

## Nanoclay를 이용한 EPDM/SBR 블렌드 나노복합재료의 팽윤 및 압축변형, 마모저항 특성

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## Swelling Properties, Compression Set Behavior and Abrasion Resistance of Ethylene-propylene-diene Rubber/Styrene Butadiene Rubber Blend Nanocomposites

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**Abstract:** The ethylene-propylene-diene monomer (EPDM)/styrene-butadiene rubber (SBR)/nanoclay (NC) nanocomposites were prepared with various nanoclay contents loading and different crosslinking systems by using an open mill mixer. Sulfur, dicumyl peroxide and the mixed system were used as crosslinking systems for the nanocomposites. The effects of nanoclay loading and crosslinking systems on the swelling behavior, compression set behavior, abrasion resistance, hardness, rebound resilience and water uptake of EPDM/SBR blends were investigated. Mole percent uptake of aromatic, aliphatic and chlorinated hydrocarbons through the nanocomposites was investigated at 23 °C. The peroxide cured nanocomposites have exhibited the lowest solvent uptake in all the penetrant as well as the lowest uptake exhibited by aliphatic hydrocarbons. An increase in nanoclay loading resulted in reduction in water uptake and rebound resilience as well as increases in compression set, hardness, and abrasion resistance in all the crosslinking systems.

**Keywords:** EPDM/SBR blends, nanoclay loading, crosslinking systems, nanocomposites.

### Introduction

The unique properties which cannot be obtained from single components can be achieved by polymer blending. Polymeric blends are widely used in rubber products in order to improve physical and mechanical properties, service life, easy processing, at cheaper rate.<sup>1</sup> In the recent years, polymer nanocomposites are developed as a new class of materials and attracted substantial investment in research and development. The polymer nanocomposites have most interesting properties such as mechanical properties, thermal properties and barrier properties are attained at very low loading of the nanofillers compared to macro or micro-sized fillers.<sup>2-4</sup> As the decrease in fillers particle size, increases the specific surface area and the interaction between the matrix and the filler, which results in

improved properties of the polymer nanocomposites.<sup>2</sup> In the past, rubber/layered silicate nanocomposites are progressively attracting scientific and technological considerations due to the high reinforcing efficiency of the nano-silicate.<sup>5-7</sup> The reinforcing effect is reduced for nanocomposites with higher nanoclay loading due to the poor dispersion of clay.<sup>8</sup> Perhaps three types of nanocomposites were categorized, depending upon the dispersion of the nanoclay in the polymer matrices i.e., traditional polymeric nanocomposites, intercalated polymeric nanocomposites and exfoliated polymeric nanocomposites.<sup>9,10</sup>

The nanoparticles have significant potential of filling the gaps in the rubber and reduce the gas diffusion and permeability in the rubber. Many investigators and researchers have considered addition of the nanoparticles to the rubber.<sup>11-16</sup> The properties can also be significantly improved, including increased resistance to solvents and flammability.<sup>17</sup> The high aspect ratio clay layers having nano-size in the composites significantly reduce liquid and gas permeability by impressive a tortuous pathway to the permeant. The polymer solvent inter-

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action through the filled rubber composite are affected by various factors such as nature of the polymer, nature and distribution of crosslinks, nature of plasticisers, nature of the penetrants, filler, temperature, polymer molecular weight, crystallinity and orientation and nature of blending. Swelling behaviour of nanocomposites is mainly depending on the crosslinking in nanocomposites. Crosslinking is mainly depending on the amount of curing agents, filler rubber interaction and temperature.<sup>18</sup>

Mostafa *et al.*<sup>19</sup> observed that swelling percentage decreases, compression set increases with increasing content of carbon black (CB) for both styrene butadiene rubber (SBR) and acrylonitrile butadiene rubber (NBR) filled compounds. Arroyo *et al.*<sup>5</sup> reported that the incorporation of octadecyl amine modified montmorillonite (10 phr) into the natural rubber (NR) is sufficient to achieve the same mechanical behavior compared to the nanocomposites containing NR with 40 phr of carbon black. Rajasekar *et al.*<sup>20</sup> investigated the incorporation of nanoclay in epoxidized natural rubber (ENR) by solution mixing and then ENR-nanoclay composites (ENC) are incorporated in the NBR with sulfur as a curing agent. They observed that there is a significant improvement in mechanical properties, compression set, dynamic mechanical properties, swelling and morphological studies of the nanocomposites. Many researchers broadly studied about the fluid resistance and compression set in rubber compounds and rubber blend compounds filled with different kinds of filler.<sup>21-24</sup> Anil Kumar *et al.*<sup>25</sup> studied that the transport characteristics of the EPDM and EPDM/high density polyethylene (HDPE) blends in terms of the blend ratio, morphology, penetrant size, and temperature. The transport behavior of these blends using different organic liquids (aromatic and aliphatic hydrocarbons) and vapour permeation behaviour of these blends using chlorinated hydrocarbons also was studied. Dannenberg *et al.*<sup>26</sup> investigated the effect of a variety of carbon blacks, having a wide range of surface areas, on the reduction of the equilibrium swelling volume of synthetic rubber. Boonstra *et al.*<sup>27</sup> reported equilibrium swelling of a series of solvents in natural rubber, SBR, butyl rubber, neoprene and nitrile rubber containing carbon blacks, silica and hard clays as fillers. It was observed that certain fillers, cause a reduction in swelling of the membranes which is commensurate with the volume loading of the filler, and the effect of different carbon blacks and varying loadings were reported.<sup>28-31</sup> The kinetics of swelling of rubber and black-filled SBR vulcanizates in the presence of iso-octane has been studied.<sup>32</sup> Aminabhavi *et al.* have published a series of articles

relating the various rubber-solvent interactions.<sup>33-36</sup>

The aim of this research work is to prepare the blends of ethylene-propylene-diene monomer and styrene-butadiene rubber filled with nanoclay and to study the effect of nanoclay loading and crosslinking systems on the solvent uptake (mole percent uptake), percentage of the compression set, abrasion resistance and water uptake of the EPDM/SBR rubber blends.

## Experimental

**Materials.** Ethylene-propylene-diene monomer (KEP 270), content of ethylene 68 wt%, content of ethylidene norbornene 4.5%, Mooney viscosity (ML (1+4) 125 °C) 60 M, density 0.86 g/cm<sup>3</sup> and styrene-butadiene rubber (SBR 1502), content of styrene 23 wt%, Mooney viscosity (ML (1+4) 100 °C) 52 M, density 0.93 g/cm<sup>3</sup> were bought from Lanxess India Pvt. Ltd, India. Cloisite 30B (cation exchange capacity of 90 meqv./100 g clay), were obtained from Southern Clay Products, Inc., USA. The rubber chemicals used such as zinc oxide, stearic acid, mercapto benzo thiazyl disulfide (MBTS), tetramethyl thiuram disulfide (TMTD), sulfur and dicumyl peroxide were of commercial grade. The solvents benzene, toluene, xylene, *n*-pentane, and chloroform were obtained from Sigma Aldrich (Subra Scientific Company, Pondicherry, India), Merck grade with 99.98% initial purity.

**Preparation of Nanocomposites.** The rubber nanocomposites were prepared in a two roll mixing mill operated at 80 °C and rotors having friction ratio of 1:1.4. EPDM was masticated and then blended with SBR. Then nanoclay and curatives were added orderly. The compounding formulations of the nanocomposites are shown in Table 1. The different types of crosslinking systems used namely are sulfur (S), dicumyl peroxide (DCP) and the mixed system consisting of sulfur and dicumyl peroxide (S+DCP) are indicated as S, P and M, respectively. The nanocomposites containing sulfur system are labeled as S<sub>0</sub> (80/20/0 EPDM/SBR/NC), S<sub>2.5</sub> (80/20/2.5 EPDM/SBR/NC), S<sub>5</sub> (80/20/5 EPDM/SBR/NC) and so on. Similarly, the nanocomposites containing dicumyl peroxide and mixed systems are labeled, respectively, as P<sub>0</sub> and M<sub>0</sub> (80/20/0 EPDM/SBR/NC), P<sub>2.5</sub> and M<sub>2.5</sub> (80/20/2.5 EPDM/SBR/NC), P<sub>5</sub> and M<sub>5</sub> (80/20/5 EPDM/SBR/NC) and so on. The compounded blends were molded into sheets of 2 mm thickness using an electrically heated hydraulic press under a pressure of 30 MPa at a 160 °C and at an optimum curing time.

**Measurements. Swelling Measurements:** Swelling test according to ASTM D471 was performed on 25 mm×25 mm

**Table 1. Formulation for EPDM/SBR/NC Rubber Blends**

Sample code	Crosslinking system types	Compounds (phr)								
		EPDM	SBR	Clay	Zinc oxide	Stearic acid	MBTS	TMTD	Sulfur	Dicumyl peroxide
S <sub>0</sub>	Sulfur system	80	20	0	4	1.5	1.2	1	2.5	-
S <sub>2.5</sub>		80	20	2.5	4	1.5	1.2	1	2.5	-
S <sub>5</sub>		80	20	5	4	1.5	1.2	1	2.5	-
S <sub>7.5</sub>		80	20	7.5	4	1.5	1.2	1	2.5	-
S <sub>10</sub>		80	20	10	4	1.5	1.2	1	2.5	-
P <sub>0</sub>	Peroxide system	80	20	0	-	-	-	-	-	4
P <sub>2.5</sub>		80	20	2.5	-	-	-	-	-	4
P <sub>5</sub>		80	20	5	-	-	-	-	-	4
P <sub>7.5</sub>		80	20	7.5	-	-	-	-	-	4
P <sub>10</sub>		80	20	10	-	-	-	-	-	4
M <sub>0</sub>	Mixed systems	80	20	0	4	1.5	1.2	1	2.5	4
M <sub>2.5</sub>		80	20	2.5	4	1.5	1.2	1	2.5	4
M <sub>5</sub>		80	20	5	4	1.5	1.2	1	2.5	4
M <sub>7.5</sub>		80	20	7.5	4	1.5	1.2	1	2.5	4
M <sub>10</sub>		80	20	10	4	1.5	1.2	1	2.5	4

×2 mm sample from the vulcanized sheet by the immersion method. The corners of the specimen were slightly curved to obtain uniform absorption. The initial dry weight of the specimens was measured. Then the specimen completely immersed in a series of aromatic (benzene, toluene, and xylene), aliphatic (*n*-pentane) and chlorinated (chloroform) hydrocarbons in glass diffusion bottles at room temperature for 72 h. After, the test specimen was taken out and cleans the surface of the samples using tissue paper and the swollen weight of the specimens was measured. The mole percent uptake  $Q_t$  for solvent was determined using the eq. (1)

$$Q_t = \frac{(M_t - M_0)/MW}{M_0} \times 100 \quad (1)$$

Where,  $M_t$  is the mass of the specimen after time 72 h of immersion,  $M_0$  is the initial mass of the specimen and  $MW$  is the molecular weight of the solvent.

**Compression Set Measurements:** Compression set test according to ASTM D395 was performed on cylindrical specimen size of  $\Phi 29 \pm 0.1$  mm and thickness  $12 \pm 0.2$  mm. The test sample is placed in the middle of the rectangular plates of the compression device by the spacers arranged each side of it, allowing adequate clearance for bulging of the rubber when a compressive load is applied. The bolts are tightened; therefore

they are drawn together uniformly until in contact with the spacers. The percentage of compression working is 25% of its original thickness. Then the assembled device was placed at 70 and 100 °C for 24 h in an air circulating oven. After completion, the compression device is taken from the air circulating oven and then the test specimen removed instantaneously and allowable to cool for ambient temperature. The final thickness is measured by an electronic digital Vernier caliper with 0.01 mm accuracy. The compression set was determined using eq. (2)

$$\text{Percentage of compression set} = \frac{t_0 - t_1}{t_0 - t_s} \times 100 \quad (2)$$

Where  $t_0$  is the original thickness of the specimen,  $t_1$  is the specimen thickness after removed from the compression device and  $t_s$  is the spacer bar thickness which is used.

**Mechanical Properties:** The abrasion test of the EPDM/SBR nanocomposites was performed using the DIN abrasion tester in order to determine the abrasion loss of the rubber vulcanizates according to ASTM D 5963. The hardness of the rubber nanocomposites was measured by Shore A hardness Durometer tester as per ASTM D 2240 standard. The rebound resilience of the EPDM/SBR nanocomposites was carried out according to the ASTM D 2632. In this method, a plunger suspended from a given height above the specimen was released

and the rebound height was determined. The ratio of the rebound height and the original height is stated to as the rebound resilience and expressed as a percentage. The test was performed on the vertical rebound tester as resiliometer. The density of the rubber nanocomposites was calculated using the Archimedes' principle by the help of electronic weighing balance with an accuracy level of 0.001 gm. The minimum of five readings was measured, and the average values were reported.

**Water Uptake:** Water uptake test according to ASTM D 471 was performed on 25 mm×25 mm×2 mm sample from the vulcanized sheet by the immersion method. The initial weight of the sample was measured using an electronic weighing balance with an accuracy level of 0.001 gm. The samples were completely immersed in water in glass bottles kept at uniform temperature. The samples were removed from the water at specific time intervals (7, 14, 21, 28, 35, 42 and 84 days), excess water at the surface removed using filter paper and weighed. The samples were then put in the glass bottle immediately. The process was continued at seven different intervals are reached. The water uptake was calculated using the eq. (3).

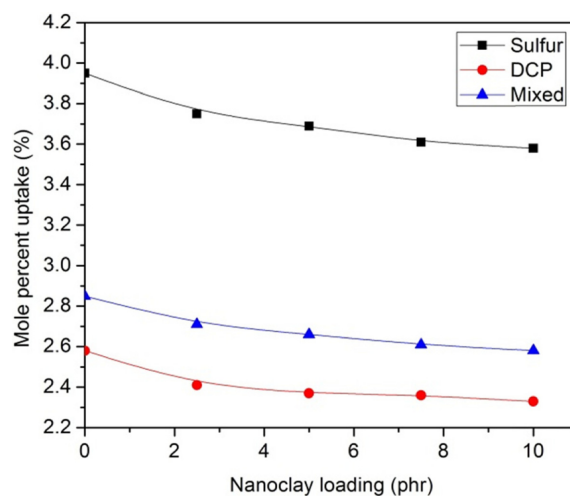
$$\frac{W_t - W_0}{W_0} \times 100 \quad (3)$$

Where  $W_t$  is the weight of samples at different interval and  $W_0$  is the initial weight of the samples before placing in water. The average of five readings is reported for each sample.

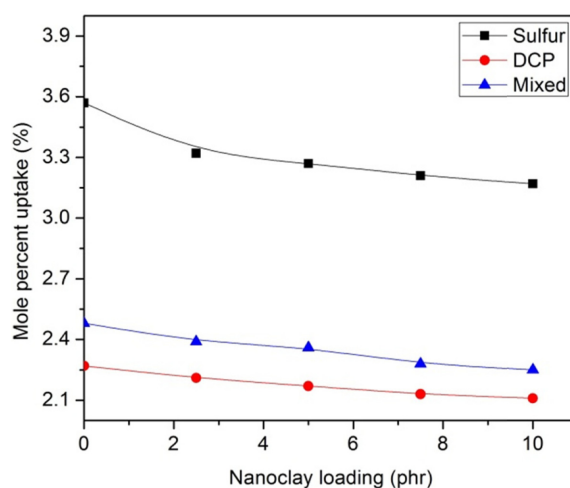
## Results and Discussion

**Swelling Behaviour.** In order to determine the effect of the nanoclay loading on swelling behavior of EPDM/SBR nanocomposites, the mole percent uptake is carried out at different hydrocarbons such as aromatic, aliphatic and chlorinated hydrocarbons. Benzene, toluene, xylene, *n*-pentane and chloroform solvents were used. Benzene, toluene, and xylene is an aromatic, *n*-pentane is an aliphatic while chloroform is chlorinated solvent. Rubbers have been used in a number of barrier applications in which it comes under the influence of solvents. These solvents have different ability to dissolve or to swell the rubber nanocomposites.

In this present work, the influence of nanoclay loading, crosslinking systems and nature of penetrants on swelling through EPDM/SBR blends was analyzed. The swelling behavior of nanocomposites depends on the types of filler, matrix, reaction between solvent and matrix, temperature, etc. The Figure 1 shows mole percent uptake of benzene  $Q_t\%$  with

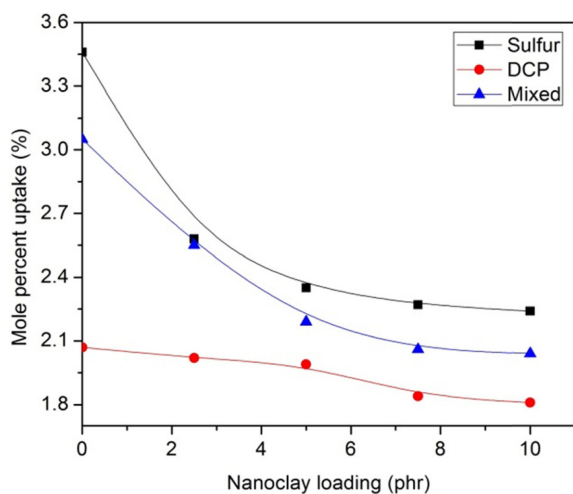


**Figure 1.** Mole percent uptake of benzene for EPDM/SBR/NC rubber blend nanocomposites.

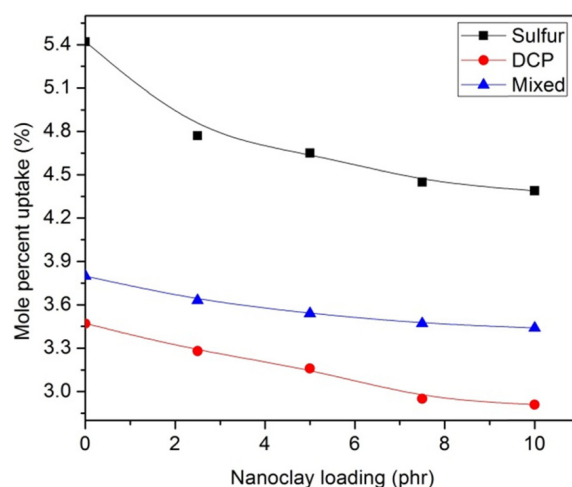


**Figure 2.** Mole percent uptake of toluene for EPDM/SBR/NC rubber blend nanocomposites.

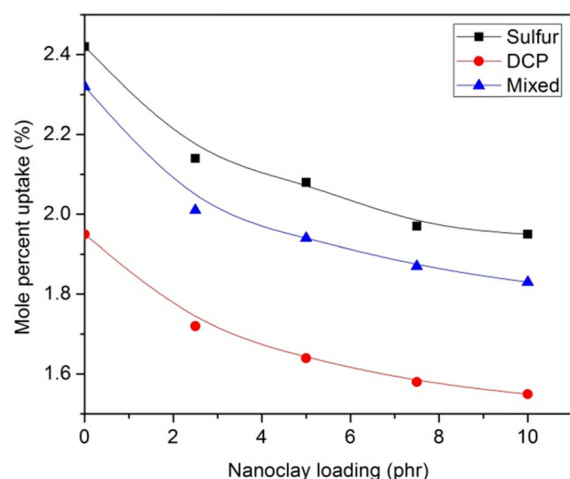
three different crosslinking systems, namely, sulfur, peroxide, and the mixed systems, at different nanoclay loading reinforced EPDM/SBR blends nanocomposites. The mole percent of benzene uptake was decreased with increasing content of nanoclay for all the crosslinking systems. The sulfur cured nanocomposites show the relatively fast in the great affinity to uptake benzene. In this figure, clearly shows that peroxide cured nanocomposites have the lowest equilibrium uptake while the sulfur cured nanocomposites have the highest equilibrium uptake. The mixed system exhibited an intermediate behavior. The difference in the uptake values of EPDM/SBR vulcanized with different crosslinking systems may possibly due to the formation of different types of crosslinks between



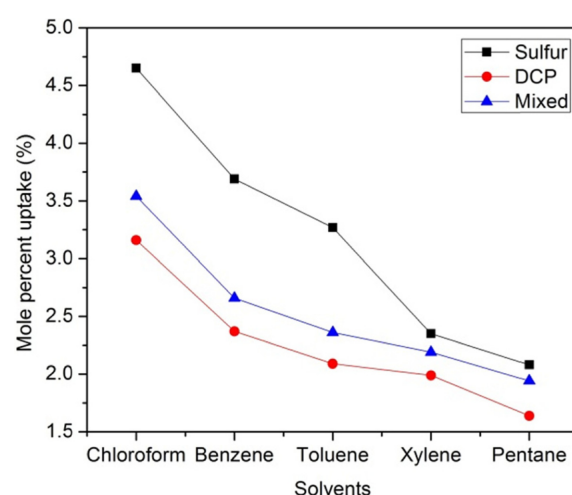
**Figure 3.** Mole percent uptake of xylene for EPDM/SBR/NC rubber blend nanocomposites.



**Figure 5.** Mole percent uptake of chloroform for EPDM/SBR/NC rubber blend nanocomposites.



**Figure 4.** Mole percent uptake of *n*-pentane for EPDM/SBR/NC rubber blend nanocomposites.



**Figure 6.** Mole percent uptake of different solvents for 5 phr nanoclay filled EPDM/SBR rubber blend nanocomposites.

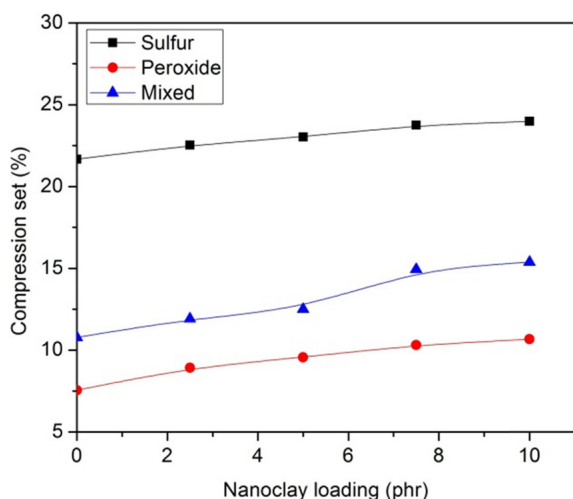
rubber chains during vulcanization.<sup>37</sup> The sulfur crosslinked system introduces flexible polysulfide bonds between the macromolecular chains. This permits the easy accommodation of solvents molecules within the EPDM/SBR matrix. The peroxide crosslinked system has only stable C-C bonds and as a result lowest uptake values. The same trend was observed with toluene, xylene, *n*-pentane and chloroform as shown in Figures 2-5, respectively. It is interesting to note that the solvent uptake values decrease in the order sulfur > mixed > peroxide. The mole percent uptake reduces with the increasing of the network.

From the Figures 1-3, it is experimentally observed that benzene uptake is maximum while the xylene uptake is minimum

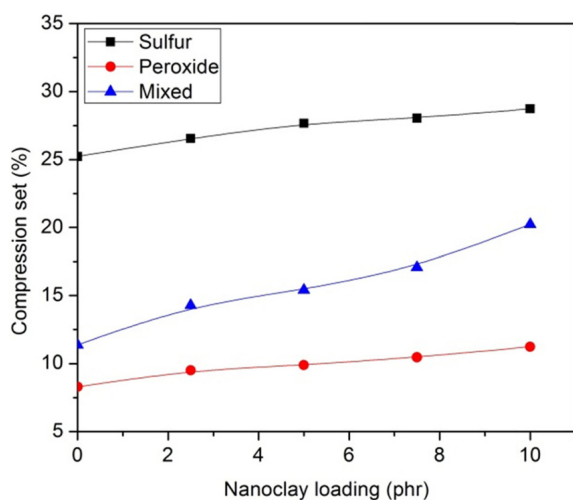
in aromatic hydrocarbons. From benzene to xylene, there is a decrease in the mole percent uptake in all the crosslinking systems. This decrease in mole percent uptake with increase in penetrant size is because of the greater activation energy necessary for activation of the diffusion process.<sup>38</sup> On the other hand, the low molecular weight of the penetrant molecule shows the highest uptake as well as the high molecular weight of the solvent shows the lowest uptake. From the Figures 4-5, it clearly shows that swelling behavior of aliphatic (*n*-pentane) and chlorinated hydrocarbons (chloroform) through EPDM/SBR-NC nanocomposites vulcanized by different crosslinking systems follows a similar trend to that of aromatic hydrocarbons (benzene, toluene and xylene). Figure 6 shows the

mole percent uptake of different solvents for 5 phr nanoclay filled EPDM/SBR rubber blends nanocomposites. The solvent uptake follows the trend chlorinated > aromatic > aliphatic hydrocarbons, among the three hydrocarbons used.

**Compression Set Properties.** In order to determine the effect of nanoclay loading on the compression set behavior of EPDM/SBR nanocomposites, the compression set test is carried out at different exposure temperature and constant hours such as 70 and 100 °C for 24 h. The Figures 7-8 represents the compression set for EPDM/SBR nanocomposites filled with different nanoclay loading under different conditions 70 and 100 °C for 24 h, respectively. Figure 7 shows the variation of



**Figure 7.** Effect of nanoclay loading on the compression set of EPDM/SBR rubber blend nanocomposites at 70 °C.



**Figure 8.** Effect of nanoclay loading on the compression set of EPDM/SBR rubber blend nanocomposites at 100 °C.

the percentage of compression set of the EPDM/SBR nanocomposites with the nanoclay loading and different crosslinking systems at 70 °C. In the case of unfilled nanoclay compounds, the compression set is low, while as nanoclay loading increases, the compression set increases. This is due to nanoclay loading increases the crosslinking density increases and the mobility of the long rubber chains decreases; consequently, induce stiffness in the nanocomposites.<sup>39</sup> The definite amount (25% strain) of compression is applied to the rubber samples, the enormous crosslinks attempt to the resistance of this compression which stated as increasing the stiffness of the rubber nanocomposites. During this compression resistance some of the crosslinks have been broken; consequently when the load relieved the number of crosslinks responsible for this strain recovery is less than the number of crosslinks responsible to resisting compression. Hence, the samples not recovered to its original thickness. As anticipated for increasing crosslinking density, the alteration to break more crosslinks increase which consequences in high percentage of compression set. The sulfur cured nanocomposites show the highest compression set. Compression set at different crosslinking systems follows the order sulfur > mixed > peroxide. The lower compression set shows the better retainable elastic properties. The same trend was observed with 100 °C compression set as shown in Figure 8. The condition 100 °C compression set test exhibit the highest value compare to 70 °C. The temperature increases compression set also increases. The compression set is lower, the better the material for use.

**Mechanical Properties.** The additions of fillers in the matrix enhance the mechanical properties of the composite. The reinforcement effect in the polymer materials is directly related to the interphase properties and depends on the nature of the specific interactions between the polymer matrix and fillers.<sup>40</sup> The incorporation of filler into the polymer materials imparts many useful properties to the composite materials. The properties mostly depend on the dispersion condition of filler particles such as particle size, surface area, surface activity, aggregate structure and rubber-filler interactions.<sup>41</sup> Optimum reinforcing control can be achieved by the advantage of filler is better dispersed in the rubber matrix. The chemical or physical interaction between the filler and the rubber is an additional important aspect in the reinforcing effect.<sup>42</sup> The interaction between reinforcing fillers and rubber matrix has an important effect on the properties of rubber composite. A rubber-rubber interaction primarily occurs when rubber blends are used in composites and are not considered as important to

filler-filler and filler-rubber interactions. Filler-filler interaction is explained by the attraction of filler to filler and the ability to form a network while filler-rubber interactions are explained by the compatibility of the filler with the rubber. Filler-filler interactions are a most important mechanism in reinforcement, particularly at high filler loading. These interactions depend on chemical interactions between the filler particle surfaces such as filler-filler and filler-rubber, physical interactions such as Vander Waals forces and hydrogen bonding, filler volume fraction and morphology of the filler network.

The significant results obtained from the mechanical properties such as DIN abrasion test, Shore A hardness, rebound resilience and density of the nanoclay filled EPDM/SBR nanocomposites are shown in the Table 2. Abrasion resistance of the nanoclay filled EPDM/SBR nanocomposites, expressed as abrasion loss has been studied for sulfur, peroxide and mixed system cured blends, and is presented in Table 2. The abrasion resistance of a solid body is defined as its ability to withstand the progressive removal of material from its surface as the result of the mechanical action of a rubbing, scraping, or erosive nature.<sup>43</sup> The abrasion resistance of nanocomposites increases with increase in nanoclay content for all the three different curing system. Nanoclay as reinforcing filler, that interacts better with the rubber phase, as revealed by the higher reduction of abrasion loss in the nanocomposites. This

improvement is may be due to the better rubber-filler interfacial adhesion and greater surface area resulting in an enhanced abrasion resistance.<sup>44</sup> Fine particles, in fact, reflect their greater interfacial adhesion between the filler and the rubber matrix as well as are responsible for a better abrasion resistance. Similar effects were also reported by former researchers.<sup>45,46</sup> The peroxide cured system exhibits higher abrasion loss, sulfur cured system shows the lowest abrasion loss and the mixed system exhibited an intermediate behavior. It was evident that the abrasion resistance of the S<sub>2.5</sub>, S<sub>5</sub>, S<sub>7.5</sub> and S<sub>10</sub> of the sulfur cured nanoclay loaded nanocomposites was 31, 44, 54 and 59% higher than that of their respective control S<sub>0</sub>. Similarly, peroxide cured nanocomposites was 18, 27, 32 and 34% as well as mixed system cured nanocomposites was 18, 29, 36 and 43% higher than that of their respective control P<sub>0</sub> and M<sub>0</sub>.

Hardness is defined as the resistance to indentation. It is an indication of the relative stiffness of rubber nanocomposites.<sup>43</sup> As clear from the Table 2, incorporation of nanoclay into the EPDM/SBR matrix was found to enhance the hardness of nanocomposites. It can be found that nanoclay improved the stiffness of the rubber nanocomposites. Improvement of hardness in the case of polymer-nanoclay nanocomposites has similarly reported by these researchers.<sup>44,47-49</sup> They proposed that the increase of hardness is interconnected to the degree of dispersion of nanoclay layers within the polymer matrix. The generally increased reinforcement of the nanocomposites must be attributed to the dispersed structure of nanoclay at the nano-level, the high aspect ratio and the planar orientation of the silicate layers.<sup>50</sup> The hardness increases in nanocomposites as an indication of the resistance to indentation is high with adding nanoclay in the rubber matrix. Sulfur cured nanocomposites exhibited the lowest hardness; mixed system shows an intermediate as well as the peroxide system shows a higher hardness. It was evident that the hardness of the S<sub>10</sub>, P<sub>10</sub> and M<sub>10</sub> nanocomposites was 19%, 23% and 22% higher than that of their respective control S<sub>0</sub>, P<sub>0</sub>, and M<sub>0</sub> respectively. Density also increases with increasing nanoclay content for all the crosslinking systems. The mixed system exhibited the highest density, sulfur cured nanocomposites shows an intermediate and peroxide cured system has the lowest density. Density of the above respective nanocomposites was 2.99, 2.89 and 3.12% higher than their respective controls.

The effect of nanoclay loading and crosslinking system on the rebound resilience of the nanocomposites is seen in Table 2. The rebound resilience of nanocomposites decreases with increase in nanoclay content for all the three different curing

**Table 2. Mechanical Properties of EPDM/SBR Filled Nanoclay**

Sample code	Abrasion loss (mm <sup>3</sup> )	Hardness (Shore A)	Rebound resilience (%)	Density (g/cm <sup>3</sup> )
S <sub>0</sub>	79.1	59	78	1.171
S <sub>2.5</sub>	60.3	63	77	1.180
S <sub>5</sub>	54.8	65	74	1.190
S <sub>7.5</sub>	51.2	68	70	1.198
S <sub>10</sub>	49.9	70	66	1.206
P <sub>0</sub>	189.8	62	71	1.143
P <sub>2.5</sub>	161.4	66	69	1.152
P <sub>5</sub>	149.7	69	66	1.158
P <sub>7.5</sub>	144.3	74	62	1.166
P <sub>10</sub>	141.9	76	57	1.176
M <sub>0</sub>	113.8	57	73	1.185
M <sub>2.5</sub>	96.8	62	72	1.197
M <sub>5</sub>	88.1	66	70	1.205
M <sub>7.5</sub>	83.9	70	66	1.214
M <sub>10</sub>	79.5	73	63	1.222

**Table 3. Percentage Uptake of Distilled Water by the EPDM/SBR Blends Filled with Nanoclay at Ambient Temperature**

Sample code	Water uptake (%)						
	After 7 days	After 14 days	After 21 days	After 28 days	After 35 days	After 42 days	After 84 days
S <sub>0</sub>	0.14	0.21	0.35	0.56	0.69	1.25	1.53
S <sub>2.5</sub>	0.08	0.16	0.31	0.47	0.55	0.78	1.17
S <sub>5</sub>	0.07	0.14	0.22	0.29	0.43	0.65	1.01
S <sub>7.5</sub>	0.07	0.14	0.22	0.22	0.37	0.52	0.9
S <sub>10</sub>	0.07	0.14	0.14	0.28	0.35	0.49	0.69
P <sub>0</sub>	0.22	0.36	0.5	0.86	1.59	2.31	3.46
P <sub>2.5</sub>	0.15	0.3	0.45	0.68	1.21	1.67	2.27
P <sub>5</sub>	0.15	0.22	0.37	0.6	0.97	1.49	2.09
P <sub>7.5</sub>	0.07	0.14	0.34	0.48	0.69	1.24	1.72
P <sub>10</sub>	0.07	0.14	0.28	0.41	0.62	0.83	1.31
M <sub>0</sub>	0.15	0.38	0.76	1.53	1.76	1.91	2.21
M <sub>2.5</sub>	0.14	0.28	0.56	0.97	1.11	1.39	1.74
M <sub>5</sub>	0.07	0.22	0.44	0.73	1.02	1.24	1.61
M <sub>7.5</sub>	0.07	0.14	0.35	0.49	0.69	0.9	1.39
M <sub>10</sub>	0.07	0.14	0.2	0.34	0.47	0.68	0.95

system. The decreasing tendency may be attributed to better rubber-filler interaction. As filler particles increases in the rubber matrix, the elasticity of the rubber chains is reduced, resulting in lower rebound resilience properties.<sup>51</sup> The important factor in the rubber nanocomposites is a surface activity, showing the extent of rubber-filler interaction. The increasing incorporation of the nanofillers into rubber matrix, this can lead to an increase in hardness as well as a reduction in rebound resilience, predominantly with more reinforcing filler.<sup>52</sup> The rebound resilience of the (S<sub>10</sub>, P<sub>10</sub> and M<sub>10</sub>) nanocomposites was 15, 20, and 14% lesser than their respective controls (S<sub>0</sub>, P<sub>0</sub> and M<sub>0</sub>). From the Table 2, sulfur cured nanocomposites show the highest rebound resilience. Rebound resilience at different crosslinking systems follows the order sulfur > mixed > peroxide.

**Water Uptake Properties.** The distilled water uptake properties of different crosslinking systems cured EPDM/SBR blends with nanoclay loading were investigated and the water uptake at regular intervals is shown in Table 3. The water uptake of the EPDM/SBR blends with nanoclay loading in seven stages after 7, 14, 21, 28, 35, 42 and 84 days were studied. Table 3 are clearly shown that the uptake of water decreased with an increase in nanoclay content due to the increase in crosslink density of the nanocomposites. The peroxide cured system showed highest uptake of distilled water

and the sulfur system exhibited lowest uptake of distilled water. The mixed system exhibited an intermediate behavior. The highest distilled water uptake of peroxide cured nanocomposites may be due to the free volumes created by the leaching out of unreacted peroxide, which is water sensitive, from the polymer matrix and nanoclay. Hence, the water resistance increases with an increasing content of nanoclay.

## Conclusions

In the present study, swelling properties from mole percent uptake, compression set, mechanical properties and water uptake behavior of EPDM/SBR filled with nanoclay compounds the following conclusions were derived from the investigational results:

The mole percent uptake decreases with increasing nanoclay content. The solvent uptake at different hydrocarbons and crosslinking systems follows the order chlorinated > aromatic > aliphatic hydrocarbon solvent and sulfur > mixed > peroxide cured nanocomposites, respectively.

Compression set increases with increasing content of nanoclay due to crosslinking density increases but the mobility of the long rubber chains decreases. It is of different crosslinking systems follows the order sulfur > mixed > peroxide. The lower compression set shows the better retainable elastic prop-



erties. The temperature increases compression set also increases. The compression set is lower, the better the material for use.

The abrasion resistance of nanocomposites increases with increase in nanoclay content for all the three different curing system due to the better rubber-filler interfacial adhesion and greater surface area. The abrasion resistance of different cross-linking systems follows the order peroxide > mixed > sulfur cured nanocomposites.

As hardness increases, rebound resilience decreases with increasing content of nanoclay due to better rubber-filler interaction. Uptake of water decreased with an increase in nanoclay content due to the increase in crosslink density of the nanocomposites.

## References

1. W. M. Hess, P. C. Vegvari, and R. A. Swor, *Rubber Chem. Technol.*, **58**, 350 (1985).
2. L. Szazdi, A. Pozsgay, and B. Pukanszky, *Eur. Polym. J.*, **43**, 345 (2007).
3. P. C. LeBaron, Z. Wang, and T. J. Pinnavaia, *Appl. Clay Sci.*, **15**, 11 (1999).
4. L. A. Goettler, K. Y. Lee, and H. Thakkar, *Polym. Rev.*, **47**, 291 (2007).
5. M. Arroyo, M. A. Lopez Manchado, and B. Herrero, *Polymer*, **44**, 2447 (2003).
6. J. Carretero-Gonzalez, R. Verdejo, S. Toki, B. S. Hsiao, E. P. Giannelis, and M. A. Lopez-Manchado, *Macromolecules*, **41**, 2295 (2008).
7. F. Al-Yamani and L. A. Goettler, *Rubber Chem. Technol.*, **80**, 100 (2007).
8. Y. Munusamy, H. Ismail, M. Mariatti, and C. T. Ratnam, *J. Reinf. Plast. Compos.*, **27**, 1925 (2008).
9. Z. Zhang, L. Zhang, Y. Li, and H. Xu, *Polymer*, **46**, 129 (2005).
10. J. T. Yoon, W. H. Jo, M. S. Lee, and M. B. Ko, *Polymer*, **42**, 329 (2001).
11. S. R. Ha, S. H. Ryu, S. J. Park, and K. Y. Rhee, *Mater. Sci. Eng. A*, **448**, 264 (2007).
12. M. Arroyo, M. A. Lopez-Manchado, J. L. Valentin, and J. Carretero, *Compos. Sci. Technol.*, **67**, 1330 (2007).
13. S. J. Ahmadi, Y. Huang, and W. Li, *Compos. Sci. Technol.*, **65**, 1069 (2005).
14. Y. P. Wu, Y. Q. Wang, H. F. Zhang, Y. Z. Wang, D. S. Yu, L. Q. Zhang, and J. Yang, *Compos. Sci. Technol.*, **65**, 1195 (2005).
15. W. G. Hwang, K. H. Wei, and C. M. Wu, *Polymer*, **45**, 5729 (2004).
16. M. Apostolo and F. Triulzi, *J. Fluorine Chem.*, **125**, 303 (2004).
17. W. Kim, S. K. Kim, J. H. Kang, Y. Choe, and Y. W. Chang, *Macromol. Res.*, **14**, 187 (2006).
18. E. M. Asha, R. P. Singh, and S. Thomas, *Polym. Eng. Sci.*, **43**, 704 (2003).
19. A. Mostafa, A. Abouel-Kasem, M. R. Bayoumi, and M. G. El-Sebaie, *Mater. Des.*, **30**, 1561 (2009).
20. R. Rajasekar, K. Pal, G. Heinrich, A. Das, and C. K. Das, *Mater. Des.*, **30**, 3839 (2009).
21. A. N. Nabil, D. G. Hundiware, U. R. Kapadi, and S. Mishra, *Polym. Plast. Technol. Eng.*, **44**, 1159 (2005).
22. M. Y. L. Chew and X. Zhou, *Polym. Test.*, **21**, 187 (2002).
23. M. Kojima, M. Tosaka, E. Funami, K. Nitta, M. Ohshima, and S. Kohjiya, *J. Supercrit. Fluids*, **35**, 175 (2005).
24. P. V. Anil Kumar, Ph.D. Thesis, Mahatma Gandhi University, Kerala, India, March 2012.
25. K. T. Gillen, M. Celina, and R. Bernstein, *Polym. Degrad. Stabil.*, **82**, 25 (2003).
26. E. M. Dannenberg, *Ind. Eng. Chem.*, **40**, 2199 (1948).
27. B. B. S. T. Boonstra and E. M. Dannenberg, *Rubber Age*, **82**, 838 (1958).
28. L. S. Waksman, N. S. Schneider, and N. H. Sung, *Barrier Polymers and structures*, Am. Chem. Soc. Symp. Ser. 423, Koros WJ Ed., Washington, Chap.20 (1990).
29. E. M. Southern and A. G. Thomas, *Trans. Faraday Soc.*, **63**, 1913 (1967).
30. E. Southern and A. G. Thomas, *J. Polym. Sci.; Part A: Polym. Chem.*, **3**, 46 (1965).
31. S. N. Lawandy and F. H. Helaly, *J. Appl. Polym. Sci.*, **32**, 5279 (1986).
32. P. B. Stickney and W. J. Mueller, *Rubber Chem. Technol.*, **42**, 604 (1969).
33. T. M. Aminabhavi and S. B. Harogopad, *J. Chem. Educ.*, **68**, 343 (1991).
34. U. S. Aithal and T. M. Aminabhavi, *Polymer*, **31**, 1757 (1990).
35. U. S. Aithal and T. M. Aminabhavi, *J. Chem. Educ.*, **67**, 82 (1990).
36. T. M. Aminabhavi, R. H. Balundgi, and P. E. Cassidy, *Polym. Plast. Technol. Eng.*, **29**, 235 (1990).
37. G. Unnikrishnan and S. Thomas, *Polymer*, **39**, 3933 (1998).
38. S. C. George, S. Thomas, and K. N. Ninan, *Polymer*, **37**, 5839 (1996).
39. M. V. D. Schuur and R. J. Gaymans, *Polymer*, **46**, 6862 (2005).
40. V. Arrighi, S. Gagliardi, J. S. Higgins, A. Triolo, and J.-M. Zanotti, *Quasielastic neutron scattering as a probe of molecular motion in polymer-filler systems*, E-MRS Spring Meeting, N-15, Strasbourg, France, 2002.
41. J. Persello, *Designing nanostructured particular fillers for elastomers. Role of nanostructure and polymer filler interactions in rubber reinforcement*, E-MRS Spring Meeting, N-8, Strasbourg, France, 2002.
42. M. Zaborski and J. B. Donnet, *Macromol. Symp.*, **194**, 87 (2003).
43. M. Durandish and A. Alipour, *Chin. J. Polym. Sci.*, **31**, 660 (2013).
44. A. Alipour, G. Naderi, G. R. Bakhshandeh, H. Vali, and S. Shokoohi, *Int. Polym. Proc.*, **26**, 48 (2011).

45. P. Sae-oui, C. Rakdee, and P. Thanmathorn, *J. Appl. Polym. Sci.*, **83**, 2485 (2002).
46. M. Biswas and S. SinhaRay, *Polymer*, **39**, 6423 (1998).
47. M. A. Lopez-Manchado, B. Herrero, and M. Arroyo, *Polym. Int.*, **53**, 1766 (2004).
48. P. Bala, B. K. Samantaray, S. K. Srivastava, and G. B. Nando, *J. Appl. Polym. Sci.*, **92**, 3583 (2004).
49. S. Varghese, K. G. Gatos, A. A. Apostolov, and J. Karger-Kocsis, *J. Appl. Polym. Sci.*, **92**, 543 (2004).
50. Y. P. Wu, Q. X. Jia, D. S. Yu, and L. Q. Zhang, *J. Appl. Polym. Sci.*, **89**, 3855 (2003).
51. W. Arayaprane and L. R. Garry, *J. Appl. Polym. Sci.*, **109**, 932 (2008).
52. J. E. Jacques, *Rubber compounding, rubber technology and manufacture*, 2nd ed., Blow CM, Hepburn C, Butterworths, UK, p 386 (1985).