



Synergistic effects of silica and nanoclay on curing characteristics, processing behaviour and mechanical properties of solution styrene butadiene rubber (SBR)–based tire tread compounds

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Received: 19 June 2021 / Accepted: 2 November 2021 / Published online: 3 January 2022
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Abstract

A “green”, low rolling resistance and energy-efficient tire tread compound is formulated using organically modified nanoclay to replace part of the silica in the tread rubber composition. The performance of the tread compound as measured in the laboratory is similar to better than the solely silica-based formulation. The current study aims to investigate the role of surface modified organoclay on the rubber properties when partly replacing silica used during rubber compounding. This study will also reveal new insights on impact of functionalised organoclay as platelet filler with higher aspect on rubber properties comparing to only silica and carbon as spherical filler with low aspect ratio. The scorch time (T_{s2}) reduces progressively with increasing amount of clay in the rubber formulation. The cross-link density (as measured by torque difference) is maintained in a narrow range while the cure rate increases linearly in proportion with the amount of clay in the system. Mooney viscosity and the Payne effect (relevant to filler-filler interaction) reduce with the incorporation of clay in the formulation. Addition of clay into the formulation improved the ductility of the molded samples that sustained more than 200% of strain. Tensile strength and elongation increase steadily with increasing amount of clay. Incorporation of nanoclay in the system also improved the wet grip and reduced the rolling resistance at 5 PHR loading. The present work offers passenger car tires, truck and bus tires and other automobile tire manufacturers a more attractive, lower cost, route into the production of fuel-efficient tires with improved performance characteristics.

Keywords Silica · Clay · Payne effect · Modulus · Wet grip · Rolling resistance

1 Introduction

Some of the important properties of tires are mechanical strength, rolling resistance, abrasion resistance, braking force and wet grip etc. Researchers around the world have tried to optimise these properties by either changing the design of the tire or the compounding formulation of the tire such as by using rubber nanocomposites based on silica, carbon black, nanoclay etc. There have been efforts in improving the overall tire performance by the use of dual/hybrid fillers [1, 2]. A key problem which the tire industry faces is reduction in rolling resistance which alternatively relates to fuel consumption. The consumed energy used for

rolling resistance is transferred into the heat. It is known that at a constant speed of 100 km/h, a passenger car needs approximately 50% of its fuel to overcome rolling resistance and the remaining fuel is used to overcome air drag and driving conditions. Similarly, for a constant speed of 80 km/h, a truck needs approximately 40% of its fuel to overcome rolling resistance [3]. Viscoelastic nature of rubber plays an important role in rolling resistance. Approximately 90% of a tire's rolling loss is due to hysteresis loss coming from its rubber component. From the rubber components, the tread rubber alone is responsible for 39% of total tire's rolling resistance. To overcome the said challenges and fulfil the demands of industry, improvement in basic performance of tires is needed. To improve the overall performance of tires, different reinforcing fillers are used. For these fillers, there are some important characteristics to be considered such as particle size, structure, surface energy, morphology, surface area and volume fraction of fillers. Hysteresis behaviour of

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rubber is mainly affected by the filler-filler interaction and low interaction gives low hysteresis loss [3].

Traditionally, carbon black has been used as reinforcing filler which gives strength, wear-fatigue resistance, and increase in the storage and loss moduli. Also, its black colour helps absorb UV rays which are responsible for initiation of oxidative degradation of rubber [4]. Carbon black and precipitated silica are the two main ingredients which have been used as reinforcing fillers to improve tire tread properties. Currently, carbon black is used in conjunction with precipitated silica as filler in tires. The most widely used secondary reinforcing filler is silica which decreases the tan delta at higher temperatures affecting a reduction in rolling resistance and at low temperatures, tan delta is comparable to carbon black giving similar wet grip [4]. However, the trend is shifting towards development of advanced functional filler systems like highly dispersible precipitated silica, high aspect ratio fillers like graphite and its derivatives, organo-clay etc.

To retain the physical properties of tires, addition of modified organoclay as secondary filler into rubber can play an important role [5]. Nanoclays are minerals with a high-aspect ratio with at least one dimension of the particle in the nanometer range. Nanoclay has layered silicate structure and its structure is modified with organic groups such as quaternary alkyl ammonium ions and the modified clay is termed as organoclay. The main raw material of clay is montmorillonite (MMT) [3]. Nanoclay is amorphous in nature and has low surface energy [6]. There are different methods to improve the dispersion of clay in rubber matrix such as in situ polymerization, latex mixing, solvent mixing etc. [7]. In one such work, the surface energy of organoclay was reduced by grafting of silane such as bis (triethoxysilyl-propyl) tetrasulfide. It shows 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 after surface modification [8]. To obtain optimal properties, many references suggest that organoclay be added in low loading (below 10 phr) in addition to other filler which has less cost and become potential reinforcing filler [9]. When the organoclay is used below 1 weight part or higher than 10 weight parts, then it is observed that it is difficult to improve the wear resistance as organoclay has poor dispersibility [1]. There are literature studies which describe that addition of organoclay did not form filler-filler networks with silica; consequently, SBR/silica/organoclay nanocomposites show good skid resistance, good tensile properties, and best rolling resistance [10].

Similarly, there are references where nanoclay is used in truck tire formulation to improve mechanical and dynamic properties for natural rubber composites. It is seen that hybrid fillers in truck tire formulation give better rolling resistance compared to conventional compound

[11]. Literature shows that part replacement of silica with bentonite and modified bentonite impacted great improvement in the tensile modulus and stresses at 100%, 200% and 300% strain of natural rubber composites. Also, it gives high tensile strength and elongation at break when one used modified bentonite [12]. In another instance for EPDM/silica/Bentonite composites, the tensile strength increases at 15 phr loading of bentonite. With the addition of bentonite into silica system, the dispersion was improved as bentonite has smaller particle size, higher specific surface area, presence of surface pores which easily enter into silica particles and EPDM rubber chains enhancing the mechanical properties [13]. There are studies where a ternary system is also studied like for a SBR organoclay nanocomposite system in which combination of silica, carbon black and organoclay as a ternary filler has shown excellent mechanical, dynamic and wear resistance as a tire tread compound for passenger car [14].

The presence of organic modifier structure on the surface of clay also plays an important role for rubber nanocomposite properties [15]. In one such study, it was seen that the surfactant chain length and functional groups affected the dispersion of clay nanolayers in the matrix and the overall properties of the nanocomposites [16]. A polymer nanocomposite considerably enhances the mechanical, thermal properties by using low loading of fillers such as below 10 wt.% compared to conventional polymer composites 30–70 wt.%. [17]. Nanoclay composites are advanced functional materials with high regularity and safe toxicological profile that imparts prominent mechanical and thermal stability [18]. Similarly, for non-tire rubber formulations that go into industrial rubber applications, it has been found that incorporation of a certain amount of nano organo-clay gives best result for mechanical and chemical properties along with its abrasion and swelling resistance characteristics [19–22].

The current study aims to investigate the role of surface modified organoclay on the rubber properties when partly replacing silica used during rubber compounding. This study will also reveal new insights on impact of functionalised organoclay as platelet filler with higher aspect on rubber properties comparing to only silica and carbon as spherical filler with low aspect ratio. To be precise, in the present study, we have studied the part replacement of silica by surface modified nanoclay in a passenger car tire tread formulation that is based on a solution SBR and PBD combination. Carbon black is also present in minor proportion. We have found that the nanoclay addition enhances the tires properties such as Payne effect, rheological properties and dynamic mechanical properties. This particular choice of rubber system along with the choice of a ternary filler combination of carbon black, precipitated amorphous silica and organically modified nanoclay has been studied for the first time.

2 Experimental

2.1 Materials and methods

Ultrasil VN3 silica powder was purchased from Evonik. Organoclay used is surface modified by 15–35 wt.% octadecylamine, 0.5–5 wt.% aminopropyltriethoxysilane. The surface modified organoclay was purchased from Sigma-Aldrich. Rubber compounding study was performed at IRMRA, Thane who also supplied the required supporting chemicals. The two rubbers were purchased from Zeon Corp. (Japan) by us and supplied to IRMRA for use in this study. The rubber compounding study was done at different phr of silica such as 70, 65, 62.5 and 60 phr with progressive part replacement with nanoclay at 0, 5, 7.5 and 10 phr respectively. Carbon black (N234) was kept fixed at 5 phr in each composition. A detailed formulation is shown in Table 1 below.

2.2 Rubber compounding study

Tables 1 and 2 show the passenger car tire tread formulation used in this study. This formulation as well as the mixing sequence was shared with the authors by leading tire companies in India which they follow at their end for their internal rubber mixing. The rubber compounding was carried out

Table 1 Typical tires tread passenger car formulation with Solution-SBR/PBD rubber with conventional silica Ultrasil VN3 and part replacement of clay

Ingredients	Clay 0	Clay 5	Clay 7.5	Clay 10
Solution SBR (clear)	70	70	70	70
PBD	30	30	30	30
Silica	70	65	62.5	60
Clay 0	0	0	0	0
Clay 5	0	5	0	0
Clay 7.5	0	0	7.5	0
Clay 10	0	0	0	10
Carbon N234	5	5	5	5
Process oil	14	14	14	14
Silane coupling agent-Si 69	6.2	5.8	5.5	5.3
Stearic Acid	2	2	2	2
MC wax	1.5	1.5	1.5	1.5
ZnO	3	3	3	3
6PPD	2	2	2	2
TMQ	1	1	1	1
Sulfur	1.5	1.5	1.5	1.5
CBS	1.7	1.7	1.7	1.7
TBzTD	0.3	0.3	0.3	0.3
DPG	1.5	1.5	1.5	1.5

Table 2 Mixing sequence of ingredients during rubber compounding formulation

Mixing stage	Time	Temperature	Activity
I	0 min	50 ± 2 °C	Polymer + silica + coupling agent + carbon black + Stearic acid + wax
II	7 min	89–105 °C	6PPD + TDQ + ZnO
III	9 min		Master batch dumping between 8 and 9 th min at 155 ± 2 °C

in a 1.6-l (Bainite make, Model MB Series 1.6 L IM RES-O-LAB) mixer volume intermix with fill factor 75–76%. Starting temperature for mixing is 50 ± 2 °C and dumping temperature is 155 ± 2 °C, RAM pressure is 20 kg. For initial 6 min, polymer along with Silica, Coupling agent, Carbon black, Processing Oil, Stearic acid, and Wax masticated at speed 50–60 rpm. In second stage, 6PPD, TDQ and ZnO added and further masticated for 2 to 3 min till dumping temperature 155 ± 2 °C. During this process, speed is varied between 60 and 70 rpm to achieve the dumping temperature. The details of mixing sequence are mentioned in Table 2 below.

Final batch was prepared in open two-roll mill (12 × 16") at room temperature, with friction ratio of 1:1.25. While adding accelerator and curatives nip gap is kept approximately 1 mm and masticated for 4 to 6 min. For all compounds, final sheet taken out from approximately 3.8 mm nip gap. All compounds were conditioned for 24 h at room temperature and then submitted for characterization.

2.3 Characterization of the unvulcanized and vulcanized rubber compounds

The cure characteristics or rheological properties of the unvulcanized compounds were studied as per ASTM D5289 in a Montech Rheometer (MDR-3000) at 160 °C. The curing characteristics of the materials were expressed in terms of the scorch time (tS2), optimum cure time (ts90), delta torque ΔT (which is the difference of maximum and minimum torques MH and ML respectively and also represents the cross-link density), and cure rate index (CRI = 100/(ts90-ts2)). Filler-Filler and Filler-Polymer interaction was analysed by using Payne effect. This test was carried on RPA2000 at 100 °C, 1.667 Hz frequency, and strain sweep from 0.28 to 280%. Payne effect is denoted as the difference in storage modulus G' at the minimum and maximum % strain values (ΔG').

For testing properties of vulcanized rubber compounds, rubber slab and other samples were cured at 160 °C as per their respective curing times. Molded samples were

preconditioned at room temperature before further testing. The stress–strain properties and tear strength of the vulcanizates were measured on an Instron Universal Testing Machine as per ASTM D412 and ASTM D624 respectively at 500 mm/min speed. The hardness of the composites was measured by the shore A Durometer according to ASTM 2240. Abrasion Resistance Index (ARI) test was carried out on rotating drum abrasion tester (prolific make) as per IS-3400 (pt-3) standard. The test specimen (16 + 0.2 mm) was gripped in the specimen holder in such a manner that it projected 2 + 0.2 mm beyond the face on grip. Thermal ageing was carried out as per ASTM D573 wherein test pieces were exposed @ 80 °C in air circulated oven for 7 days. After exposure and conditioning completion period, all samples were tested at room temperature (25 ± 2 °C).

For measuring the dynamic properties ($\tan \delta$) tests were carried out as per ASTM D5992 by using Dynamic Mechanical Analyser (DMA) at temperatures of 0 °C and 60 °C @ 0.5% static strain, 0.1% dynamic strain and 5 Hz frequency. Fourier transform infrared (FTIR) spectra of the rubber samples were obtained at room temperature using a Bruker Vertex 70 Instrument by attenuated total reflectance (ATR) mode with the scanning range from 400 to 4000 cm^{-1} and the characteristic peaks were analysed. Field emission scanning electron microscope (FESEM) analysis of the rubber molded products was carried out using field emission scanning electron microscope FEI NOVA NANOSEM 450 FESEM with an accelerating voltage of 0.5 to 30 kV and a resolution of 1.4 nm under high vacuum. In order to view the sample, the sample is placed on the stub above a C tape and

then gold coated and inserted in the vacuum chamber post in which images are taken and analysed at different magnifications. EDS analysis was also performed on selected images.

3 Results and discussion

3.1 Characterization of rubber compounds filled with silica alone and silica with clay

Figure 1 shows the FESEM image of the silica compounded with rubber sample along with EDS analysis. The low and high magnification FESEM images (a and b) depict the surface of the compounded rubber with silica nano-aggregates. EDS analysis (c and d) of the same resulted into elemental composition of rubber and silica with minimal presence of Zn as part of curative agent used during rubber compounding.

Figure 2 shows the FESEM image of the silica and clay compounded with rubber sample along with EDS analysis. The low and high magnification FESEM images (a and b) depict the surface of the compounded rubber with silica and clay nano-aggregates. Considering the very low amount of clay, it is difficult to differentiate the nano-aggregates of clay and silica. However, the EDS analysis (c and d) clearly indicates the presence of aluminium (signature fingerprint from clay) along with standard rubber, silica and zinc

Figure 3 shows the FTIR spectra of the only rubber sample, silica compounded with rubber sample and the silica

Figure. 1 a and b Field Emission Scanning Electron Micrographs of silica compounded with rubber. c Energy Dispersive X-Ray Spectroscopy (EDS) study of silica compounded with rubber. d Elemental Composition through EDS of silica compounded with rubber

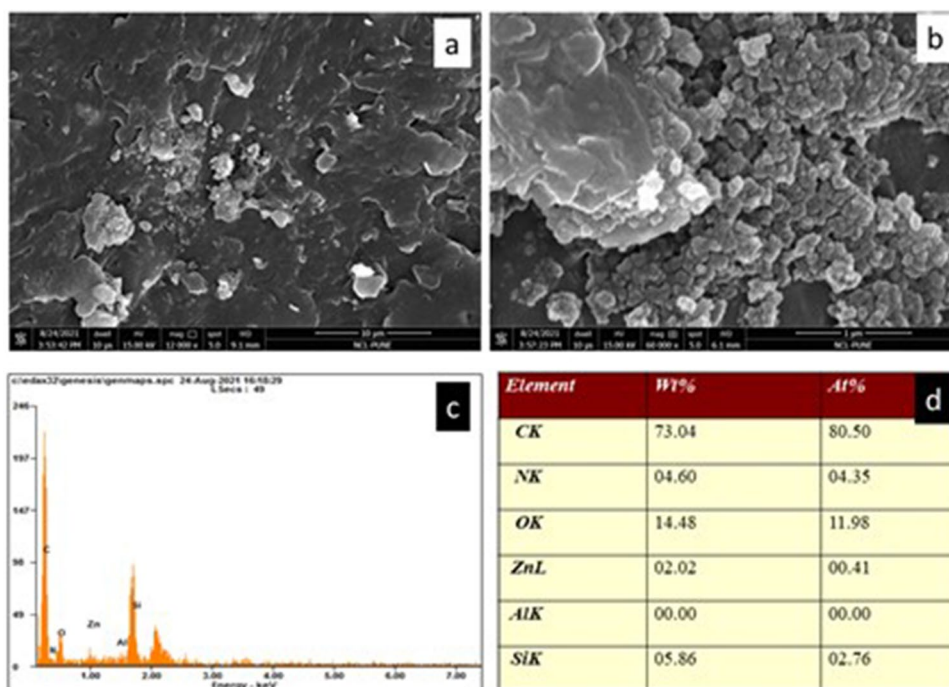
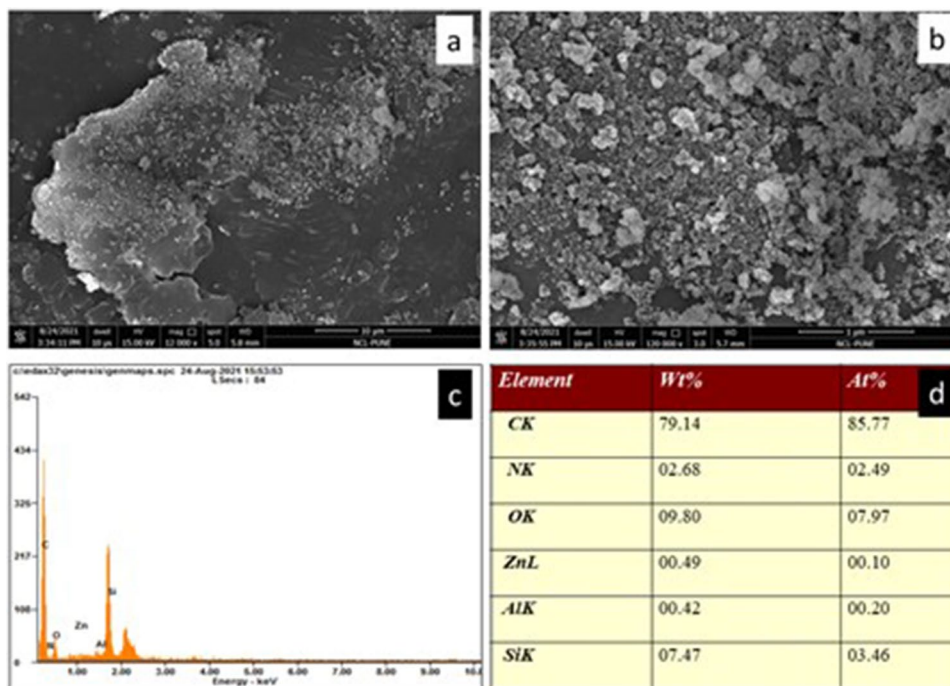


Figure. 2 **a** and **b** Field Emission Scanning Electron Micrographs of silica and clay compounded with rubber. **c** Energy Dispersive X-Ray Spectroscopy (EDS) study of silica and clay compounded with rubber. **d** Elemental Composition through EDS of silica and clay compounded with rubber



and clay compounded with rubber sample respectively at different wavenumbers.

The FTIR spectra curve 1 in Fig. 3 show different absorption bands occurring groups such as 1,4 cis-butadiene (754.8 cm^{-1}), 1,4 trans-butadiene (965.1 cm^{-1}), 1,2-butadiene units (909.9 cm^{-1}) and elongation of CH groups in styrene aromatic rings (2919.2 and 2849.9 cm^{-1}) respectively. Vibration stretches in CH_2 and CH_3 groups (1600 cm^{-1}) and elongation of the C-C groups of aromatic rings (980 cm^{-1}) absorptions are typical of the SBR. The FTIR spectra curve 2 in Fig. 3 shows the FTIR peaks of rubber samples compounded with only silica, which is having signatures at 1147 cm^{-1} , 1050 cm^{-1} and 997 cm^{-1} corresponding to Si–O stretching bond vibrations. Similarly, the FTIR spectra curve 3 in Fig. 3 shows the FTIR spectra of rubber samples compounded with silica and clay together. Along with the characteristic peaks of rubber and silica, a peak at 628 cm^{-1} (Fig. 3b, curve 3) corresponds to twisting vibrations of Al–OH and Si–O and stretching vibrations of Al–O signifies presence of clay. Since the amount of clay added to the rubber compounding is significantly lower in comparing to silica, the characteristic peaks of clay are not very prominent and the signal is believed to be overlapping with silica signatures.

3.2 Properties of the un-vulcanized compounds

Figure 4 shows two important properties out of the rheological characteristics namely ts_2 and ts_{90} for the un-vulcanized or green compounds. ts_2 is the time by which the torque

has raised by two units above the minimum torque and is an indicative of scorch safety. A higher scorch safety is preferred because it allows the operator more freedom to operate and load the sample comfortably without worrying about non-uniform curing. ts_{90} is the time by which 90% of the cure has taken place. Lower ts_{90} is indicative of better productivity. It was observed that Scorch time decreases as the amount of nanoclay increases. Samples are becoming scorchie in nature with progressive addition of clay in the system. Similarly, the optimum cure time is also reducing as the clay phr is increased. Along with surface functionalization, it is the anisotropic platy morphology of the clay as opposed to the isotropic spherical shape of the silica filler that is causing faster curing of the samples. Similar studies reported in literature suggested that amine functionalities in the filler facilitated the curing reaction of rubber stocks and reduced the cure time. It has been suggested that the zinc–sulfur accelerator complex reacts with the amine functionalities of the organomodifier during the curing reaction thereby reducing the cure time of nanoclay composites [23].

Figure 5 shows the remaining properties as part of the rheological characteristics namely the cure rate index and the torque difference. The cure rate index is a measure of the linear slope of the rising curve. It is the rate at which cross-linking and the development of stiffness (modulus) of the compound occur after the scorch point. ML is a cure property measured in the uncured state while MH is the characteristic of the cured rubbers. Beyond minimum torque (ML) when cross-links are introduced, they connect the long polymer chains of the rubber together. The

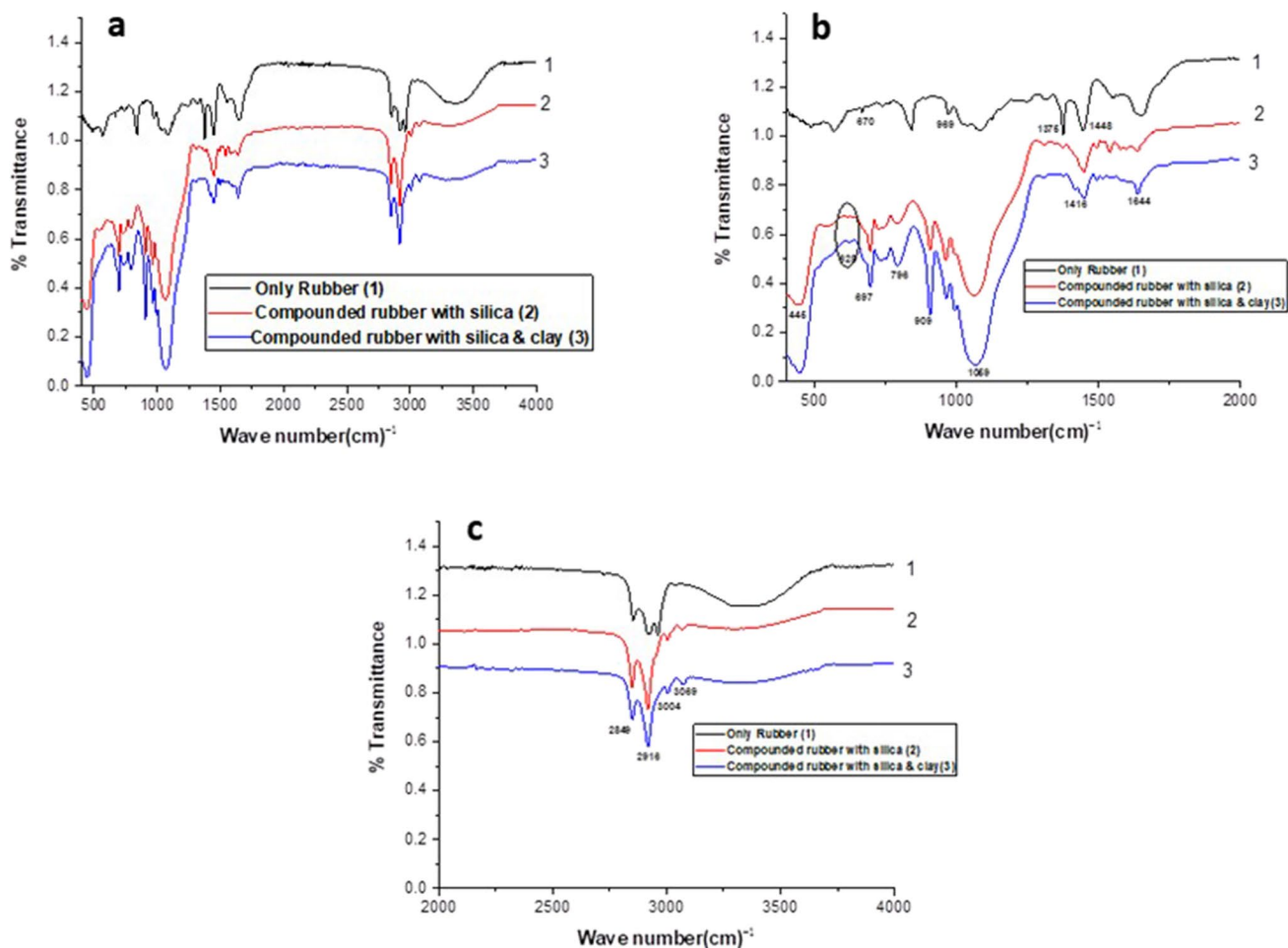


Fig. 3 Fourier transform infrared (FTIR) spectra of rubber sample, silica compounded with rubber sample and silica and clay compounded with rubber sample in the scanning range of **a** 400 to 4000 cm⁻¹; **b** 400 to 2000 cm⁻¹ and **c** 2000 to 4000 cm⁻¹

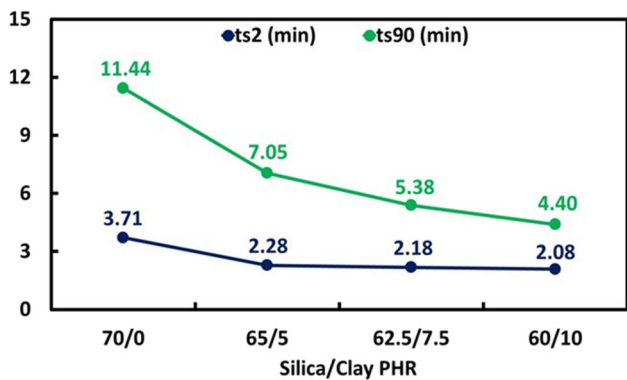


Fig. 4 Scorch time and optimum cure time with different PHR of organoclay

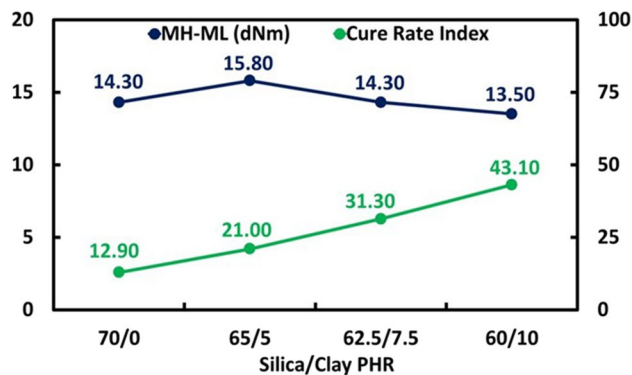


Fig. 5 Torque difference (MH-ML) and cure rate index with different PHR of organoclay

properties of the compound change from a soft glue to a tough elastic material. Polymer chains become more firmly connected and the stiffness (modulus) of the compound increases as more and more cross links are introduced. The

torque difference (MH-ML) indicates the extent of cross linking and rubber–filler interaction. Torque difference is a measure of the shear dynamic modulus which indirectly relates to the crosslink density of the composites. It is

observed that by replacing silica with nanoclay, cross-link density is increased at a certain level. In another study, it was noted that in the nanoclay loaded EPDM/SBR vulcanizates the minimum torque, maximum torque and delta torque increases with increasing content of nanoclay for all of the crosslinking system. This may be due to the ethylene and propylene monomers present in EPDM resulting in good interactions and interfacial adhesion between the nanoclay and the rubber matrix. Also, a high CRI value was observed showing higher vulcanisation rate. This may be due to nanoclay acting as an effective crosslinking agent for SBR/EPDM nanocomposites and it is leading a substantial increase in the rubber vulcanisation rate [24].

Figure 6 shows the results for Mooney viscosity and Mooney scorch time for the un-vulcanized or “green” compounds. For better processing, lower mooney viscosity is preferred. It was observed that mooney scorch time reduces as the clay phr increases. It is observed that less addition of clay improves rubber processability parameter during compounding and as the addition of clay increases, the mooney viscosity is found to be increased.

Figure 7 shows the trend for Payne effect with increasing amount of clay as part replacement of silica in the compounded samples. Payne effect is a measure of filler-filler and filler-rubber interactions in unvulcanized compounds and is defined as the difference of storage modulus at 0 and infinite % strains. Experimentally, it is denoted as the difference of G' at lowest and the highest % strain during the strain sweep. In order to avoid the noise at lower strains, the Payne effect here is reported as difference in G' at 3 and 280% strains while the test was conducted from 0.28 to 280% strains as mentioned in the experimental section earlier. A higher $\Delta G'$ value is indicative of a stronger filler-filler interaction requiring more shearing force to break the filler network. The higher is the Payne effect, the poorer is the dispersion. Payne effect for just silica alone having 0 phr of clay is high due to surface silanol groups showing more

filler-filler interactions during rubber compounding. On the other hand, nanoclay has amine-based surface functionalities which show less filler-filler interactions. With initial incorporation of clay in the formulation, the Payne effect is considerably reduced, but as the clay amount increases, it shows reverse effect, supporting a literature study where optimum addition of nanoclay is preferred [25].

3.3 Properties of vulcanized compounds

For testing properties of vulcanized rubber compounds, rubber slab and other samples were cured at 160 °C. Figure 8 below shows the modulus at various strains for the as molded samples before thermal ageing. At a low strain of 50%, all samples shows comparable modulus. However, as the strain increases to 100%, the modulus drops with part replacement of silica with clay. This is probably due to the fact that hard spherical shaped filler such as silica is slowly getting replaced by softer platy shaped filler such as the clay in this case. An interesting observation to note here is that, only the clay-filled samples are able to sustain the higher 200% strain while the only silica sample is brittle enough

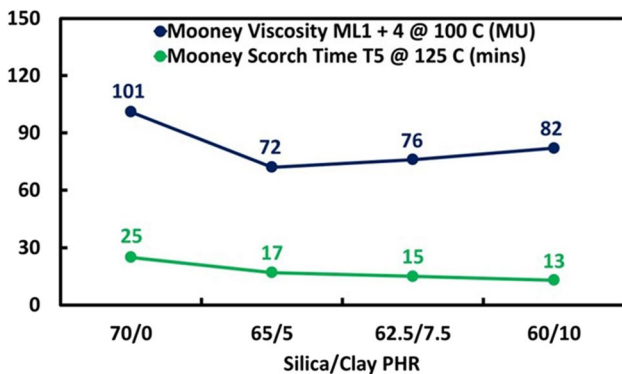


Fig. 6 Mooney viscosity and Mooney scorch time with different PHR of organoclay

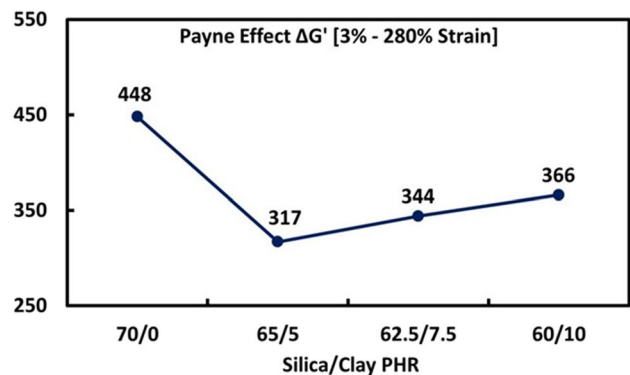


Fig. 7 Payne effect with different PHR of organoclay

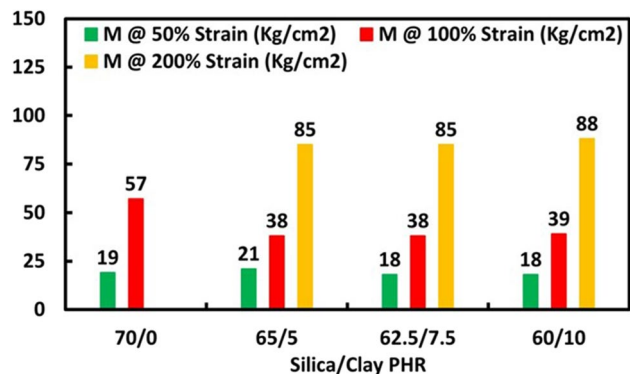


Fig. 8 Graph of modulus at various strains before ageing with different PHR of organoclay

to not reach the 200% strain mark. This is an improvement due to the part replacement of silica with organoclay as the samples are now more ductile and less brittle.

Figure 9 shows the modulus at various strains after thermal ageing. It is observed that the modulus at different strains before ageing (Fig. 8) as well as after ageing (Fig. 9) follows the similar trend in nature with different phr of clay. As the samples are aged over time and temperature, it results in further development of cross-links due to which modulus increases in general. This can be seen in Fig. 9 where the modulus at respective strains has increased significantly as compared to the un-aged samples. Again, it is observed that the clay filled samples are still ductile enough to sustain the 200% strain mark.

Literature studies also reveal that vulcanizates filled with silica and organoclay show that filler networking sets in at much lower loading in organoclay-filled rubber. It is mentioned in literature that the modulus values are greater for organoclay filled system as compared to vulcanizates filled with silica. These properties are a consequence of the highly anisotropic platelet-like structure of organoclay aggregates [26]. The choice of rubber system, clay type and phr plays a very important role in deciding the final properties of the vulcanizates.

Figure 10 shows the tensile strength, elongation at break, hardness and tear strength for the different loading of clay samples before thermal ageing. Significant increase in tensile strength is found as the clay phr is increased from 5 to 7.5 to 10 phr. At the same time, there is considerable improvement in the elongation at break as well as the part replacement of silica with clay increases from 5 to 10 phr. As gradually silica is replaced with clay, the rubber samples are becoming stronger and more ductile in nature. This is crucial for any tire formulation. Similarly, we find that the tear strength is also improving with the incorporation of clay in the system at the cost of silica. Hardness is however comparable for all the samples.

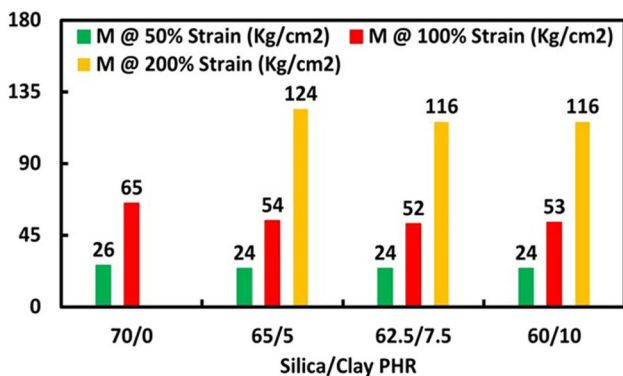


Fig. 9 Graph of modulus at various strains after ageing with different PHR of organoclay

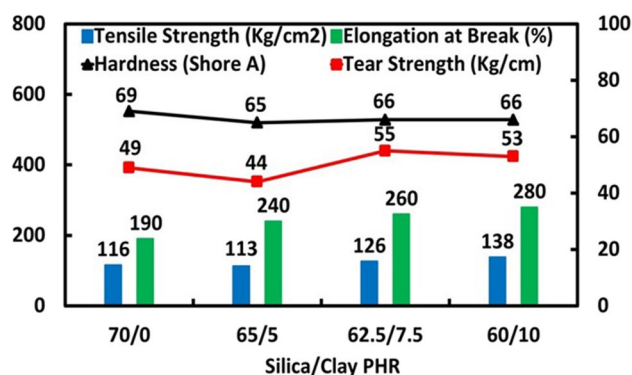


Fig. 10 Showing the tensile strength, elongation at break, hardness and tear strength before ageing with different PHR of organoclay

Figure 11 below shows the tensile strength, elongation at break, hardness and tear strength for the four samples after thermal ageing. In general upon thermal ageing strength and elongation are reduced as more and more crosslinks are developed in the system. The same is observed here in our study as well. Hardness has improved as a result of increase in crosslinks for all the samples and they are all still comparable.

Figure 12 showing the abrasion resistance for the clay samples with different loading. The abrasion resistance is related to the rupture of small particles of the compound under the action of frictional forces, when sliding takes place between the compound surface and a substrate. It can be seen that with gradual replacement of silica with clay, the abrasion resistance is reducing. This could be due to the platy structure of the clay particles facilitating the abrasion more than the scenario where silica alone is present.

Dynamic mechanical analysis is usually used to evaluate tire performance. Figure 13 below shows the dynamic mechanical data ($\tan \delta$ @ 0 and 60 °C) for the various samples.

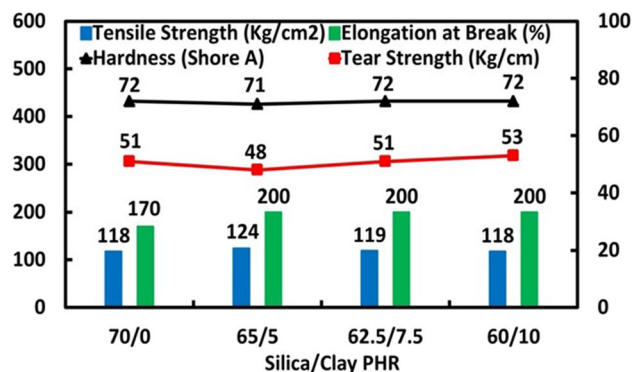


Fig. 11 Showing the tensile strength, elongation at break, hardness and tear strength after ageing with different PHR of organoclay

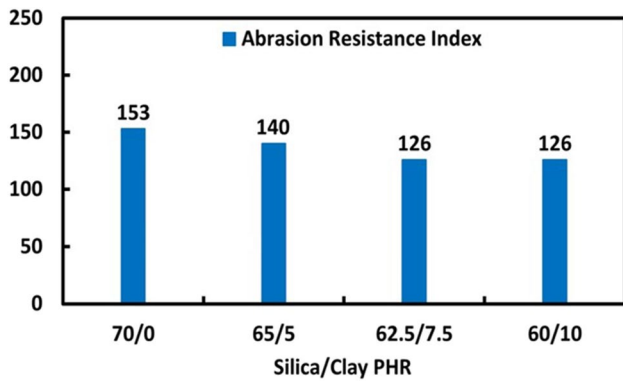


Fig. 12 Graph of abrasion resistance with different PHR of organo-clay

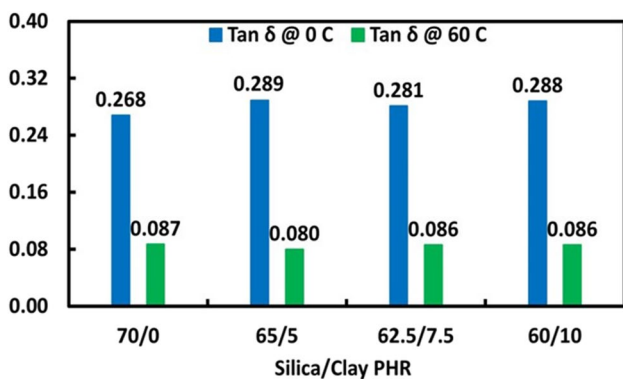


Fig. 13 Graph of tan delta at 0 °C and 60 °C with different PHR of organoclay

It is well recognized that high values of tan delta at 0 °C mean better wet grip whereas low values of tan delta at 60 °C are correlated with lower rolling resistance (lower fuel consumption). The higher the tan δ at 0 °C, the better the traction or skid resistance or wet grip performance. This refers to the maximum frictional force that can be produced between surfaces without slipping. In the design of vehicles, high traction between the wheel and the road surface is desirable as it allows for more energetic acceleration (including cornering and braking) without wheel slippage. On the other hand, the lower the tan δ at 60 °C the lower the rolling resistance and the lesser is the fuel consumption. Tan δ at 60 °C also relates to the heat build-up of the tire tread. The higher the tan δ , the higher is the heat build-up and more is the energy loss by hysteresis. Rolling resistance (RR) of a tire can be considered as a force that opposes vehicle motion. Reduced filler-filler interaction and increased filler-polymer interaction cause less hysteresis and consequently lowers RR of tire treads. By lowering rolling resistance, the fuel consumption also reduces [27].

It can be seen from Fig. 10 that addition of nanoclay significantly improves the wet grip. Similarly, addition of nanoclay is also found to reduce the rolling resistance. It appears that at 5 phr of clay, the tan delta at 0 °C and at 60 °C is optimum.

Generally, conventional tread rubber compounds that optimise tan δ at one temperature negatively impact tan δ at the other temperature and therefore one component of tread performance is traded for another. The magic triangle of tire technology talks about the relationship between the three major properties rolling resistance (RR), traction or wet skid resistance (WSR) and wear or abrasion resistance (AR). According to this principle, any improvements in one of these properties would lead to a change — mostly undesirable — in the other two properties. A compromise between these characteristics is therefore always aimed for. In the automobile industry, manufacturers will often specify levels of both wet traction and rolling resistance when sourcing tires.

4 Conclusions

This study presents the use of surface modified nanoclay that can act as tertiary filler in addition to silica and carbon black by partly replacing silica. As the amount of clay increases, it is observed that the samples become scorchie in nature. To get balanced rheological properties, an optimum amount of clay of 5 phr is found to be optimum. Introducing organically modified nanoclay in rubber formulation by replacing silica shows more ductile and stronger nature of rubber samples which is a key aspect of any tire rubber formulation. In addition, nanoclay samples are sustainable more than 200% of strain and significantly reduce the Payne effect. Incorporation of nanoclay in the system also improved the wet grip and reduced the rolling resistance at 5-phr loading. Nanoclay addition is an effective green solution for tire manufacturers to resolve some of the challenges facing industry as of.

Acknowledgements The authors would like to thank the Head innovation at Tata chemicals Innovation Center for his support and encouragement to pursue this work. The authors would also like to acknowledge Indian Rubber Manufacturer Research Association (IRMRA) for making all the compounding and testing possible and supplying all the necessary chemicals related to it.

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