Research Article

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Enhancement of mechanical properties of natural rubber–clay nanocomposites through incorporation of silanated organoclay into natural rubber latex

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Abstract: In this study, cetyl trimethyl ammonium bromide (CTAB) modified montmorillonite (MMT) which is called as organoclay (OMMT) was mixed with natural rubber, and masterbatches were produced using the acid-free co-coagulation (AFCC) method in the presence of a combined gelling agent, a mixture of CTAB and sodium dodecyl sulfate. The OMMT was further modified by grafting of bis(triethoxysilylpropyl)tetrasulfide as to reduce the surface energy in silanated organoclay (OMMT-S). As expected, the nanocomposites prepared with OMMT-S compared to those with OMMT exhibited greater mechanical properties due to the development of rubber–clay interactions and due to proper dispersion of small clay layers in the rubber matrix combined with the gelling agent. The improvement of elongation at break, hardness and tear strength of the nanocomposites with OMMT/OMMT-S was an added advantage when the nanocomposites are prepared using the AFCC method without having any adverse effect from the combined gelling agent.

Keywords: nanocomposite, natural rubber, co-coagulation, organoclay, gelling agent

1 Introduction

Natural rubber (NR)-based products are at high demand due to remarkable properties of NR, which are not found in other materials. NR exhibits excellent mechanical properties with the addition of fillers, vulcanizing systems and other specialty chemicals (1). Composition of the cis-1,4-polysoprene polymer together with non-rubber substances such as various proteins and phospholipids plays an important role to enhance tensile strength and green strength due to its unique behavior of strain-induced crystallization (2). Carbon black, silica, calcium carbonate, kaolin and mica are widely used as conventional fillers in enhancing different properties of NR, depending on the type of filler used. In general, carbon black-filled NR exhibits a higher modulus than silica-filled NR at a similar filler loading (3). However, silica provides a unique combination of tear strength and ageing resistance but not the best tensile strength. Conventional clay is also not good for achieving highly improved tensile properties. In recent years, nanoclays at a loading of less than 10 phr have attracted attention in enhancing such properties of NR (4–6). However, tensile properties were not improved as expected; the tensile strength was less than 30 MPa and the elongation at break was less than 600% (2,7–14).

Montmorillonite (MMT) clay is widely used in the preparation of nanocomposites with NR, due to its availability, intercalation/exfoliation chemistry, higher surface area with improved surface activity and excellent swelling behavior (15). The incorporation of MMT into dry NR using conventional mechanical mixing is difficult due to its incompatibility and hence organically modified clay (organoclay) is used in common. Increased interlayer gallery space of organoclay was exhibited in NR nanocomposites; however, the tensile strength was not improved greatly (16–21). The preparation of dispersions of organoclay without clay aggregation is difficult due to its poor solubility in the aqueous medium and hence its addition to natural rubber latex (NRL) is limited (22), especially by the latex blending method. This limitation could be overcome by modifying clay with silane coupling agents that form sulfur crosslinks between clay and rubber chains (23) and increase interphase strength of both inorganic and organic phases (24). The hydrophilic nature of clay is converted into hydrophobic nature after silane modification (25). Alkoxo groups of the silane coupling agents react with silanol groups of clay such as silica and form

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siloxane bonds, thereby the surface energy of clay is reduced (26), which assists in releasing clay layers from clay stacks at the stage of mechanical mixing. This silane modification provides many advantages in the NR clay nanocomposite such as reduction of both compound viscosity and filler–filler interactions and improvement of rubber–clay interactions and thereby improves mechanical properties (27). Silane coupling agents are directly added as a liquid form into clay-filled rubber in many industrial applications. However, a proper distribution of clay and silane coupling agents in NR by such method is difficult at moderate temperature (27). Silane coupling agents could react with curatives (28) and non-rubber (29). Self-condensation of silane coupling agents and steric hindrance for vulcanization are possible when excess silane is used. However, silane agents are mixed with clay-filled rubber at the compounding stage before the addition of curatives to prevent the reaction with curatives. These undesirable effects associated with the direct addition of silane coupling agents to clay are prevented by grafting silane coupling agents on clay before incorporation into NR. Some studies reported that silane-grafted MMT (30–32) or silane-grafted organically modified MMT (33,34) was incorporated into various polymers mainly by mechanical mixing, but for NR it was not frequently used. However, few studies used silane-grafted clay with NR by mechanical mixing (35) and latex blending (36). However, none of the studies were carried out using the newly developed acid-free co-coagulation (AFCC) method.

The AFCC method has been used, as an alternative method to the conventional latex blending method, in the preparation of NR–clay nanocomposites by incorporating dispersions of organoclay into NRL in previous studies (37,38). These studies reported that a greater tensile strength along with less reduction in elongation at break was achieved at the organoclay loading of 2 phr, due to retaining of exfoliated clay structures during destabilization of NRL. However, the slow drying stage of the AFCC method was the major drawback to establish this method for large-scale production in industrial applications. Therefore, an attempt was made to prevent slow drying of the AFCC method using proper gelling agents and is presented in this study. Modification of organoclay by silane coupling agents, formation of gelling agent by combination of cetyl trimethyl ammonium bromide (CTAB) and sodium dodecyl sulfate (SDS) and destabilization of clay-filled NR by the newly developed AFCC method for improving the mechanical properties are discussed as a new trend in the field of clay-filled NR nanocomposites.

2 Experimental

2.1 Materials

High ammonia preserved centrifuged NRL with a dry rubber content of 60% was purchased from Hanwella Rubber (Pvt) Ltd (Sri Lanka). MMT under the trade name of Cloisite-116 was supplied by Southern Clay Products (USA). MMT has a cation exchange capacity (CEC) of 80 meq/100 g and an interlayer distance of 1.25 nm (in non-hydrated form). CTAB, which was used to modify the MMT and as a component of the gelling agent, and SDS, which was the other component of the gelling agent, were purchased from GloChem Pvt Ltd (Sri Lanka). Bis(triethoxysilylpropyl)tetrasulfide (TESPT) used as the grafting agent was purchased from Evonik Catalyst Pvt Ltd (India). Ethanol, sodium salt of a condensed acrylsulfonic acid (Dispersol LR) as a surfactant for dispersion of organoclay, sulfur, mercaptobenzothiazole sulfonamide (MBTS), zinc oxide, stearic acid for vulcanization and phenolic type antioxidant Lowinox CPL were of industrial grade and were used without further purification.

2.2 Preparation of silanated organoclay

A 3 wt% aqueous suspension of MMT was prepared under vigorous stirring using a magnetic stirrer at 40–50°C. Further mixing was carried out by means of an attrition mill (model 01HD; Union Process, USA) operated at 600 rpm speed for 30 min and of an ultrasonic stirrer (Qsonica, USA) operated at 20 kHz frequency for 15 min. Eighteen millimoles of CTAB in 500 dm³ of water were added into 3 wt% MMT suspension and mixed in the attrition mill for 30 min and in the sonicator for 15 min. The suspension was left aside overnight and the product was filtered. The de-watered suspension was washed several times with distilled water using vacuum filtration to remove bromide ions and checked for no white precipitate with 0.1 M AgNO₃. It was then dried in a vacuum oven at 60°C for 2 days. The resultant CTAB-modified MMT particles were ground using a mortar and pestle into a fine powder (called as OMMT). A 3 wt% OMMT suspension was prepared, in the
presence of 15 wt% Dispersol LR, using a mechanical stirrer operated at a speed of 200 rpm followed by further mixing in the attrition mill and the ultrasonic stirrer under the same processing conditions.

OMMT was further modified by TESPT. The amount of TESPT required for the modification of MMT was determined according to the following equation (39):

\[
\text{Amount of TESPT (g)} = \frac{\text{CEC} \times 1.2 \times \text{M. wt. of TESPT} \times \text{Amount of MMT}}{1,000}
\]

Molecular weight (M.wt.) of TESPT and CEC of MMT used in the modification were 538.95 g and 80 meq per 100 g of MMT, respectively. OMMT was added to the TESPT in ethanol solution (maintaining a pH value of 4 using hydrochloric acid) and mixed at 70°C for 2 h under refluxing. Ethanol concentration was adjusted to 90 wt% by adding distilled water and mixing was continued for 14 h under the same conditions. The product was filtered, washed with distilled water to remove the un-reacted TESPT, and dried in an oven at 60°C for 48 h. The modified OMMT crystals were ground into a powder (called as OMMT-S). A 3 wt% OMMT-S suspension was prepared similar to the preparation of OMMT suspension.

2.3 Characterization of OMMT and OMMT-S

The Fourier transform infrared (FTIR) spectra of MMT, OMMT and OMMT-S were obtained using a FTIR spectrometer (Bruker Alpha) in the attenuated total reflectance (ATR) mode. The spectra were taken using a KRS-5 prism placed at an angle of incidence of 45° at a resolution of 4 cm\(^{-1}\). One hundred scans were signal averaged for each material over the spectral range of 400–4,000 cm\(^{-1}\).

X-ray diffraction (XRD) technique was used to evaluate the structural behavior of OMMT and OMMT-S at a wavelength of 1.54 Å of Cu Kα radiation using a diffractometer (D8, Bruker, Germany). Scanning was carried out over a Bragg angle (2\(\theta\)) ranging from 4° to 10° at a rate of 0.01° of step size. Interlayer gallery space, \(d\), of OMMT/OMMT-S was calculated using the conventional Bragg equation, given by:

\[
n\lambda = 2d \sin \theta
\]

where \(\lambda\) is the wavelength of X-rays, \(\theta\) is the angle between incident radiation and scattering plan and \(n\) is the order of diffraction.

2.4 Preparation of NR–clay nanocomposites

OMMT and OMMT-S suspensions were added to the deammoniated centrifuged NRL in the presence of 1 phr loading of 10 wt% SDS dispersion and stirred at 60 rpm for 24 h to prepare nanocomposite masterbatches having 2 and 5 phr loadings of OMMT/OMMT-S. A 2 phr loading of 10 wt% CTAB dispersion was then added to the OMMT/OMMT-S NRL mixtures in aluminum pans for gelling. The optimum CTAB:SDS ratio was 2:1 based on the gelling efficiency. The resultant gels were pressed by hand and were dried in an air-circulated oven at 50°C for 1 day. The dried sheets were milled to obtain even thickness and were dried again for another 2 days in a smoke house under similar conditions used in ribbed smoke rubber production. The prepared masterbatches were named as C-2 and C-5 (2 and 5 phr of OMMT) and S-2 and S-5 (2 and 5 phr of OMMT-S). The masterbatch prepared without OMMT or OMMT-S was named as Control.

Zinc oxide, stearic acid and antioxidant were incorporated into the masterbatches as per the formulation given in Table 1 using a Brabender plasticorder operated at a speed of 60 rpm for 5 min. Sulfur and MBTS were added to the compounds using a two-roll mill operated for 2 min. The nanocomposite compounds were vulcanized using an electrically heated hydraulic press (Moore, England) at 140°C under 15 MPa applied pressure for the cure times, \(t_{90}\), determined from the respective cure curves.

| Ingredient | Loading (phr) |
|------------|---------------|
| NR-clay MB | 100           |
| Sulfur     | 2             |
| ZnO        | 5             |
| Stearic acid | 2         |
| MBTS       | 2             |
| Antioxidant| 1             |

2.5 Characterization of nanocomposites (cured)

Cure characteristics of nanocomposite compounds were obtained using a rubber process analyzer (RPA flex, USA) operated at a temperature of 140°C as per ASTM standard D 2048-95. Maximum torque (\(M_H\)), minimum torque (\(M_L\)), cure time that represents the time for an
increase by two units from minimum torque \( t_s \) and cure time that corresponds to 90% of cure \( t_{90} \) were determined. The cure rate index (CRI) is expressed as:

\[
\text{CRI} = \frac{100}{t_{90} - t_s}
\]  

(3)

Nanocomposites were fractured under liquid nitrogen and their scanning electron microscopy (SEM) images were taken using a scanning electron microscope (Evo 18 made in Carl-Zeiss, Germany). Fracture surfaces were gold sputter coated to prevent charging under the electron beam.

Dynamic mechanical thermal analysis (DMTA) of the nanocomposites was carried out using a dynamic mechanical analyzer (Q 800 of TA instrument, USA). The dual cantilever mode of deformation was selected. Rectangular test specimens having dimensions of 40 mm × 12 mm × 2 mm were examined over a temperature range of −80 to 80°C, at a heating rate of 2°C/min. Liquid nitrogen was used as the cooling medium. Storage modulus, loss modulus and tan δ of each nanocomposite were recorded in the temperature sweep mode at 1.0 Hz.

Tensile properties such as tensile strength, elongation at break, modulus at 300% elongation (mod 300%) and tear strength were measured using a Hounsfield H10KT tensile tester as per ISO 37 and ISO 34, respectively. Dumbbell specimens (type 1) and angle specimens were punched from 2 mm thick vulcanized sheets and strained at a rate of 500 mm/min. Crosshead movement was taken as the extension. Hardness of the nanocomposites was determined using a dead load hardness tester (H14/PC; Wallace Instruments, UK) according to ISO 48. Specimens having a thickness of 12.5 ± 0.5 mm and a diameter of 29.0 ± 0.5 mm were used.

Abrasion loss of the nanocomposites was measured using an electromechanical abrasion tester (Zwick 6102, USA) according to ASTM D5963-04. The cylindrical shape specimens with a diameter of 16 ± 0.3 mm and a height of 6 mm were kept on a rotating sample holder and 5 N load was applied. The abrasion loss was calculated according to the following equation:

\[
\Delta V = \frac{\Delta m}{\rho}
\]  

(4)

where \( \Delta m \) is the mass loss of sample during the abrasion test, \( \rho \) is the density of the specimen and \( \Delta V \) is the abrasion loss in cm³.

3 Results and discussion

3.1 Characterization of OMMT-S

Figure 1 shows the FTIR spectra of MMT, OMMT and OMMT-S. OMMT was used after washing with water to remove bromide ions. The spectrum of OMMT compared to that of MMT exhibits three additional peaks at 2,925, 2,852 and 1,450 cm⁻¹, which correspond to C–H asymmetric and symmetric stretching vibrations and to the bending vibration of CH₃ in CTAB, respectively. These peaks confirm the retention of CTAB with MMT without washing away during bromide ion removal. Although the grafting of TESPT on OMMT was identified using peaks at 2,925 and 2,852 cm⁻¹ corresponding to C–H stretching vibrations (40), it is not valid for such identification in this study since the same peaks appeared for CTAB in OMMT (41). A peak in the range of 988–998 cm⁻¹ in the spectra of MMT and OMMT was broadened and overlapped with the strong absorption peak at 1,030 cm⁻¹, which is attributed to Si–O–Si stretching vibration of the silicate (36,42), and the peak at 1,075 cm⁻¹ is attributed to Si–O–C groups (42), and the later one could also be used to confirm the silane grafting on OMMT in this study. Furthermore, the appearance of absorption peak at 1,255 cm⁻¹ attributed to CH₂ and CH deformation in TESPT confirms the grafting of TESPT on OMMT in OMMT-S. The suggested reaction scheme of the preparation of OMMT-S and formation of rubber–clay interactions in the clay-filled nanocomposite is shown in Figure 2.
Figure 2: Modification of organoclay by silane coupling agents and its reaction with NR.

Figure 2 shows the modification of organoclay by a TESPT silane coupling agent and its reaction with NR. The silanol bond of clay is converted to the siloxane bond by primary and secondary reactions, finally the siloxane network is created. Clay layers are bound to the siloxane network and sulfur in the TESPT created crosslinks with NR. This phenomenon helps to increase the interactions between clay and rubber reducing the surface energy.

Figure 3 shows XRD diffractograms of MMT, OMMT and OMMT-S. The corresponding peak for MMT exhibits at a diffraction angle (2θ) of 6.2. A low 2θ of 4.11 of OMMT corresponding to an interlayer gallery space of 2.15 nm confirms that the interlayer gallery space of MMT (1.42 nm) is increased after modification of MMT with CTAB. Modification of OMMT as OMMT-S is confirmed by the shift of 2θ to higher side, from 4.11° to 4.88°. With this modification, the interlayer gallery distance (d) of OMMT was reduced from 2.15 to 1.81 nm at their corresponding intrinsic peaks and may be due to the formation of chemical bonds during grafting of silane into OMMT. A similar variation was shown in another study when modified hectorite was incorporated into styrene butadiene rubber (43). Another study also reported similar results (44), which described that the interlayer gallery space of OMMT after TESPT modification slightly decreased when quaternary onium ion surfactant was used. It may be due to the reason that some of CTAB left from the gallery space because quaternary amine cannot form hydrogen bond with clay at interlayer gallery space as primary amine. The chain length of TESPT is smaller than that of CTAB and may form coupling reaction at edges and gallery spaces as well. As a result, interlayer gallery space of OMMT-S is reduced but the ability of separating clay layers from clay stacks is assumed to be increased.

3.2 Formation of gelling structures

Gelling clusters are formed by the combination of oppositely charged gelling agents (cationic CTAB and anionic SDS). NR particles in NRL have the ability to adsorb both CTAB and SDS onto their surfaces, but the greater ability is for CTAB (45). In this study, with the intention of enhancing the adsorption capacity of NR for CTAB, SDS was added to NRL prior to the addition of CTAB. It was reported that when CTAB was introduced into the SDS-adsorbed NR particles, head-to-head electrostatic interactions would occur between CTAB and SDS. Since the CTAB loading is higher than that of SDS (CTAB:SDS = 2:1), the excess CTAB molecules would form the second CTAB layer on the CTAB and SDS-adsorbed NR particles through tail-to-tail hydrophobic interactions, a behavior similar to that discussed in the literature (45). Based on this hypothesis, a structure for the gelling cluster is proposed and presented in Figure 4.
3.3 Characterization of nanocomposites

3.3.1 Cure characteristics

Figure 5 shows \( t_{90}, t_{90}^{*}, \) and CRI of each nanocomposite compound. The excess amount of CTAB in the gelling agent not intercalated into interlayer gallery space of OMMT and OMMT-S is responsible for similar cure characteristics.

![Figure 5: Cure properties of C and S nanocomposite compounds.](image)

3.3.2 Morphology

Figure 6 shows SEM images of the Control and the four nanocomposites prepared with OMMT/OMMT-S. It is difficult to identify the excess CTAB and SDS in gelling clusters by the SEM images. However, white particles in the Control are identified as ZnO and sulfur by energy-dispersive X-ray spectroscopy (EDS) in Figure 6a. Very few aggregated clay structures are visible in C-2 and S-2 nanocomposites because most of the clay layers are well dispersed in the presence of excess amount of CTAB and SDS. Figure 6b shows aggregated clay structures identified by EDS. The nanocomposites prepared with 5 phr of OMMT/OMMT-S (C5 and S5) have randomly distributed large clay stacks and aggregated clay structures and they appeared in the SEM images of Figure 6c and e. The S-2 nanocomposite exhibits minimum quantity of aggregated clay structures in Figure 6d due to lower surface energies thereby clay layers are easily separated from clay stacks, which is attributed to the effect of TESPT grafting.

3.3.3 XRD analysis

Figure 7 presents the XRD diffractograms of SDS, CTAB, Control and the nanocomposites prepared. SDS exhibits peaks at 2\( \theta \) of 7.08, 4.80 and 9.32, whereas CTAB exhibits peak at 2\( \theta \) of 7.5. Three prominent peaks appeared in the diffractograms of the Control, C-2 and S-2 nanocomposites at 2\( \theta \) of 4.4, 6.6 and 8.2 and are due to the presence of excess CTAB and SDS which consist of different crystalline arrangements in NR. Similar to this observation, Fathuroman et al. (46) and Kim et al. (47), have reported that the appearance of a prominent peak for stearic acid in the diffractograms of the rubber compounds, and vulcanizates, when stearic acid was used in excess. The 2\( \theta \) value slightly decreased from their original value due to the effect of interaction between CTAB and SDS in the gelling cluster proposed in Figure 4. It shows that the two surfactants are packed in the crystalline structure. The XRD observations are in agreement with the morphology of the nanocomposites and the characteristic peak, which corresponds to MMT at a 2\( \theta \) of 6.2 (48), is not visible in the C-2 and S-2 nanocomposites, and it may be due to exfoliation of clay layers at low clay loading with excess surfactants. Diffractogram of the C-5 nanocomposite shows overlapping of few peaks corresponding to the aggregated clay structures and gelling clusters. The evidence thus suggests that the peaks corresponding to the aggregated clay structure occurred in the nanocomposite at OMMT/OMMT-S loading at 5 phr. With the increase in OMMT-S loading to 5 phr, the intensity of those peaks is less compared to that of the C-5 nanocomposite due to better dispersion of OMMT-S.

3.3.4 DMTA

Figure 8 shows tan \( \delta \) versus temperature curves for the nanocomposites prepared with OMMT and with OMMT-S at two different loadings. With the increase in OMMT loading from 2 to 5 phr, the glass transition temperature (\( T_g \)) of the nanocomposites was increased from \(-48.8\) to \(46.1^\circ\)C and is due to the filler effect of higher loading. At 2 phr loading, nanocomposites with OMMT-S (S-2) showed an increase in \( T_g \) by 2.7°C than that of nanocomposites with OMMT (C-2) due to the effect of improved rubber–clay interactions. However, at 5 phr loading, both nanocomposites with OMMT and OMMT-S showed similar \( T_g \) values. These results explain that the \( T_g \) variation due to modification of OMMT with TESPT is effective only at lower loadings. The tan \( \delta \) value at the peak of nanocomposites at 2 phr OMMT/OMMT-S loading was similar and that was lowered when loading was at 5 phr due to the reinforcement that occurred at higher filler loading.

3.3.5 Mechanical properties

Figure 9 shows tensile strength, elongation at break and modulus at 300% strain (mod 300%) of the
nanocomposites. The S-2 nanocomposite showed the highest tensile strength of 39.4 MPa and is associated with the developed rubber–clay interactions and effective dispersion of smaller clay layers in the presence of highest number of exfoliated clay layers. With the increase in OMMT-S loading from 2 to 5 phr, the aggregation of clay increases and hence the S-5 nanocomposite showed a lower tensile strength of 31.3 MPa. Elongation at break is also lowered from 650% to 575%. It was reported in some studies (49,50) that the minimum reduction of elongation at break occurs with the effect of improved slippery action due to the addition of higher

Figure 6: SEM images of nanocomposites (a) Control, (b) C-2, (c) C-5, (d) S-2 and (e) S-5.
amount of plasticizers at lower clay loadings. It was also reported that the network structure of siloxane would reduce the tensile strength of the silica-reinforced rubber composite due to an increase in incompatibility between non-polar NR and polar clay at 5 phr clay loading. Compared to the S-2 nanocomposite with 2 phr loading of OMMT-S, both C-2 and C-5 nanocomposites exhibited lower tensile strength and mod 300% values due to the lack of rubber–clay interactions developed in OMMT with NR. Interestingly, tensile strength of the S-5 nanocomposite is less than that of the C-5 nanocomposite. It may be due to the effect of the siloxane network around a higher number of clay layers which is not compatible with NR when loading of OMMT-S is increased to 5 phr. As expected, mod 300% increased with the OMMT/OMMT-S loading and with the grafting of OMMT with TESPT.

Figure 10 shows that the tear strength of the nanocomposites at 5 phr OMMT/OMMT-S loading (C-5 and S-5) was similar and was slightly greater than that of nanocomposites at 2 phr loading (C-2 and S-2). It denotes that the tear strength is mainly based on the amount of finely dispersed clay layers and not due to the effect of OMMT modification with TESPT. As expected, the hardness of the nanocomposites was increased by 2 IRHD (International Rubber Hardness Degrees) with the MMT loading from 2 to 5 phr and further increased by 1 IRHD with the modification of OMMT with TESPT.
3.3.6 Abrasion loss

The abrasion losses of the nanocomposites prepared with OMMT-S (S-2 and S-5) were similar and were lower than those of the nanocomposites prepared with OMMT (C-2 and C-5) (Figure 11). The lower abrasion loss of S-2 and S-5 nanocomposites is due to the properly dispersed OMMT-S clay layers in the rubber matrix and the effect of rubber–clay interactions, developed through the modification of OMMT with TESPT. Among them the S-2 nanocomposite shows the lowest abrasion loss due to less aggregation of clay layers.

4 Conclusion

FTIR spectroscopy and XRD analysis revealed that the modification of OMMT by grafting of TESPT was successful. The SEM images and the X-ray diffractionograms of the nanocomposites confirmed the presence of aggregated clay structures at higher clay loading (5 phr) in the nanocomposites prepared with OMMT and OMMT-S. The silanated organoclay (OMMT-S) has reduced polar nature on its surface and as a result, the clay layers are well separated from clay stacks and dispersed properly in the rubber matrix. At 2 phr loading, a proper balance between polar silanated organoclay and non-polar rubber was obtained and hence the S-2 nanocomposite showed a highest tensile strength of 39.4 MPa and an elongation at break of 650%. At 5 phr loading, the aggregation behavior of OMMT-S and improved mod 300% in the S-5 nanocomposite showed lowered tensile strength and elongation at break. However, when the OMMT-S loading was increased from 2 to 5 phr, tear strength and hardness increased, and it is an added advantage. The nanocomposites prepared with OMMT showed relatively lower tensile strength, tear strength and hardness, along with higher abrasion losses at every clay loading. Further enhancement of the properties of the nanocomposites with higher OMMT-S loadings could be expected if the NR phase is modified by polar groups to maintain a balance between polar OMMT-S with non-polar NR. This effect will be evaluated in a next level of study.

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