sulfonate ionomer is a polymeric material, consisting of a hydrophobic organic backbone chain and a relatively small amount of pendant ionic sulfonate groups ($-SO_3^-$) neutralized by metal counterions. An interest in sulfonate ionomer is primarily due to its unique properties, derived from strong associative interactions between ionic groups (Bazuin and Eisenberg, 1993). For example, increases in modulus, tensile strength, melt strength and glass transition temperature are some of the major changes when the ionic groups are incorporated into polymers. Recently, several sulfonate ionomers have been found to be effective as compatibilizers in various immiscible polymeric blends. (Dutta *et al.*, 1996; Li *et al.*, 2002; Son and Weiss, 2003; Zheng *et al.*, 2003; Bhiwankar and Weiss, 2006; Xie *et al.*, 2006). The compatibilizing effect has been shown by modification of the interfacial activity, which gives rise to improved morphology and superior mechanical properties of the blends. The addition of zinc salts of lightly sulfonated polystyrene ionomers (Zn-SPSs) as compatibilizers into blends of aromatic liquid crystalline polyester (LCP) and syndiotactic polystyrene significantly reduced the dispersed domain size and improved the tensile strength, ultimate elongation, and flexural toughness of the blends (Son and Weiss, 2003). Dutta *et al.* (1996) used Zn-SPS to increase tensile modulus and stress at break of LCP and polyamide (PA6) blends. They have shown that the increase in mechanical properties of the blends is caused by strong intermolecular interactions between the sulfonate and amide groups, leading to a reduction in dispersed phase size and an improvement in interfacial adhesion between the phases. Xie *et al.* (2006) have shown that blends of polystyrene and CSM with incorporation of ionomers of sulfonated styrene-butadiene-styrene copolymers possessed better mechanical properties and compatibility than those of blends without ionomers.

To the authors' knowledge, there has been no attempt to use zinc salt of sulfonated natural rubber as a compatibilizer for NR/CSM blend. However, the preparation of sulfonated type natural rubber (Faullimmel *et al.*, 1990) and synthetic rubbers (Canter, 1972; Rahrig *et al.* 1979; Xavier *et al.*, 2001; Xie *et al.*, 2005) was reported. Therefore, a rubbery ionomer of zinc salt of sulfonated natural rubber (Zn-SNR) was synthesized and used as a compatibilizing agent for preparation of NR and CSM blends. Epoxidized natural rubber (ENR) was also prepared and used as a compatibilizer in the blends for comparison reason because ENR containing a low level of epoxide groups (25%mole) is reported to be miscible with CSM at all blend composition (Mukhopadhyay and DE, 1991). FTIR was used to investigate the structure of compatibilizers. The effect of level of the Zn-SNR on melt viscosity of NR/CSM blends was investigated to determine the proper concentration of the compatibilizer for the preparation of NR/CSM blends. The mechanical, oil resistant properties and morphology of NR/CSM blends with and without compatibilizers were then studied.

2. Experimental

2.1 Materials

Chlorosulfonated polyethylene (CSM) is Hypalon®40 (DuPont Co., USA) with Mooney Viscosity of 63 [ML(1+4) at 100°C]. It contains 35% chlorine and 1% sulfur as sulfonyl chloride. The natural rubber used was Air-dried sheet (Thavorn Rubber Industry, Songkhla, Thailand). The natural rubber latex (Yala latex Co., Ltd., Yala, Thailand) used has a high concentration of ammonia with a dry rubber content of 60%. The chemical reagents used for preparation of sulfonated natural rubber (SNR) were triethyl phosphate or TEP (99%, Aldrich Chemical Co., Ltd, Germany) and fuming sulfuric acid (30% oleum with free SO_3 content 27-33%, Aldrich Chemical Co., Ltd, Germany). Zinc acetate (99.5%, Ajax Chemical Co., Ltd, Australia) was used as neutralizing agent. Teric N30 (alkylphenol ethoxylate) (Huntsman Corp. Australia Pty Ltd, Australia) was used as a non-ionic surfactant to stabilize the latex during epoxidation. Formic acid (94%, Fluka Chemie, Switzerland) was used as a reactant for preparation of ENR. Hydrogen peroxide (50% aqueous solution, Riedel De Haën, Germany) was used as a co-reactant for preparation of ENR. Potassium hydroxide (85%, Ajax Chemical Co., Ltd, Australia), phenolphthalein (99.8%, Riedel De Haën, Germany), methanol (99.8%, Lab Scan Asia Co., Ltd., Thailand), chloroform (99.8%, Aldrich Chemical Co., Ltd, Germany), 1,2-dichloroethane (99%, Aldrich Chemical Co., Ltd, Germany) were used as received. Magnesium oxide (Global Chemical Co., Ltd, Thailand) and stearic acid (Imperial Chemical Co., Ltd, Thailand) were used as activators. Sulfur (Ajax Chemical Co., Ltd, Thailand) was used as a vulcanizing agent. Dipentamethylenethiuram tetrasulfide (DPTT) (Flexsys, USA) was used as an accelerator.

2.2 Methods

2.2.1 Preparation of zinc salt of sulfonated natural rubber (Zn-SNR)

NR was masticated on a two-roll mill (150x300 mm) at room temperature. A masticated NR with Mooney viscosity [ML(1+4) at 100°C] of approximately 60 was used for preparation of zinc sulfonated natural rubber and also for blending with CSM. Sulfonation of NR was carried out by using the method described by Canter (1972). Triethyl phosphate (TEP) (0.005 mole) was dissolved in 1,2-dichloroethane (51.51 gm), and the mixture was cooled down to 5-6°C. Fuming sulfuric acid (0.015 mole) was slowly added into the mixture with agitation for 1 h. A complex of TEP/SO$_3$ was then added into the solution of NR in chloroform (5%wt). The sulfonation reaction was carried out at 30°C for 1 h. The sulfonated natural rubbers (SNRs) were precipitated using methanol and washed several times with distilled water. The modified rubbers were dried in a vacuum oven at 40°C for 36 h. The level of sulfonation was determined to be 17.5 miliequivalents (meq)/100 g of SNR by titration method (Makowski *et al.*, 1980). The SNRs were then dissolved in chloroform and added with excess zinc acetate to neutralize the acid groups. The rubbers were recovered using methanol and washed several times with distilled water before drying in a hot-air oven at 40°C for 48 h. The resultant products were designated as 17.5Zn-SNR, where 17.5 is the concentration of acid in meq/100 g of the Zn-SNR.

2.2.2 Preparation of epoxidized natural rubber (ENR)

ENR was prepared by epoxidation of NR latex with performic acid (Nakason *et al.*, 2001). The NR latex (2.05 moles or 232.50 gm) was added with distilled water (697 gm) and Teric N30 (10 gm). The mixture was then stirred for 30 min at 40°C. Formic acid (1.025 moles or 50.19 gm) and hydrogen peroxide (4.1 moles or 278.80 gm) were added to form *in situ* performic acid. The epoxidation was carried out for 2 h at 40°C to reach a required epoxy content of 20 mole% in ENR. The NR latex was coagulated in methanol and washed thoroughly with distilled water and dried in a vacuum oven at 40°C for 24 h. The level of the epoxide contents in the ENR products was studied by infrared spectroscopy via a calibration curve. (Davey and Loadman, 1984)

2.2.3 Preparation of blends

For the study of effect of the 17.5Zn-SNR concentration on the melt flow behaviour of NR/CSM blends, the NR was mixed with CSM in the composition of 50/50 %wt/wt. The blends were prepared in a brabender plasticorder mixer (PLE 331) operating at a chamber temperature of 70°C, rotor speed of 40 rpm, and blending time of 6 min. Firstly, the masticated NR was introduced into the preheated mixing chamber for 2 min, and added with the CSM. After mixing for 2 min, the Zn-SNR compatibilizers with different loading levels of 6, 10, 14, 18, 22 and 26% by weight of NR were mixed into the blends, and the mixing process was continued for another 2 min. The 50/50 blends without incorporation of the 17.5Zn-SNR were prepared using the identical experimental conditions and processing. In the case of the study of compatibilizing effect on the mechanical properties, oil resistant properties and morphology of the NR/CSM blends, the ratio of NR and CSM was kept at 20/80 %wt/wt to form the morphology, which NR was dispersed in CSM matrix. The preparation of 20/80 blends, with and without the compatibilizers (17.5Zn-SNR and ENR-20), were also prepared according to the procedure outlined above.

2.2.4 Compounding of blends

The masticated NR, CSM and 20/80 blends were compounded with other ingredients (stearic acid, MgO, Dipentamethylenethiuram tetrasulfide (DPTT) and sulfur) on a two-roll mill. The required quantities of ingredients are given in Table 1. The compounds were then compression molded at 150°C at their respective optimal cure time obtained by using ODR 100S.

2.2.5 Melt viscosity measurement

The melt viscosity of the 50/50 NR/CSM blends as a function of apparent shear rate with the addition of different concentrations of the 17.5Zn-SNR compatibilizer were characterized by using a Rosand single bore capillary rheometer (model RH7, Rosand Precision Ltd, Gloucestershire, UK). A capillary of length/diameter (L/D) ratio of 16/1 and an angle of entry 90° was used in all experiments. All studies were done in the shear range of 100-1500s^{-1}, and with a temperature of 70°C. The apparent values of shear rate and shear viscosity were calculated using a derivative of the Poiseuille law for the capillary flow as written in the following Eqs (1), (2) and (3); (Cogswell, 1981)

$$\tau = \frac{R\Delta P}{2L} \tag{1}$$

Table 1 Formulation of rubber compound

Ingredients	Parts per hundred parts of rubber
NR, CSM and Rubber blend[a]	100
MgO	10
Stearic acid	2
DPTT[b]	2
Sulfur	1.5

[a] 20/80 NR/CSM with and without 17.5Zn-SNR or ENR-20
[b] dipentamethylenethiuram tetrasulfide

$$\overset{\bullet}{\gamma}_{app} = \frac{4Q}{\pi R^3} \qquad (2)$$

$$\eta = \frac{\tau}{\overset{\bullet}{\gamma}_{app}} \qquad (3)$$

where τ is apparent shear stress (Pa), $\overset{\bullet}{\gamma}_{app}$ is apparent wall shear rate (s^{-1}), η is apparent shear viscosity (Pa s^{-1}), Q is the volumetric flow rate ($m^3 s^{-1}$), R is the capillary radius (m) and L is the length of the capillary (m).

2.2.5 Mechanical measurement

The tensile properties were determined according to ASTM D412 and the tear resistance was determined according to ASTM D642 at room temperature on Tensometer model H10KS at a speed of 500±50 mm/min.

2.2.6 Oil resistance measurement

Oil resistance measurements of blend vulcanizates were carried out according to ASTM D471-79. The test specimens were immersed in ASTM oil no.1 and IRM903 oil at room temperature (30±2°C) for 7 days. Thereafter, the test specimens were removed from the oil, quickly dipped in acetone, and blotted lightly with filter paper to remove excess oil from the surfaces. The percentage of change in volume of the specimen after oil immersion was used to determine the oil resistance of the blends.

2.2.7 Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectra were recorded on an Omnic ESP Magna-IR 560 in the ranges of 4000 to 400 cm^{-1} with a resolution of 2 cm^{-1}. The rubber spectra were obtained by using casting films on KBr discs. The solvent (toluene) was evaporated in a hot-air oven at 40°C for 1 h and in a vacuum oven at 40°C for 3h.

2.2.8 Scanning electron microscopy (SEM)

Studies of fracture surfaces of rubber blends were performed by using a scanning electron microscope (SEM) model VP 145, manufactured by Leo Co., Ltd., Cambridge, UK. Samples were cryogenically cracked in liquid nitrogen to avoid any possibility of phase deformation and gold-coated. The SEM photomicrographs were taken at magnification of 1500X.

3. Results and Discussion

3.1 FTIR analysis of the compatibilizers

IR spectroscopy has been widely used for identification of sulfonate groups in sulfonate ionomer (Lu and Weiss, 1992; Rahrig *et al.*, 1979; Xie *et al.*, 2005) and epoxide
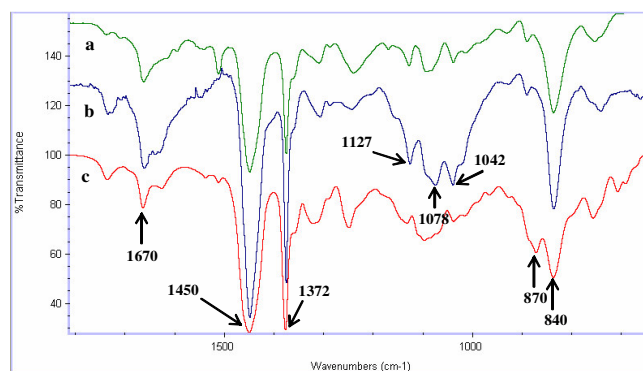

Figure 1. Infrared spectra of (a) NR, (b) 17.5Zn-SNR and (c) ENR-20.

groups in ENR (Nakason *et al.*, 2001). Figure 1 shows FTIR spectra of NR, 17.5Zn-SNR and ENR-20. It is seen from Figure 1 that the NR and modified NR samples show absorbance bands at 1372 and 1450 cm^{-1}, assigned to C-H bending of –CH$_2$ and CH$_3$ in NR backbone. The characteristic bands at 1670 cm^{-1} are due to the stretching of C=C in cis 1,4-polyisoprene. The peak at 840 cm^{-1} is ascribed to CH out of plane bending on C=C in cis 1,4-polyisoprene. The 17.5Zn-SNR (Figure 1(b)) shows broad and intense absorption peaks at 1042 cm^{-1} due to symmetrical stretching vibration of sulfonated anion (-SO$_3^-$) associated with zinc (SO$_3^-$Zn$^{2+}_{1/2}$) (Lu Weiss, 1992; Weiss *et al.*, 1991). This indicates the neutralization of acid functional groups in ionomer with zinc acetate. The two extra peaks at 1078 and 1127 cm^{-1} result from a sulfonate anion (SO$_3^-$) attached to a hydrocarbon backbone (Weiss *et al.*, 1991; Xavier *et al.*, 2001). In the case of ENR, there are two new absorption peaks at 1252 and 870 cm^{-1}, resulting from C-O stretching vibration and cis-epoxy ring vibration of epoxy groups, respectively (Roychoudhury *et al.*, 1993).

3.2 Effect of concentration of 17.5Zn-SNR on melt viscosity of NR/CSM blends

The experimental results obtained from melt viscosity measurements are tabulated in Table 2. Curves of apparent shear viscosity versus apparent shear rate of the 50/50 NR/CSM blends containing different concentrations of the 17.5 Zn-SNR compatibilizer are shown in Figure 2. It is clear from Figure 2 that the shear viscosity of the blends decrease with increasing shear rate. At lower shear rate, the viscosity of the compatibilized blends with the ionomer content in the range of 6-18% wt of NR appears to be relatively greater than that of the uncompatibilized blends (Figure 2 and Table 2). However, at higher shear rates the viscosity seems to be unaffected by compatibilization. By considering the apparent shear rates in the range of 100-400s^{-1}, curves of shear viscosity plotted against the concentration of 17.5Zn-SNR are shown in Figure 3. It is clearly seen from Figure 3 that the addition of the 17.5Zn-SNR into 50/50 NR/CSM blends results in an increase in melt viscosity of the blends.
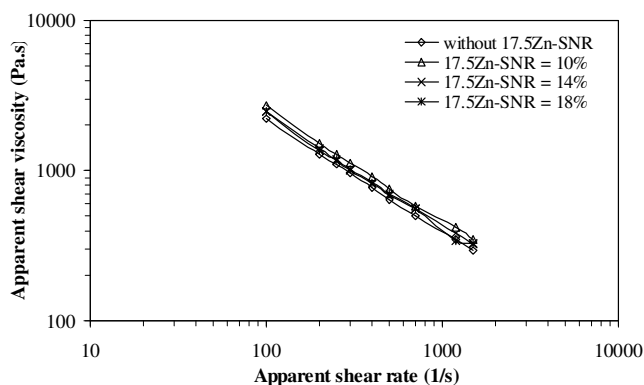
Figure 2. Effect of apparent shear rate on the melt viscosity of 50/50 NR/CSM blends with different concentrations of 17.5 Zn-SNR.

Figure 3. Effect of concentration of the 17.5Zn-SNR on melt viscosity of the 50/50 blends at apparent shear rates of 100-400s^{-1}.

In an incompatible blend, it is well accepted that the interface is characterized by sharp interface and no interaction between the two phases (Willis and Favis, 1988). Therefore, the blend frequently shows interlayer slip, giving rise to low viscosity of the blend. Upon compatibilization with the 17.5 Zn-SNR, the ionomer would locate at the interface between NR and CSM in the blend, and react with the rubber components to form a strong link at the interface. As a result of the addition of the ionomer, interfacial adhesion increased, leading to a reduction in slippage at the interface. Thus, this contributes to an increase in shear viscosity of the blends. At a given shear rate, increasing the content of 17.5Zn-SNR from 6 to 10 %wt of NR causes the viscosity of the blends to increase. However, further increasing the amount of Zn-SNR causes the viscosity of the blends to fall off. At higher content of the ionomer, the compatibilizer forms micelles in the blends (George *et al.*, 1999). The micelles dispersed in the blend may act as lubricant for the blend system, thus leading to a reduction of the blend viscosity. Hence, these results suggest that introduction of 17.5Zn-SNR increases the melt viscosity of the blends and that the addition of 10
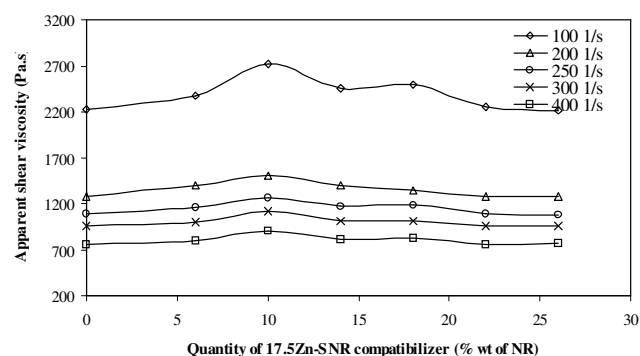
%wt of NR in NR/CSM blends provides the best compatibilizing effect.

3.3 Effect of 17.5Zn-SNR and ENR-20 on physical properties and morphology of NR/CSM blends

3.3.1 Tensile properties

Figure 4-7 show 100% modulus, tensile strength, elongation at break and tear strength of the 20/80 NR/CSM blends containing the 17.5Zn-SNR and ENR-20 compatibilizers (10% wt of NR) compared with the neat blends. The data of pure NR and CSM vulcanizates are also included in these figures. From these figures, it is seen that the mechanical properties of the pure CSM are higher than those of the pure NR, except in the case of elongation at break, and that the tensile and tear properties of the uncompatibilized NR/CSM blends fall in between the pure components. The addition of the 17.5 Zn-SNR and ENR-20 increases the 100% modulus, tensile strength and tear strength over those of the corresponding neat blends. The level of improvement in

Table 2. Summary of results obtained from melt viscosity measurements of 50/50 NR/CSM blends with different concentrations of 17.5Zn-SNR.

| Apparent shear rate (1/s)	Apparent shear viscosity (Pa.s)						
	Content of 17.5Zn-SNR (%wt of NR)						
	0	6	10	14	18	22	26
100	2223	2377	2714	2453	2496	2247	2217
200	1284	1397	1511	1399	1343	1283	1279
250	1096	1162	1269	1172	1191	1093	1079
300	956	994	1117	1009	1014	958	959
400	761	806	906	817	826	763	772
500	640	706	748	690	696	637	644
700	498	562	575	552	552	491	504
1200	345	394	418	384	343	338	331
1500	296	325	348	322	329	307	300
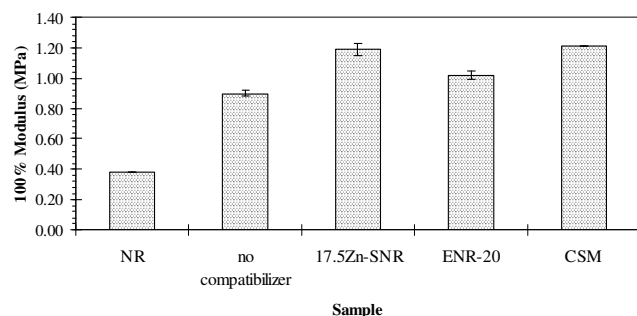
Figure 4. Comparison of 100% Modulus of NR, CSM and various 20/80 NR/CSM blends with and without incorporation of 17.5Zn-SNR and ENR-20.
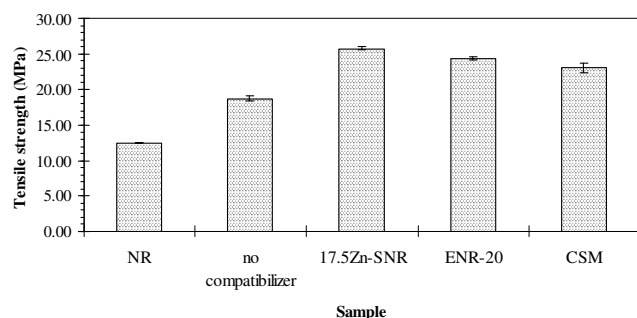

Figure 5. Comparison of tensile strength of NR, CSM and various 20/80 NR/CSM blends with and without incorporation of 17.5Zn-SNR and ENR-20.
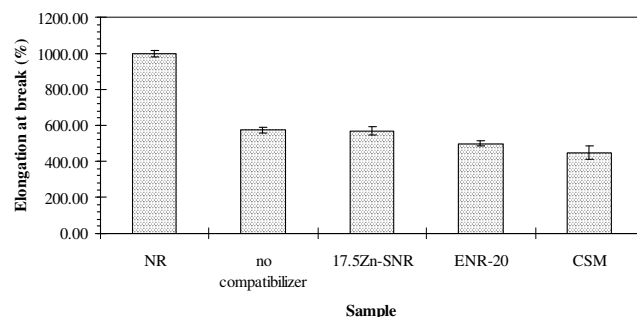

Figure 6. Comparison of elongation at break of NR, CSM and various 20/80 NR/CSM blends with and without incorporation of 17.5Zn-SNR and ENR-20.
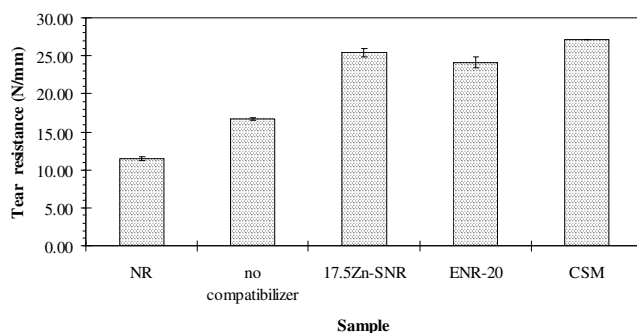

Figure 7. Comparison of tear strength of NR, CSM and various 20/80 NR/CSM blends with and without incorporation of 17.5Zn-SNR and ENR-20.

100% modulus, tensile and tear strength of the blends incorporating with the 17.5Zn-SNR is comparatively higher than those combined with the ENR-20. It is also interesting to note that the compatibilized blends exhibit greater tensile strength than those of the parent rubbers. It has been shown that the improvement in mechanical properties of compatibilized blends is due to an increase in the tolerable level of stress that could be transferred across the interface between blend components, resulting from improved adhesion at phase boundaries (Barlow and Paul, 1984). In our cases, the increase in modulus, tensile, and tear strength of the compatibilized 20/80 blends is due to the promotion of interfacial adhesion between rubber phases. This is attributed to an increase in specific interactions between the ionomer and ENR-20 with the component rubbers. In the case of the blends with the 17.5Zn-SNR, we propose that the sulfonic acid groups resulting from interactions between sulfonyl chloride in the CSM and water, obtained by the presence of MgO and stearic acid, reacted with the zinc sulfonated group ($SO_3^- Zn^{2+}_{1/2}$) in the ionomer to form ionic crosslinking between ionomer and CSM phases as shown in Figure 8. Consequently, the adhesion between the NR and CSM increases as a result of ionic crosslinking between the 17.5 Zn-SNR and CSM, and the compatibility of ionomer with the NR. For the ENR-20 compatibilized blends, it is believed that the epoxy group interacted with sulfonyl chloride of the CSM to yield sulfonate ester. Upon heating, the loss of sulfur dioxide ($-SO_2$) from sulfonate ester intermediate resulted in
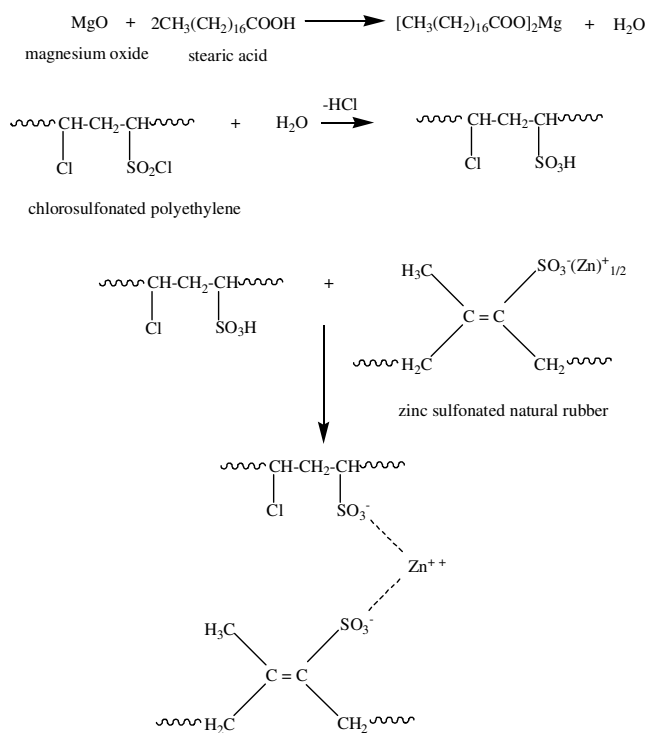

Figure 8. Possible ionic crosslinking reaction between zinc salt of sulfonated natural rubber (Zn-SNR) and chlorosulfonated polyethylene.
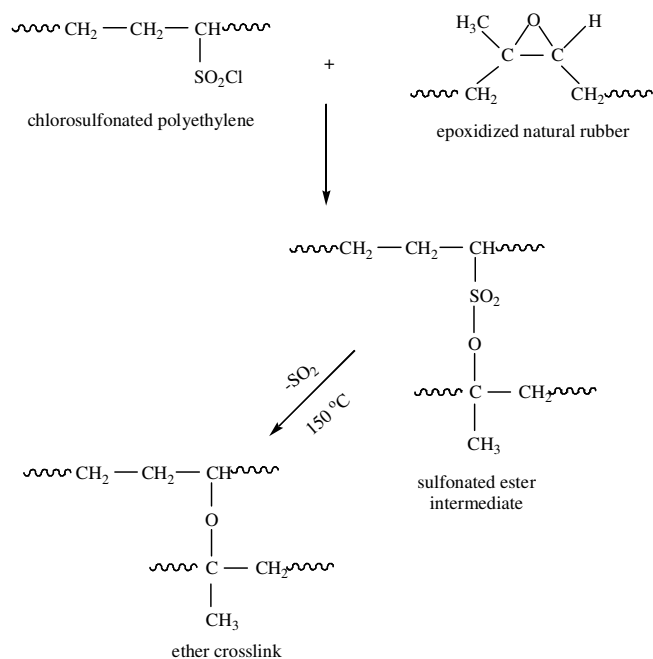
Figure 9. Possible crosslinking reaction between epoxidized natural rubber (ENR) and chlorosulfonated polyethylene.

ether linkage at the ENR and CSM interface (Roychoudhury *et al.*, 1993). The mechanism of blend compatibilization by ENR-20 may be written as shown in Figure 9. Therefore, the improved adhesion in blends with the ENR-20 is caused by ether linkages between the ENR-20 and CSM, also by the compatibility of ENR-20 and NR component. These results are in line with the observation obtained from shear viscosity measurements.

3.3.2 Oil resistance properties

Figures 10 and 11 show percent change in volume, corresponding to degree of oil resistance of the NR, CSM and various 20/80 blends. As expected, the % change in volume of the NR is much higher than that of the CSM, indicating a relatively low level of oil resistance. The 20/80 blend has a percentage of change in volume between those of the individual rubbers. Compatibilization by 17.5 Zn-SNR and ENR-20 leads to a greater degree of oil resistance in the blend. This is probably due to adequate interfacial adhesion at phase boundaries and an increase of surface area between NR and CSM by compatibilizing effect of ionomer and ENR-20.

3.3.3 Morphological properties

SEM micrographs of the cryogenically fractures for the 20/80 NR/CSM blends with and without compatibilizers are presented in Figure 12. The compatibilized blend of NR/CSM shows finer morphology with relatively smaller domains of the dispersed NR phase in the CSM matrix than
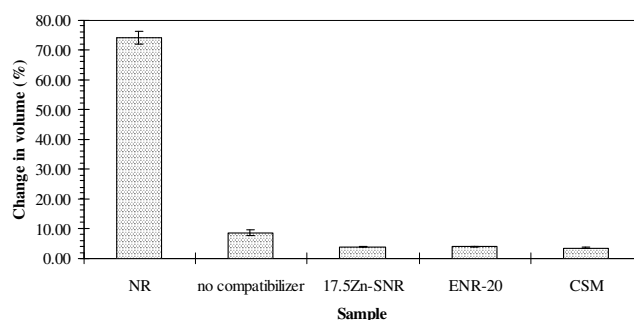

Figure 10. Comparison of % change in volume of NR, CSM and various 20/80 NR/CSM blends with and without 17.5 Zn-SNR and ENR-20 after immersion in ASTM oil No.1.
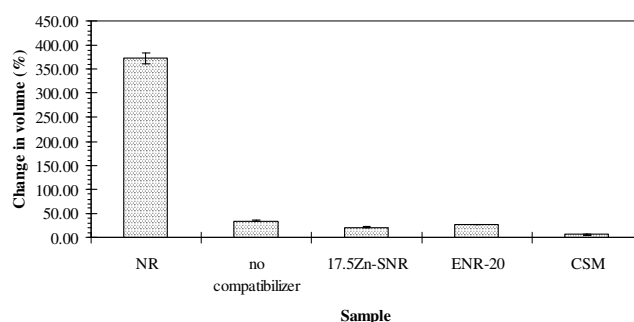

Figure 11. Comparison of % change in volume of NR, CSM and various 20/80 NR/CSM blends with and without 17.5 Zn-SNR and ENR-20 after immersion in IRM903 oil.

that of the uncompatibilzed blend, indicating reduced interfacial tension between rubber phases. Furthermore, it is seen from the figure that the incorporation of ionomer and ENR-20 improves interfacial adhesion between the NR particles and the CSM matrix as shown by a decreased number of particle cavities where the dispersed NR phase detached from the matrix. This suggests an increase in blend compatibility. Therefore, the SEM studies corroborate well with the results obtained from shear viscosity, mechanical and oil resistance measurements.

4. Conclusion

Zinc salt of sulfonated natural rubber (Zn-SNR) containing 17.5 meq/100 of SNR was prepared and used as a new compatibilizer for the preparation of NR and CSM blends. ENR-20 was also used as compatibilizer for such blends. The effect of ionomer concentration on shear viscosity at different constant shear rates was investigated. It was found that the shear viscosity of the blends with ionomers was higher than that of the neat blends, suggesting strong interaction between rubber phases. The shear viscosity of the blends was highest when combined with ionomer concentration of 10%wt of NR. The effect of 17.5Zn-SNR and ENR-20 at 10%wt of NR on the tensile, tear and oil resistant properties of 20/80 NR/CSM blends was studied. The incorporation of 17.5Zn-SNR and ENR-20 into 20/80 NR/
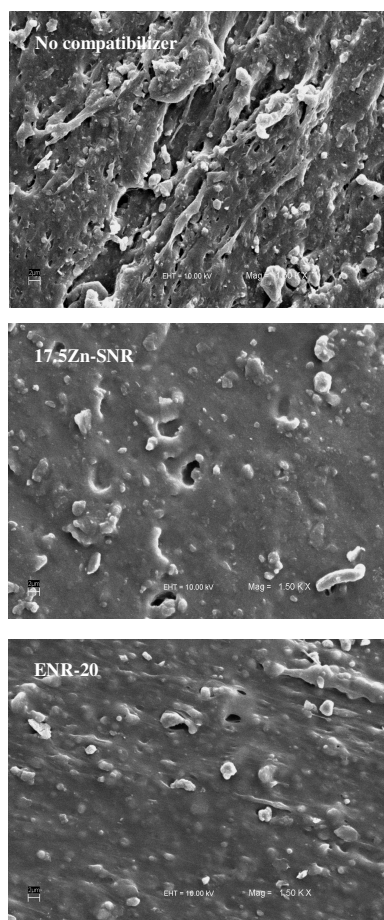
Figure 12. SEM micrographs of various 20/80 NR/CSM blends with and without 17.5Zn-SNR and ENR-20 (x1500).

CSM blends increased 100% modulus, tensile strength, tear strength and oil resistance as compared with those of uncompatibilized blends. The blends containing 17.5Zn-SNR showed a greater level of enhancement in 100%modulus, tensile and tear strength compared to those of ENR-20. SEM studies showed a reduced dispersed NR phase size and improved interfacial adhesion between NR and CSM in the blends with compatibilizers.

Acknowledgements

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