

MORPHOLOGY, RHEOLOGY AND MECHANICAL PROPERTIES OF NR, NR/BR AND NR NANOCOMPOSITE

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Abstract

This paper investigates the comparative influence of adding butadiene rubber to natural rubber (NR) as a blend or silica filler as a nanocomposite in the morphological, rheological, and mechanical properties. Tensile, flexing fatigue, IRHD hardness, abrasion wear, and rheology (Mooney viscosity) tests were conducted for the NR compound, the blend of natural rubber/polybutadiene rubber (60NR-40BRcis), and the hybrid nanocomposite of natural rubber/nano-silica (NR/SiO₂). Results show that the addition of BR and nano silica into the NR compound increased the abrasion wear resistance, flexing fatigue, and hardness. Tensile strength and elongation at the fracture of the NR compound decremented when blended with BR by 15% and 50%, respectively, while enhanced when added nano-silica by 38% and 17%, respectively. The maximum Mooney viscosity was observed for the blend, the nanocomposite, and the NR compound. The homogeneity index of the NR compound was decremented by 16% when blended with BR while enhanced by approximately 17% when reinforced with nano-silica. The curing index of NR compounds was increased by more than 47% when blended with BR and 19% for nanocomposite. The enhancement percentage of the number of cycles was 45% and 128% for the NR compound during the flexing fatigue test when respectively blended with BR and nanocomposites. IRHD hardness and abrasion wear resistance were also enhanced for the NR compound when blended with BR or added nano-silica.

Keywords: Blend, Butadiene rubber, Flexing fatigue, Mooney viscosity, Nano-composite, Natural rubber.

1. Introduction

Composite-based nanofiller have gained distinct attention in the industrial and academic fields worldwide in the last decades. These nanofiller have been considered promising novel materials due to their capability to combine desired properties from hybrid substances. The most common earliest composite was a polymeric composite, which demonstrated widely versatile applications with the largest quantities in ambient temperature; this composite is also easily reproducible, lightweight, ductile, and cheap [1-6].

The current study mainly focused on elastomer composites. The major types of elastomer, such as Natural Rubber NR, Nitrile Butadiene Rubber, NBR, Styrene Butadiene Rubber SBR, Butadiene Rubber BR, Butyl Rubber IIR, Chloroprene Rubber CR, and Isoprene IR, are vulcanizable (conventional). These rubber vulcanizates are commonly reinforced by particulate fillers. Therefore, the reinforcing fillers, such as silica, alumina, carbon black, and clay, increase the strength of vulcanized rubbers more than tenfold. Moreover, rebound or resilience can be reduced to increase the hardness, stiffness, modulus, abrasion resistance, tear resistance, and the frictional coefficient for traction. Other fillers, such as vulcanization system ingredients, antidegradants, plasticizers, and processing aids, are necessarily added to compounding rubber [7, 8]

Rubbery components have an important role in engineering processes and products. Nearly 70% of rubber production lies in the transport sector with tires and related products. The other percentage is represented by belting, hosing, sealing, fabrics, rainwear, footwear, pipes and tubing, tank lining, gaskets and diaphragms, rubber roller, toys, balloons, sports goods, and others [9-11]. Rubber compounds are also used for the protection of engineering apparatus, bridges, and buildings from vibration effects due to the elastic characteristics of rubber materials, which enable energy dispersion [12]. Rubber is used in rubber engine mounts, bushings, tie bars, and nozzle ports, which must withstand the resulting distortion caused by the thermal deformation of the exhausts [13].

Rubber composite materials with dissimilar types of rubbers are used in different applications. Therefore, a large field of studies is available due to the excellent properties of rubber. Thus, a different modification of rubber composite for loading resistance can be established. Moreover, the correlation of usage conditions with mechanical loads, such as environmental effects at elevated temperatures in the presence of oils and friction, results in the formation of new blended polymers, such as NBR, NR, SBR, and CR [7, 14]

Polymer blends are currently utilized largely in a variety of applications. Particularly, polymer blends are used in the manufacturing of tire and rubber mounts depending on the application requirements [15]. NR is known to have several excellent characteristics as gas permeability and oil resistance despite its relatively high cost [12]. The use of synthetic and natural polymer blends is a common approach to enhance the physical and mechanical properties of composites. The development of fracture toughness can be achieved in the presence of sufficient interaction between the blends [13, 14]. For general purpose types, BR is utilized in the manufacturing of automotive tires, and this demand increases with the growth of vehicle production [16].

Ansarifar et al. [17] studied the effect of added 10, 30, or 50 pphr precipitated silica on the rheological properties of SBR at 160 °C using an oscillating disc rheometer curemeter. The cure time of the compounds was lengthened from 20 min to 280 min with the addition of 50 pphr of silica. The cure rate index sharply decreased from 8.3 min⁻¹ to 0.37 min⁻¹ when the amount of silica in the mixes reached 50 pphr. Interestingly, the scorch time (t_{s2}) of the compounds remained unaffected.

Chen et al. [18] reinforced NR with nano silica. The results showed the homogeneous distribution of nanoparticles throughout the rubber matrix in a form of a spherical nano-cluster with an average size of 80 nm under the SiO₂ content at 4 wt%, and the increase in activation energy of relaxation of the nanocomposite compared with the raw NR.

Carli et al. [19] evaluated the technical feasibility of substituting silica with NR nanocomposite with (2, 4, and 8) phr organoclay and then compared it with a sample reinforced with 50 phr of silica. The results showed the intercalation of the organoclay by the rubber chains, which reduced the enthalpy of the curing process and lowered crosslink density. Moreover, the results of the mechanical properties revealed that 50 phr of silica can be replaced by 4 phr of organoclay without any effect on the final properties.

Wisojdharmo et al. [20] aimed to optimize the performance of the tire tread compound using various compositions from the (NR)/(BR) blend. These compositions were 100/0, 95/5, and 85/15. Curing characteristics and Mooney viscosity were characterized for each formula of unvulcanised rubber. The mechanical and thermal properties of the vulcanized rubber were also investigated. They concluded that the addition of BR to the NR compound increased hardness, wear resistance, and rebound resilience while the glass transition temperature deteriorated.

Gao et al. [21] partially replaced carbon black by MWCNTs in (NR)/(BR) blends 80/20. They found that abrasion resistance was increased by 12.69% for the 5 phr MWCNTs/27.5 phr carbon black compared with that without CNTs. The high level of crosslink density, shortest cure time, highest modulus, and the best enhancement in mechanical properties were observed for 5 phr MWCNTs/35 phr carbon black compound. The thermal conductivity was also increased by 6.15%.

Jovanovic' et al. [22] prepared ternary rubber blends based on NR/BR/SBR (25/25/50) reinforced with silica (0-100) pphr. The samples were then exposed to thermo-oxidative aging at 100 °C. Tensile, hardness, rheological, and swelling testing were conducted. The samples were also characterized by SEM, FTIR, and DSC. The blend reinforced with 60 phr silica showed remarkable reductions in the optimum cure time (t_{90}) and the scorch time (t_{s2}), which were associated with a decrease in the cure rate index. The interaction between rubber blend and nano silica was confirmed by FTIR; thus, the absorption band moved from 1450 cm⁻¹ to 1480 cm⁻¹.

Robertson et al. [23] attempted to develop the fatigue strength of tires to endure more than 10⁸ cycles without cracking by measuring the intrinsic strength (fatigue threshold or endurance limit). The intrinsic strength is determined for candidate compounds of carbon black incorporated with NR/BR blend for tire applications. The intrinsic strength enhanced the blends over the neat rubber compounds after aging at temperatures 50 °C to 70 °C.

Sattayanurak et al. [24] incorporated organoclay to the silica-reinforced NR composite at 45/10 pphr silica/secondary filler to solve the low rolling resistance

and high wet grip induced by additional silica on tire performance. Mooney viscosity, cure behavior, Payne effect, scorch safety, cure rate, and mechanical properties were also significantly affected by organoclay. Rolling resistance and wet traction of a tire tread were improved by adding organoclay.

Cao et al. [25] modified nano silica with graphene oxide to improve NR-based tire treads. The fillers were homogeneously dispersed in the NR latex due to NR bonding with the modifiers. Energy dissipation capability and storage modulus showed enhancements, while elongation at break and loss factor decreased with the increase in modifier content. Tire tread containing 1% of GO enhanced the wear and wet skid resistance by 44.5% and 14.6%, respectively, and decreased the rolling resistance by 5.1%.

Dileep et al. [26] utilized silica fume as a by-product obtained from zirconium silicate production as a reinforcing filler in NR compounds versus carbon black (HAF). Transmission electron microscopy revealed the homogeneous dispersion of fillers in the hybrid composite. Compared with NR, silica content at 20 phr enhanced the modulus, tensile, and tear strength by 107%, 12%, and 28%, respectively. Compared with NR reinforced with HAF50 composite, hybrid composite showed a reduction by 72% and 64% in heat build-up and rolling resistance, respectively.

The present study aims to investigate the influence of adding BR and nano silica on the properties of NR. Therefore, approximately 70% of BR consumption is found in tire tread to enhance fatigue properties, abrasion resistance, and hardness. The nano silica used in this study is a by-product from silicate production and acts as reinforcing filler. The masterbatch compound of NR/carbon black and other additives was prepared and then blended with BR or mixed with nano silica as variables. Tensile, flexing fatigue, IRHD hardness, abrasion wear, and rheology (Mooney viscosity) tests were performed for all samples to find the relationship between morphology, rheology, and mechanical properties.

2. Experimental Work

2.1. Materials used

The basic ingredients of the compound formulation utilized in this work are illustrated in Table 1. All the ingredients are added to rubber through a certain mixing process under ASTM D3182-16 conditions. SMR20 NR and BRcis BR are the matrices (supplied by Shanghai SOCE Group International Commerce Co., Ltd, China); carbon black (type N330, Freedom Chemtech LLP, India) and 20-40 nm nano silica are the fillers (type Vulcasil C, LANXESS Deutschland GmbH, Germany); sulfur, trimethyl dihydroquinoline, and cyclohexyl benzothiazole sulfonamide are the curing accelerators. N-cyclohexylthio-phthalimide is the prevulcanization inhibitor. Zinc oxide, castor oil, and paraffin wax are already used as modifiers in the rubber industry.

2.2. Compounding formulation and mixing processes

A rubber extruder (Farrel Bridge Ltd., England) was utilized to masticate the masterbatch rubber sheet and then mix the ingredients. Three different compounds of rubber specimens were prepared in NR, 60NR-40BRcis blend, and hybrid

nanocomposite of natural NR/SiO₂. The rubber sheet was vulcanized and hot-pressed in moulds at 13 MPa pressure and 155 °C temperature for a 45 min mixing duration.

Table 1. Rubber compound formulations.

Ingredients	Formula 1 (pphr)	Formula 2 (pphr)	Formula 3 (pphr)
SMR20	100	60	100
BR _{cis}	0	40	-
Zinc oxide	5.5	5.5	5.5
Carbon black (N330)	50	50	25
Nano-silica	0	0	25
TMQ	1.5	1.5	1.5
Paraffin wax	0.5	0.5	0.5
Castor oil	5	5	5
CBS	1.5	1.5	1.5
S	2.3	2.3	2.3
CTP.100	0.15	0.15	0.15

2.3. Mechanical testing and characterization

SEM observation and EDX analysis were conducted using a microscope (Zeiss, Germany). The samples were prepared by freezing under nitrogen liquid and then broken. The cross-section was coated with gold to induce conductivity through the test.

The tensile test is commonly executed using a tensile machine (Laryee, China) to provide structural engineering information regarding strength and elongation. The tensile properties of the rubber vulcanizates were tested for five samples according to ASTM D412-16 (modulus, tensile strength, and elongation at break) for samples at 20 °C, and dumbbell-shaped specimens were used. The applied force was (1 kN) at the beginning of the test with a pulling device velocity (20 in/min or 500 mm/min). The tests utilized the microcomputer-controlled electronic universal testing machine (68SC series, Instron, USA). The applied stress in such a test is longitudinal as in Eq. (1):

$$\sigma = \frac{P}{A}, \quad (1)$$

where σ : longitudinal stress (MPa); P : applied load (N); A : cross-sectional area before testing (m²).

The following can be calculated from the obtained curve:

- Tensile strength at break;
- Modulus of elasticity at 100%, 200%, or 300% elongation (Mod 100, 200, or 300, respectively).
- Stiffness, which is equal to $K = \frac{EA}{L}$ kg/mm²;
- Elongation percentage at the break.

The flexing fatigue test was also performed. Crack initiation and propagation caused rubber failure when the rubber samples were subjected to flexing stresses, thus reducing service life. ASTM D813 and Research Methods BD 430 are bending

tests designed to initiate cracks. The number of flexes to the cracks is induced to investigate the tire performance. A flexing system (De Mattia Flex Testing Machine - F15, H.W. Wallace & Co Limited, England), which flexes a specimen with a circular groove moulded in the middle of the strip, was also conducted for 300 cycles per min.

The oscillating disk rheometer (Monsanto Rheometer MDR 2000 E, Germany) is designed to measure the complete curing characteristics of a rubber specimen. A circular test specimen taken from a sample shall be (30 ± 2) mm in diameter and (11.5 ± 1.5) mm in thickness based on the sample pressing machine. The cure meter is loaded, the dies are opened, the test specimen is placed on top of the disk, and the dies are closed. The standard test temperature was 185°C for 6 min according to ASTM D2084. A circular test specimen shall be 30 ± 2 mm in diameter and 11.5 ± 1.5 mm in thickness.

Hardness is the capability of a surface to resist cutting, scratching, wearing, indentation, and penetration. Two related rubber hardness measurements are as follows: shore (A) hardness and International Rubber Hardness Degree (IRHD).

The indenter tool is a steel needle for shore (A) and IRHD durometer, but IRHD durometer has a half-spherical end. Hardness magnitude is an index for strength and structure coherence, and its degree scale in both types of equipment ranges between (0100 hardness degrees). The usual test is conducted on flat test pieces 8-10 mm thick and at least 9-10 mm from the edge according to ASTM D2240-15 using Wallace hardness tester.

Abrasion wear resistance can be defined as the resistance to wearing away by rubbing or the sliding surface of rubber against abrasive materials, which resulted in surface material removal. A pin-on-disk test (handmade equipment), which depends on producing relative motion between the rubber and an abradant, was also conducted. The basic standard test in this study is that rubber cylindrical blocks are fixed in a vertical holder and pressed against a rotating abrasive paper disc at specific force, time, temperature, and velocity. The dimensions of samples used in this test are designed following ASTM D 5963. An abrasive paper (SiC) with a particle size of $200\ \mu\text{m}$ is pasted on a revolving drum. The applied load was 4.5 kg with 250 rpm rotating velocity. The wear rate could be computed by using Eq. (2) to estimate the abrasion resistance.

$$K_C = \frac{\Delta m}{\rho_C * V_C * t} = \frac{m_1 - m_2}{\rho_C * V_C * t}, \quad (2)$$

where: K_C : wear rate of composite (mm^3/mm); Δm : mass loss (g) = $m_1 - m_2$; m_1 : weight of specimen before test (g); m_2 : weight of specimen after test (g); ρ_C : density of specimen (g/mm^3); V_C : sliding speed (mm/s); and t : sliding time (s).

The homogeneity and topography observation were respectively conducted using a scanning electron microscope and energy-dispersive X-ray for nano silica powder, carbon black, and rubber samples. The scanning electron microscope (VEGA 3 TESCAN model, Czech Republic) with an HV range from 200 V up to 30 kV and Carl Zeiss AG (EVO family model, Germany) were utilized with acceleration voltages (5 and 20 kV) and different magnifications (1-250 kX). Samples were cooled in liquid nitrogen for 3 min and then broken to obtain a fracture surface with the required morphological features.

3. Results and Discussion

Figure 1 illustrates the SEM observation and EDX analysis of nano silica (a and b) and carbon black (c and d, respectively). The SEM images revealed the granular shape of nano silica with an average size of 20-60 nm, where an agglomerated network was for spherical carbon black within microscale average particle size. The EDX analysis indicated that the silicon and oxygen peaks have no trace of another element in the silica sample. Moreover, the EDX of carbon black has no noticeable trace of another element.

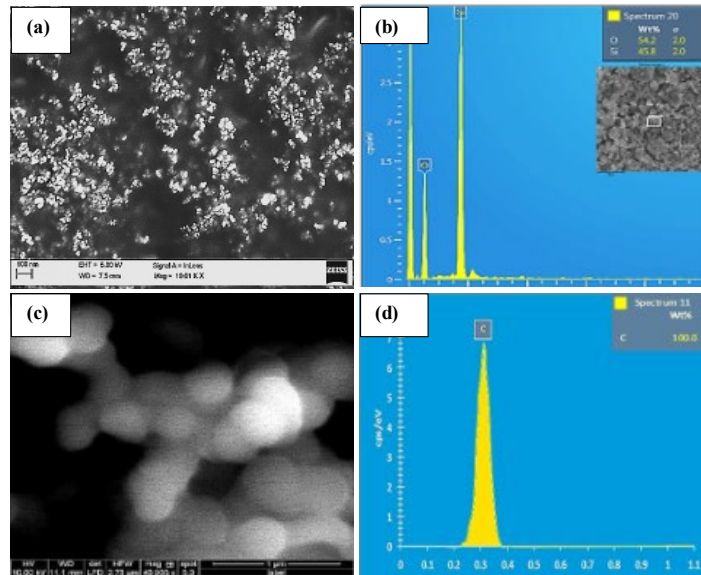


Fig. 1. SEM and EDS analysis of nano-silica (a) and (b), and carbon black (c) and (d).

The SEM images of prepared rubber samples (NR, NR/BR blend, and NR/SiO₂ nanocomposite) are illustrated in Figures 2(a), (b), and (c), respectively, thus demonstrating significant variations in different morphology. Therefore, NR has a cave-like structure, while the size of cavities is markedly diminished in blends and nanocomposites. Moreover, the homogeneity of carbon black with NR and that of BR with NR and carbon black are high. Hence, the agglomeration or nonhomogeneous regions are absent due to the successful mixing performance. The cavity size in nanocomposites was also decreased, and most of the silica nanoparticles spread uniformly with few agglomerates.

Figure 3(a) shows Young's modulus at 100%, 200%, and 300 % strain (calculated from the stress-strain curve). Meanwhile, Fig. 3(b) shows the tensile strength, elongation percentage at breakage, and the axial stiffness of prepared samples. Notably, the results of tensile strength and elongation at break of rubber compounds increased with the addition of silica, whereas Mod 100%, 200%, and 300% decreased. This behavior indicates the decrease in crosslink density in compounds. Such a reduction in crosslink density results in the decline of rubber modulus. The enhancement in tensile strength and ductility of NR compounds with nano silica

reinforcement may be attributed to the well-distributed nano silica through the matrix with satisfactory bonding, inhibiting crack initiation and propagation with increasing applied stress. This phenomenon is presented in the SEM photographs of the fractured samples. Figure 2(c) shows the uniform distribution of silica. The total amount of the fillers remained unchanged in the compounds through cross-linking, and these results agree with Zafarmehrabian et al. [27].

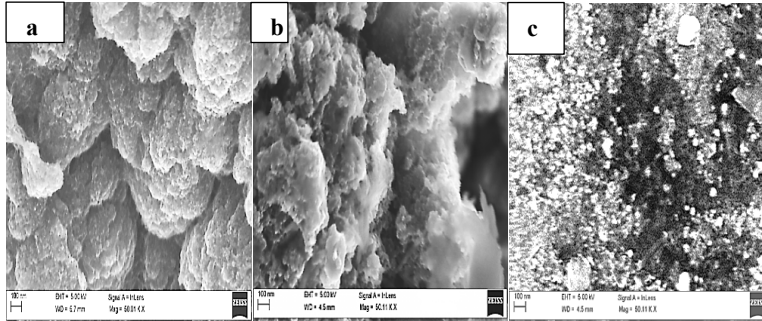


Fig. 2. SEM images of samples; (a) NR; (b) 60NR-40BRcis blend; and (c) NR/SiO₂ nanocomposite.

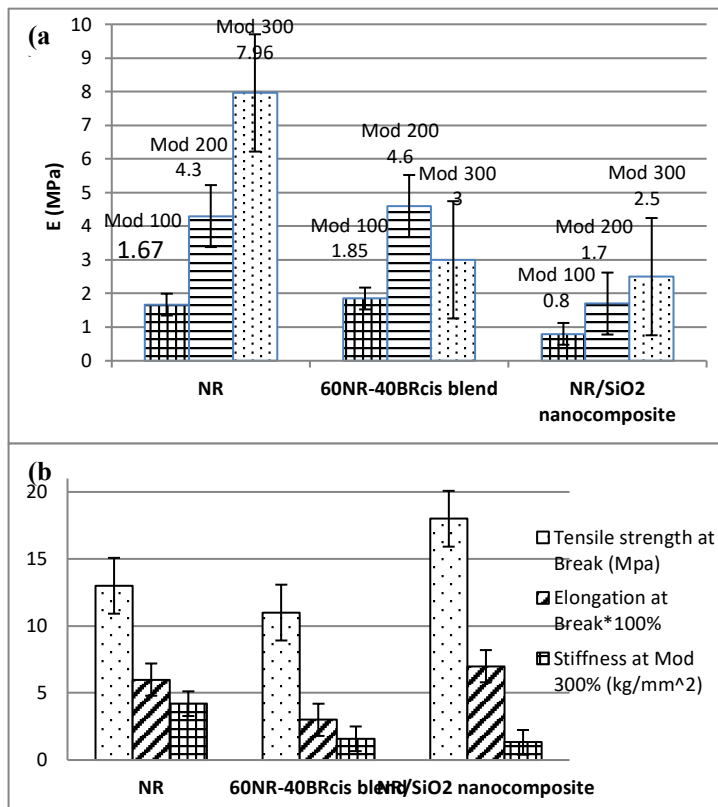


Fig. 3. Tensile test results, a) Tensile modulus Mod 100, b) Tensile strength, elongation% and stiffness.

Tensile properties of the NR compound significantly deteriorated with the addition of BR. Therefore, such an addition does not have a considerable effect on Mod 100% and 200% but deteriorated the value of Mod 300%. Modulus of elasticity and rigidity sensitively influence material resistance to elastic deformation, which significantly depends on material continuity. Therefore, blending or compositing with other materials leads to material discontinuity, decreases material resistance to elastic deformation, and also reduces modulus. Tensile strength and elongation percentage at break properties decremented due to the heterogeneous mixture of NR with BR, which led to the short polymer chains with confined miscibility, and the non-crystallinity of BR compared with NR. These results agreed with that of Cao et al. [25]. A similar observation was recorded by Wisojodharmo et al. [20] when they attributed the deterioration to the poor properties of BR because it does not have crystallization properties compared with NR.

Rheology test results are illustrated in Table 2, torque-time response curve (Fig. 4), and comparative histogram (Fig. 5). Three important findings obtained from this test are Mooney viscosity, homogeneity, and cure index. Notably, the maximum torque of the NR compound increased when nano silica was embedded within the nanocomposite but decremented when blended with BR. The obtained torque in this study represents the resistance of the material to shear motion. Therefore, maximum torque indicates additional shears stress response against the motion, which will be impeded in the presence of strange or dissimilar ingredients. An example of ingredients is represented by nano silica, which prevents the movement of rubber chains toward shear force, exhibiting high torque. The opposite effect was obtained with the blend. Therefore, BR showed lower resistance to motion compared with NR. Thus, the addition of this substance leads to the acquisition of less viscose material than the base (NR).

The above findings revealed that maximum torque was obtained for nanocomposite, NR compound, and blend. Mooney viscosity is a function of low torque M_L ($MV = 2.7 M_L$). The maximum Mooney viscosity was obtained for blend, nanocomposite, and NR compound. The homogeneity index of the NR compound was decremented by 16% when blended with BR while enhanced by approximately 17% when reinforced with nano silica. Therefore, the SEM observation revealed that the NR morphology has significant grooves, which diminished with the addition of nano silica that enhanced the homogeneity. Meanwhile, different morphologies can be observed for the NR/BR blend. Thus, numerous mini grooves were found due to the effect of added materials (polymer instead of ceramic powder) and the partial miscibility between different rubber chains and mixing conditions.

Table 2 Rheology test at temperature 185 °C.

Out findings	NR compound	60NR-40BRcis blend	NR/SiO ₂ nanocomposite
Min. Torque= ML (N.m)	0.45	0.46	0.8
Max Torque= MH (N.m)	3.36	2.9	4.22
Moony Viscosity= $2.7 * ML$	1.215	1.242	2.16
Homogeneity= $MH-ML$	2.91	2.44	3.42
Scorch time= t_s (min)	1.05	1.29	1.11
Cure time= t_{90} (min)	1.47	1.91	1.61
Cure index= $t_{90}-t_s$ (min)	0.42	0.62	0.5

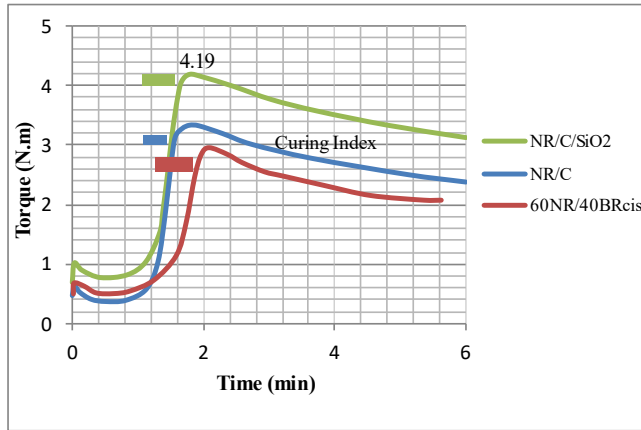


Fig. 4. Rheology test results (Torque-time response).

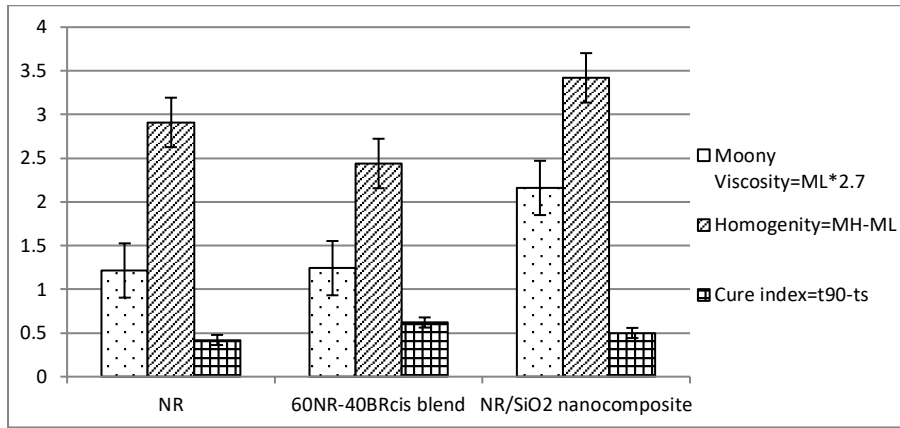


Fig. 5. Comparative histogram of rheology test out findings: Moony viscosity, homogeneity and cure index for prepared sample.

The cure index depends on the period between the start point of curing (t_s) and a certain time (t_{90} in this study, that is, after 90 s). The curing index of NR compounds was increased by more than 47% and 19% when respectively blended with BR and nanocomposite. This effect is attributed to the increase in viscosity with the addition of BR and silica to the NR (Table 2). The curing index had a significant impact on the kind of added materials (polymer compared with ceramic powder). Therefore, different behaviors were observed between blend and nanocomposite. The addition of rubber as a blend or ceramic powder as filler increased the curing index compared with the NR base. These results agreed with that of Chen et al. [18].

The results of flexing fatigue, hardness (IRHD and shore A), and abrasion wear resistance tests are illustrated in Table 3. Many cycles in which materials fail were recorded for the flexing fatigue test. Therefore, the nanocomposites withstood 836 cycles and then failed, the NR/BR blend failed at 530 cycles, and the NR compound failed at 366 cycles. This testing method deals with the evaluation of crack growth of vulcanized rubber while undergoing repetitive bending or flexing. Rubber failure

occurs due to crack growth, which propagates to flaws under mechanical forces. The cracks are material discontinuity typically 25-50 μm in length, impeding force transmission through the matrix. The initiation mechanism remains unclear: it may start from coarse particles, weak interface, pre-existing scratches, or density variation in crosslinking. The cracks rapidly propagate in size but fail.

Table 3 Flexing fatigue test, hardness (IRHD and shore A), and abrasion wear resistance results.

Sample	Flexing fatigue (No. of cycles)	Hardness (IRHD)	Hardness (Shore A)	Abrasion Wear Rate (mm^3/mm)
NR compound	366	50	45	0.56
NR/BR blend	530	52	54	0.2
NR/SiO ₂ nanocomposite	836	56	58	0.19

IRHD hardness and shore (A) show similar behaviors of surface resistance against static penetration force. The hardness of NR increased with the addition of nano silica or blending with BR. The first increment due to nano silica exhibited considerable restriction of rubber chain against applied normal forces, while rubber blends may enhance hardness due to the material (BR), which has hardness characteristics higher than NR. Abrasion wear resistance directly influences hardness behavior. Therefore, the materials with maximum hardness resist the abrasion wear.

4. Conclusion

The characteristics of NR are suitable for versatile application due to its viscoelastic behavior, long fatigue life, and adhesion capability to different surfaces. Developing NR compounds by blending or adding hybrid fillers such as nano silica, showed different characteristics compared with the NR base due to changes in material content and microstructure.

The modulus of elasticity deteriorated for NR compounds with the addition of BR and nano silica. Tensile strength and elongation at break of NR compounds decremented when blended with BR, whereas those with added nano silica were enhanced. Axial stiffness deteriorated for blend and nanocomposite compared with NR by 62% and 68%, respectively. The maximum Mooney viscosity was observed for blend, nanocomposite, and NR.

The curing index of NR compounds was increased by more than 47% and 19% when respectively blended with BR and nanocomposite. The enhancement percentage of the number of cycles was 45% and 128% for NR compounds when respectively blended with BR and nanocomposite during the flexing fatigue test. Abrasion wear resistance and hardness were also enhanced for NR compounds with additional BR or nano silica.

Investigating the influence of other nanofillers, such as alumina, titania, calcium carbonate, and calcium oxide, on the morphology, rheology, and mechanical properties of NR is recommended for future works.

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Abbreviations	
ASTM	American Society for Testing and Materials
BR	Butadiene Rubber
CBS	Cyclohexyl benzothiazole sulphonamide
CR	Neoprene Rubber
CTP	N-cyclohexylthio-phthalimide
DSC	Differential scanning calorimetry
FTIR	Fourier Transform Infra-Red
GO	Graphene Oxide
HAF	High Abrasion Furnace (carbon black)
IIR	Butyl Rubber
IR	Polyisoprene Rubber
IRHD	International Rubber Hardness Degrees
MH	Maximum torque
Mod 100, 200, 300	Modulus of elasticity at 100, 200 and 300 % elongation
MV	Moony viscosity
MWCNTs	Multi-Walled Carbon Nanotubes
NBR	Nitrile Butadiene Rubber
NR	Natural Rubber
pphr	part per hundred rubber
SBR	Styrene Butadiene Rubber
SEM	Scanning Electron Microscope
SiC	Silicon carbide
TMQ	Trimethyl-Dihydroquinoline

References

1. Saba, N.; Tahir, P.M.; and Jawaid, M. (2014). A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. *Polymers*, 6(8), 2247-2273.
2. Ahmedizat, S.R.; Al-Zubaidi, A.B.; Al-Tabbakh, A.A.; Achour, A.; and Hamead, A.A. (2020). Comparative study of erosion wear of glass fiber/epoxy composite reinforced with Al₂O₃ nano and micro particles. *Materials Today: Proceedings*, 20(4), 420-427.
3. Sallal, H.A.; Abdul-Hamead, A. A.; and Othman, F.M. (2020). Effect of nano powder (Al₂O₃-CaO) addition on the mechanical properties of the polymer blend matrix composite. *Defence Technology*, 16(2), 425-431.
4. Abed, M.S. (2018). Preparation of graphene nanoribbons (GNRs) from twisted structure carbon nanotubes using unzipping technique. *IOP Conference Series: Materials Science and Engineering*, 454, 012159.

5. Hamad, Q.A.; and Abed, M.S. (2019). Investigation of thyme and pumpkin nanopowders reinforced epoxy matrix composites. *Journal of Mechanical Engineering Research and Developments*, 42(5), 153-157.
6. Abed, M.S.; Abed, A.S.; and Othman, F.M. (2019). Green synthesis of silver nanoparticles from natural compounds: Glucose, eugenol and thymol. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 60(1), 95-111.
7. Modern Plastics; and Harper, C.A. (2000). *Modern plastics handbook*. McGraw-Hill, New York.
8. Erich, F.R. (1978). *Science and technology of rubber*. Academic Press, New York.
9. Bolton, W. (1993). *Engineering materials technology*. NEWNES (2nd ed.), Oxford.
10. Harper, C.A. (2006). *Handbook of plastics technologies*, McGraw-Hill, New York.
11. Gent, A.N. (2012). *Engineering with Rubber: How to Design Rubber Components*. Hanser (3ed.), Munich.
12. Jones, K.C.; and Tinker, A.J. (1998). *Blends of natural rubber novel techniques for blending with speciality polymers supported by the common fund for commodities*. (1998th ed.). Springer.
13. White, J.; De, S.K.; and Naskar K. (2009). *Rubber technologist's handbook*. (2nd ed.). Smithers Rapra Technology.
14. Kohjiya, S.; and Ikeda, Y. (2014). *Chemistry, manufacture and applications of natural rubber*. (Woodhead P), Amsterdam.
15. Mroczkowski, T.S. (1992). *Tire tread rubber composition: Vol. EP 0 527 3* (Patent No. EP 0 527 396 A1).
16. Sone, T. (2016). Industrial synthetic method of the rubbers. 1. Butadiene rubber. *International Polymer Science and Technology*, 43(1), 49-54.
17. Ansarifar, M.A.; Chugh, J.P.; and Haghighat, S. (2000). Effects of silica on the cure properties of some compounds of styrene-butadiene rubber. *Iranian Polymer Journal (English Edition)*, 9(2), 81-87.
18. Chen, Y.; Peng, Z.; Kong, L.; Huang, M.F.; and Li, P.W. (2008). Natural rubber nanocomposite reinforced with nano silica. *Polymer Engineering and Science*, 48(9), 1674-1677.
19. Carli, L.N.; Roncato, C.R.; Zanchet, A.; Mauler, R.S.; Giovanela, M.; Brandalise, R.N.; and Crespo, J.S. (2011). Characterization of natural rubber nanocomposites filled with organoclay as a substitute for silica obtained by the conventional two-roll mill method. *Applied Clay Science*, 52(1-2), 56-61.
20. Wisojodharmo, L.A., Fidyarningsih, R., Fitriani, D.A.; Arti, D.K.; Indriasari; and Susanto, H. (2017). The influence of natural rubber - Butadiene rubber and carbon black type on the mechanical properties of tread compound. *IOP Conference Series: Materials Science and Engineering*, 223(1), 012013.
21. Gao, J.; He, Y.; Gong, X.; and Xu, J. (2017). The role of carbon nanotubes in promoting the properties of carbon black-filled natural rubber/butadiene rubber composites. *Results in Physics*, 7, 4352-4358.
22. Jovanović, S.; Samaržija-Jovanović, S.; Marković, G.; Jovanović, V.; Adamović, T.; and Marinović-Cincović, M. (2018). Ternary NR/BR/SBR

- rubber blend nanocomposites. *Journal of Thermoplastic Composite Materials*, 31(2), 265-287.
23. Robertson, C.G.; Stoček, R.; Kipscholl, C.; and Mars, W. (2019). Characterizing the intrinsic strength (fatigue threshold) of natural rubber/butadiene rubber blends. *Tire Science and Technology*, 47(4), 292-307.
 24. Sattayanurak, S.; Noordermeer, J.W.M.; Sahakaro, K.; Kaewsakul, W.; Dierkes, W.K.; and Blume, A. (2019). Silica-reinforced natural rubber: synergistic effects by addition of small amounts of secondary fillers to silica-reinforced natural rubber tire tread compounds. *Advances in Materials Science and Engineering*, Volume 2019, Article ID 5891051, 8 pages.
 25. Cao, L.; Sinha, T.K.; Tao, L.; Li, H.; Zong, C.; and Kim, J.K. (2019). Synergistic reinforcement of silanized silica-graphene oxide hybrid in natural rubber for tire-tread fabrication: A latex based facile approach. *Composites Part B: Engineering*, 161, 667-676.
 26. Dileep, P.; Varghese, G.A.; Sivakumar, S.; and Narayanankutty, S.K. (2020). An innovative approach to utilize waste silica fume from zirconia industry to prepare high performance natural rubber composites for multi-functional applications. *Polymer Testing*, 81, 106172.
 27. Zafarmehrabian, R.; Gangali, S.T.; Ghoreishy, M.H.R.; and Davallu, M. (2012). The effects of silica/carbon black ratio on the dynamic properties of the tread compounds in truck tires. *Journal of Chemistry*, 9(3), 1102-1112.