Performance Investigation of Automobile Tires Using Nano Particles

Dr.Sanjay Soni [1], Dr.Sivaneasan Bala Krishnan[2], Dr.Subrata Chowdhury[3], Dr.Prasun Chakrabarti[4]

(Post Doctoral Researcher) Associate Professsor[1],

Associate Professor[2], S.I.T. Singapore, Associate Professor[3], SITAMS, Chittor, Director Research[3], SPS University Udaipur

ABSTRACT

In the constantly growing automotive industry, optimal vehicle performance and sustainability through innovative materials is paramount. Nanocomposite materials, incorporating nano particles such as carbon nanotubes (CNTs), graphene, and silica, have emerged as key ingredients in establishing tire technology with improved durability, efficiency, and environmental impact. The rising economy of the country has raised the demand for automobiles. In order to achieve safety, comfort and environment factors in mind automakers are investing heavily in research and development in this area. This review discusses the role of these nano composites into tire manufacturing, emphasizing their role in enhancing mechanical properties, wear resistance, and rolling efficiency while reducing environmental footprints.

Keywords: Rolling efficiency, Nano silica particles, Styrene butadiene rubber, Wear resistance

Introduction

As India is emerging towards the developed economy the increased focus of government lies on building good road network. The roads are been replaced are made of RCC in comparison with Asphalt roads. As a result the performance of automobile is on high demand. Fuel efficiency combined with higher standard of safety are now primary requirements for which automotive tire manufacturers are regularly seeking to create better and more ecological tires which have better durability with less noise Keeping this as focus nano structure material is now a new hope for tire manufactures. As incorporation of nano particles such as carbon nano tubes(CNTs), Graphine and silica have emerged as a key enablers in redefining tire technology and improved durability, efficiency and environmental impacts. The objective of present paper is to study how nono composite technology not only satisfies but also fulfills the current performance matrix capturing the more desired parameters required for optimal vehicle performance. Through complete analysis of the properties and applications of nano composite in enhancing tire performance and their importance in contributing to green automotive technologies.

Literature Review

For the optimal performance of tire the integration of nano particles has emerged as an major solution to maximize tire performance the infusion of nanoparticles into polymer matrix offers enhancement in mechanical properties, Reliability and ecofriedly environment. These materials optimize the tire performace as per required criteria such as inner grip and sidewall pillars. Present discussion revels the impact of various nano composites such as nano clays and silica nano particles for enhancing efficiency of tires. It was observed that a blend of Styrene-Butadiene Rubber (SBR a) and silica provides light improvement in rolling resistance performance and can lead to a considerable reduction in CO_2 emission (2, 14). Thus, decreasing the rolling resistance and wet traction and tread wear is a challenging and complex issue for tire industry (9). The major advantages of using silica over carbon black are attaining a lower rolling resistance and dynamic-mechanical and wear properties (3, 7). UltraSil, upper grade of slica particles have been advantageous in tire industry for fulfilling major requirements (7, 8). By adding suitable reinforcing fillers and implementing recycling approaches (10, 14) the decrease in CO_2 emissions can be achieved and this can be more better approach for rubber production and waste management. clay particles dispersed at the nanometer scale, have considerable impact on mechanical and thermal enhancements. These composites are produced through methods like sol-gel processes, intercalation, or blending. The modification of nanoclay surfaces aids in their dispersion within the rubber matrix, resulting in efficient interface bonding [11]. A large number of biomass sources, including hardwoods, softwoods, and agricultural residues, are used to generate nanocellulose [14,16]. Owing to its high strength and lightweight, CNF serves as an effective reinforcement in tires, providing an alternative to carbon black. Carbon nano tubes with a unique SP2 hybridization, where carbon atoms are arranged in a robust and efficient manner gives exceptional mechanical, electrical, and thermal properties to the material [8]. Graphene, characterized as a two-dimensional crystal comprised solely of carbon atoms, exhibits a suite of outstanding properties. Its high conductivity, unparalleled strength, and remarkable elasticity make it a candidate for diverse applications including structural nanocomposites, electronic devices, optical lenses, and energy storage devices like fuel cells, batteries, and super capacitors [3].

Methodology

A blend of styrene-butadiene rubber with styrene content of 25% and butadiene rubber (Midas rubber, ready available in Market used for tire remoulding) were used in this study as a tire tread matrix. Silicon dioxide Nanoparticles(SiO_2, amorphous) with a purity of 99.9% and Average particle size 20-50 Nm was used porosity analyzer in this study, was purchased from scientific supplier in Jabalpur Commercially available Multiwalled carbon Nanotubes with bulk density .03g/cm^{3}was used as the reinforcing filler. A bifunctional sulfur-containing organosilane, triethoxysilylpropyltetrasulfide (TESPT) was employed for the modification of the silica particle surface. TESPT, usually abbreviated as ‘‘Si69’’, is specifically applied for rubber applications and formulated with 10 wt % regarding the amount of silica filler. The rest of the materials including sulfur as the curing agent, TBBS (N-t-Butyl-2-Benzothiazole Sul fenamide) accelerator, DPG (1,3 agent, aromatic oil, and norsolene S95 resin - diphenyl guanidine) accelerator, stearic acid, zinc oxide, and TMQ (Polymerized-2,2,4-trimethyl-1,2-dihydroquinoline resin) anti-oxidant, 6PPD (N-(1,3-dimethylbutyl)-N-phenyl-p-phenylenediamine) and Nanoclay as anti-aging agent. The rubber compounding was performed using a laboratory two-roll mixing mill by a 3-pass mix sequence technique. The temperature of rollers was adjusted to be 82°C. The compounding was first started with mastication of SBR/BR with a weight ratio of 75/25. Then, the mixing sequence was as follows: after In these formulations, SBR/BR blend with weight ratio of 75:25 was used as rubber matrix with semi-efficient vulcanization system for all compounds. The control sample is a SBR/BR compound with a typical formulation suitable for car tire tread. The control compound contains UltraSil hereafter, with a high concentration of 70 phr. As UltraSil is replaced with nanonanoparticles, silica (more than half), silane, half of aromatic oil, half of process resin, rest of the silica, rest of aromatic oil, rest of process resin and wax were blended into the SBR/BR compound. The mixture was processed using a two-roll mill until a homogenous compound was obtained. The resulting compounds were subsequently exposed to a high temperature of 140°C for 10 min using a sheet mold inside a hydraulic press at 150°C and 100 bar to boost silanization reaction between silica and TESPT. Afterward, the compound was kept to rest for 4 h before the addition of the rest of the ingredients. In the third step, the compounds were then mixed with ZnO, stearic acid, TMQ, 6PDD, accelerators, and curing agents at a pre set temperature of 78°C. The compounds were finally sheeted on the two-roll mill directly after mixing and kept overnight before testing (14).

Material Characterizations

The microstructure and surface chemistry of nanocomposites were studied with attenuated total reflectance fourier transform infrared (FTIR-ATR) spectra (5). The morphologies of rubber nano composites were evaluated by employing a field emission scanning electron microscopy (FESEM) with an applied voltage of 16 kV. Cryogenic fractured surfaces of vulcanizates prepared in liquid nitrogen were used for FESEM observations. The oscillatory rheology measurements are performed in a bi-conical die heated to 160°C at an amplitude of ± 0.5° at 1.678 Hz. The uniaxial tensile testing was carried out on specimens with dumbbell shape applying universal testing machine, HIWA min. The cyclic tensile test was performed on specimens applying an extension limit of 400% in a three successive cycle of load-unload tensile test. Dynamic mechanical analysis (DMA) was carried out on tensile mode under a dry nitrogen flow over a temperature range of 90°C to 90°C with heating rate of 4°C/min at a frequency of 1 Hz (14).

Result and discussion

FTIR analysis of the control and Compound 1 samples which confirm the microstructure of nano composites. Carbon atoms stretching vibrations in the aromatic ring correspond to the distinctive spectral area at 1300–1400 $cm^{-1.30}$ the other identifying peak of the matrix is associated to the stretching vibration of cis polybutadiene units at 900 cm^{-1}. The successful coupling reaction of the silane coupling agent can be confirmed with symmetric stretching of Si-O at 700 cm^{-1} and perpendicular Si-O stretching at 650 $cm^{-1.30}$

Tensile properties

The uniaxial and cyclic uniaxial tensile behaviors of the SBR/BR vulcanizates. Several tensile properties including young’s modulus, tensile strength, elongation at break, and M300=M100 and M300=M50 modulus ratios as reinforcement indices55 (where M50, M100,and M300 are the modulus at the extension of 50%, 100%, and 300%, respectively) .

Table 1.Tire Analysis

Rubber Compound: 75:25

25% ->

Silane (TESPT), ZnO/Stearic acid, 6PPD/TMQ, Aromatic oil/Resin, Sulfur/DPG/TBBS, Wax

75% ->

Base Compound Rubber -> 70% Base Rubber + 0% Nano-SiO2

NS-1 Compound Rubber -> 65% Base Rubber + 5% Nano-SiO2

NS-2 Compound Rubber -> 60% Base Rubber + 10% Nano-SiO2

NS-3 Compound Rubber -> 50% Base Rubber + 15% Nano-SiO2

Sample Name	**Youngs Modulus (MPa)**	**Tensile Strength (MPa)**	**Density (kg/m3)**
Base Compound Rubber	2.94	18.96	1179
NS-1 Compound Rubber	3.45	19.37	1180
NS-2 Compound Rubber	3.92	19.56	1185
NS-3 Compound Rubber	3.95	19.03	1180

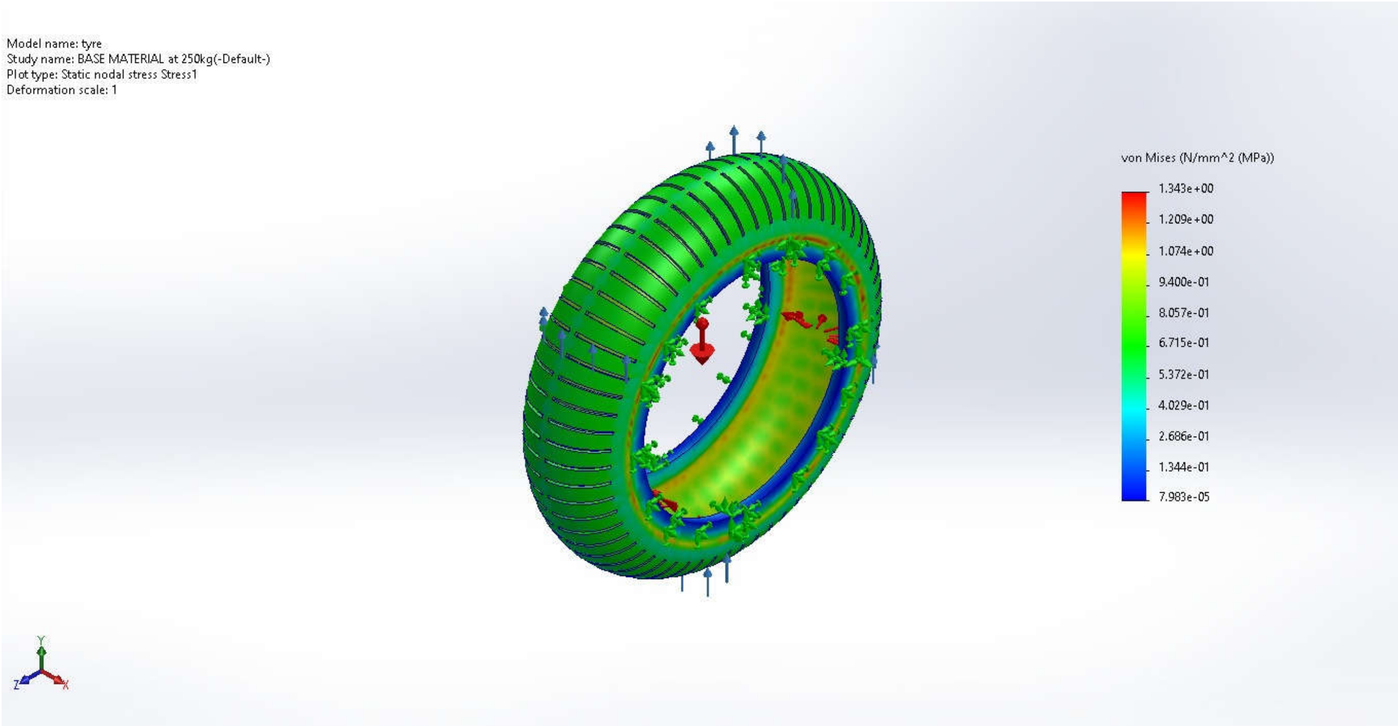
Validation of the Results

The above results obtained were validated using solid works software and results clearly reveled that after mixing a specific amount of nano particles the Displacement and strain can be considerably reduced. The reduction in displacement reveals that the tire hardness increases. The simulated results are shown

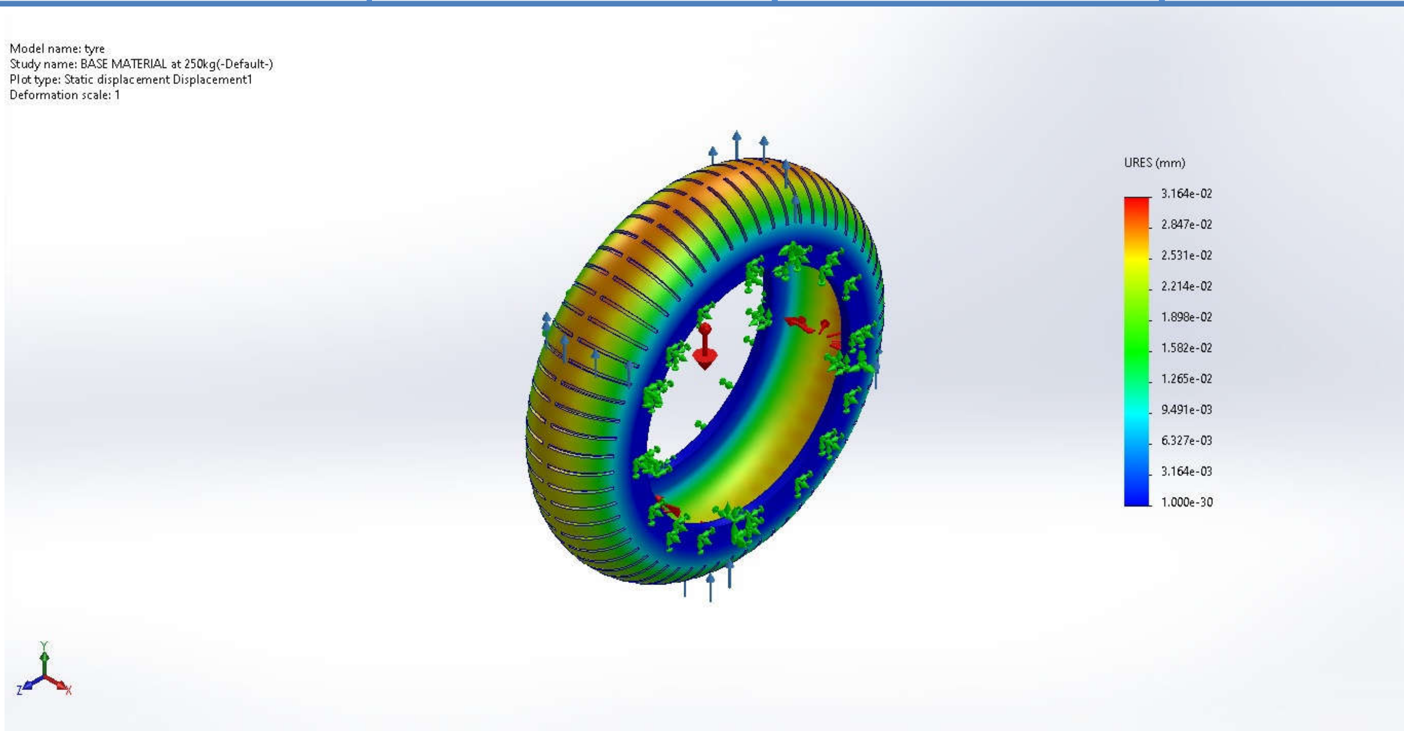
Variable/Sample Name	**Base Compound Rubber**	**NS-1 Compound Rubber**	**NS -2 Compound Rubber**	**NS-3 Compound Rubber**
Stress (MPa)	1.343	1.343	1.343	1.343
Displacement (mm)	31.64	26.96	23.73	23.55
Strain	0.03512	0.02993	0.02634	0.02614

Study Results with base Material

Name	**Type**	**Min**	**Max**
Stress1	VON: von Mises Stress	7.983e-05N/mm^2 (MPa) Node: 4160	1.343e+00N/mm^2 (MPa) Node: 39791
tyre-BASE MATERIAL at 250kg-Stress-Stress1			



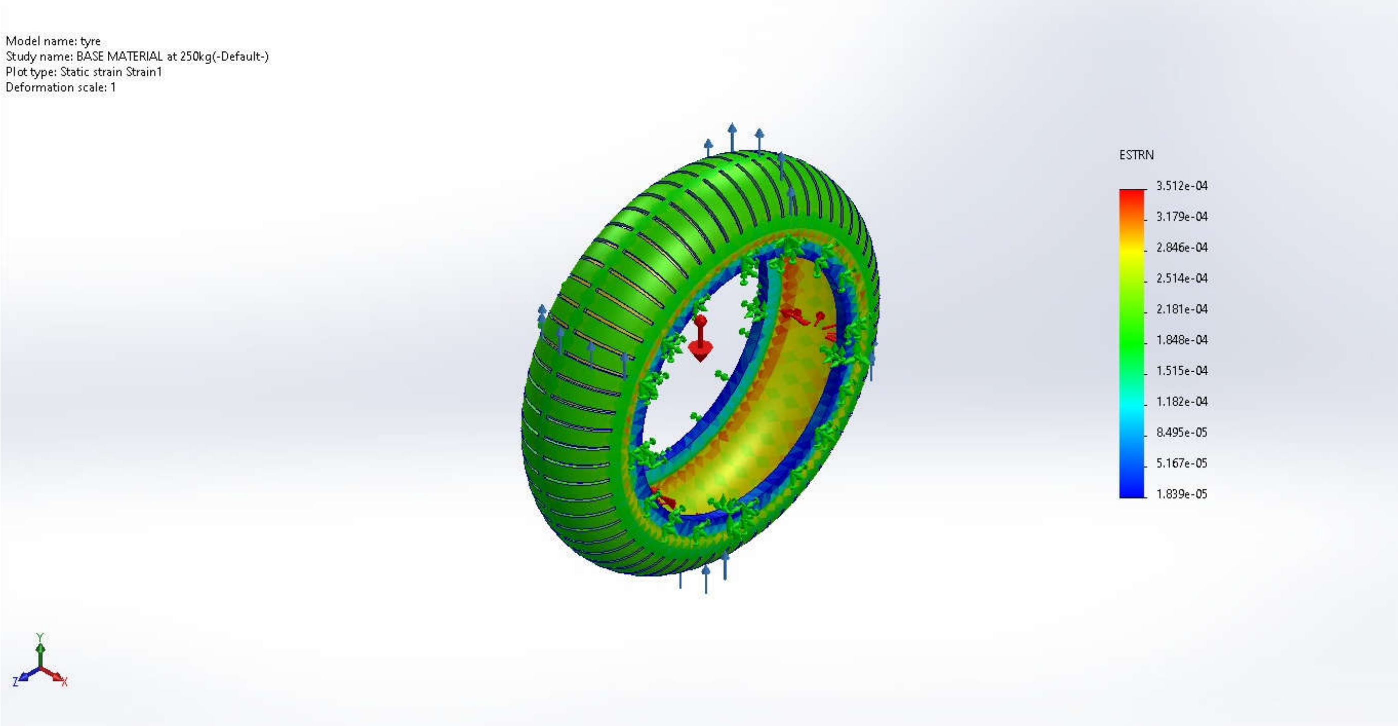
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 253	3.164e-02mm Node: 3959



tyre-BASE MATERIAL at 250kg-Displacement-Displacement1

Name	Type	Min	Max

Name	Type	Min	Max
Displacement1	**URES: Resultant Displacement**	**0.000e+00mm Node: 253**	**3.164e-02mm Node: 3959**
Strain1	ESTRN: Equivalent Strain	1.839e-05 Element: 6204	3.512e-04 Element: 1582



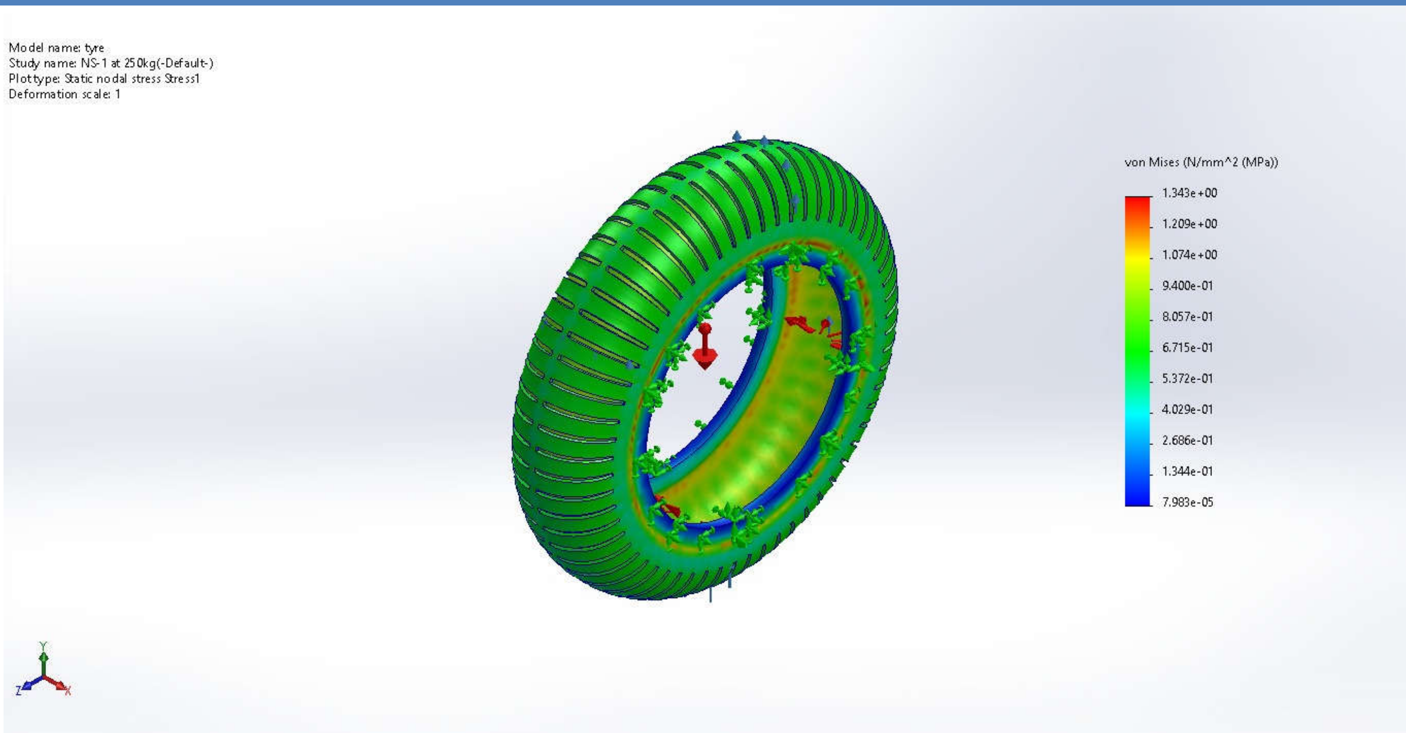
tyre-BASE MATERIAL at 250kg-Strain-Strain1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 253	2.807e-02mm Node: 4001

Study Results NS-1 Compound Rubber

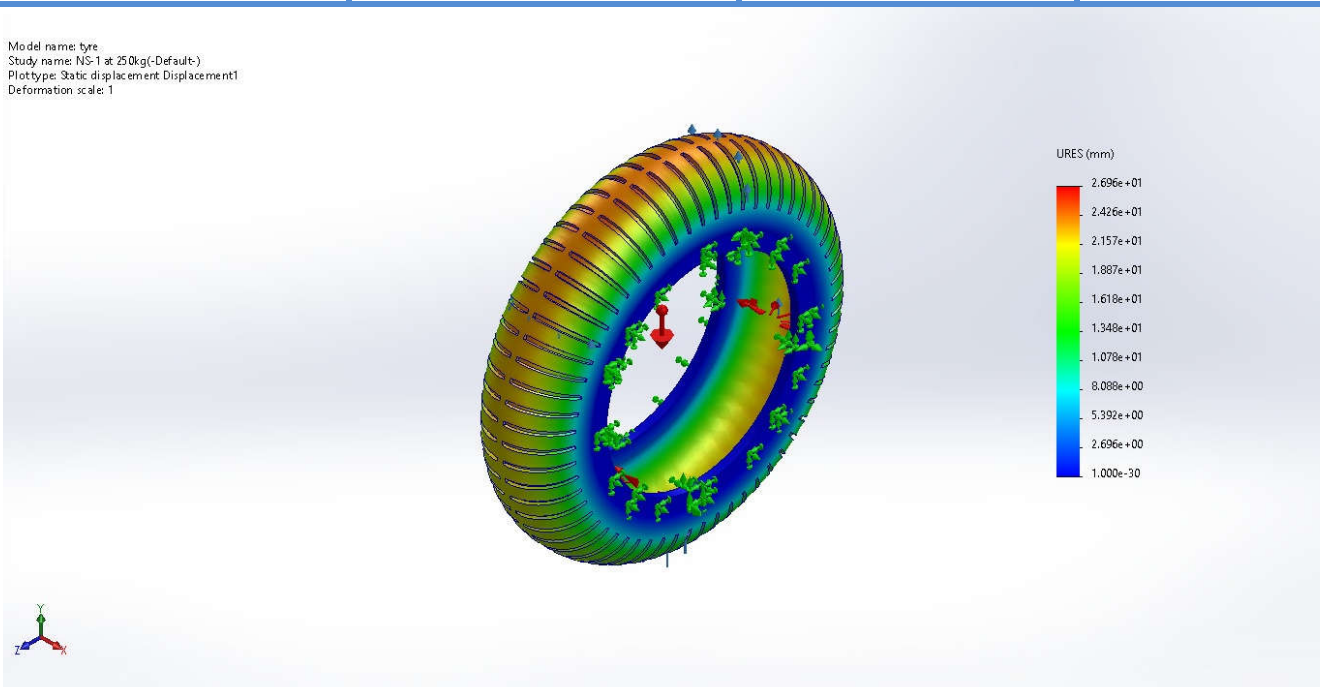
Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.983e-05N/mm^2 (MPa) Node: 4160	1.343e+00N/mm^2 (MPa) Node: 39791

Name	Type	Min	Max



tyre-NS-1 at 250kg-Stress-Stress1

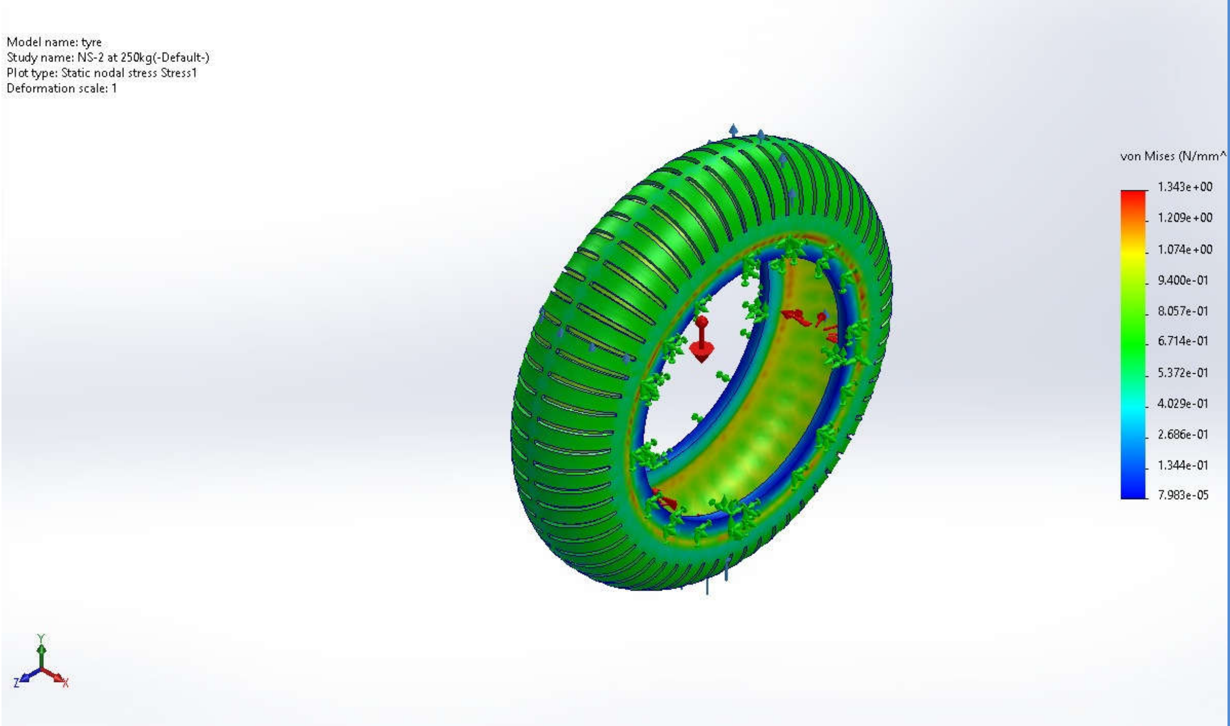
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 253	2.696e+01mm Node: 3959



tyre-NS-1 at 250kg-Displacement-Displacement1

Study Results NS-2 Compound Rubber

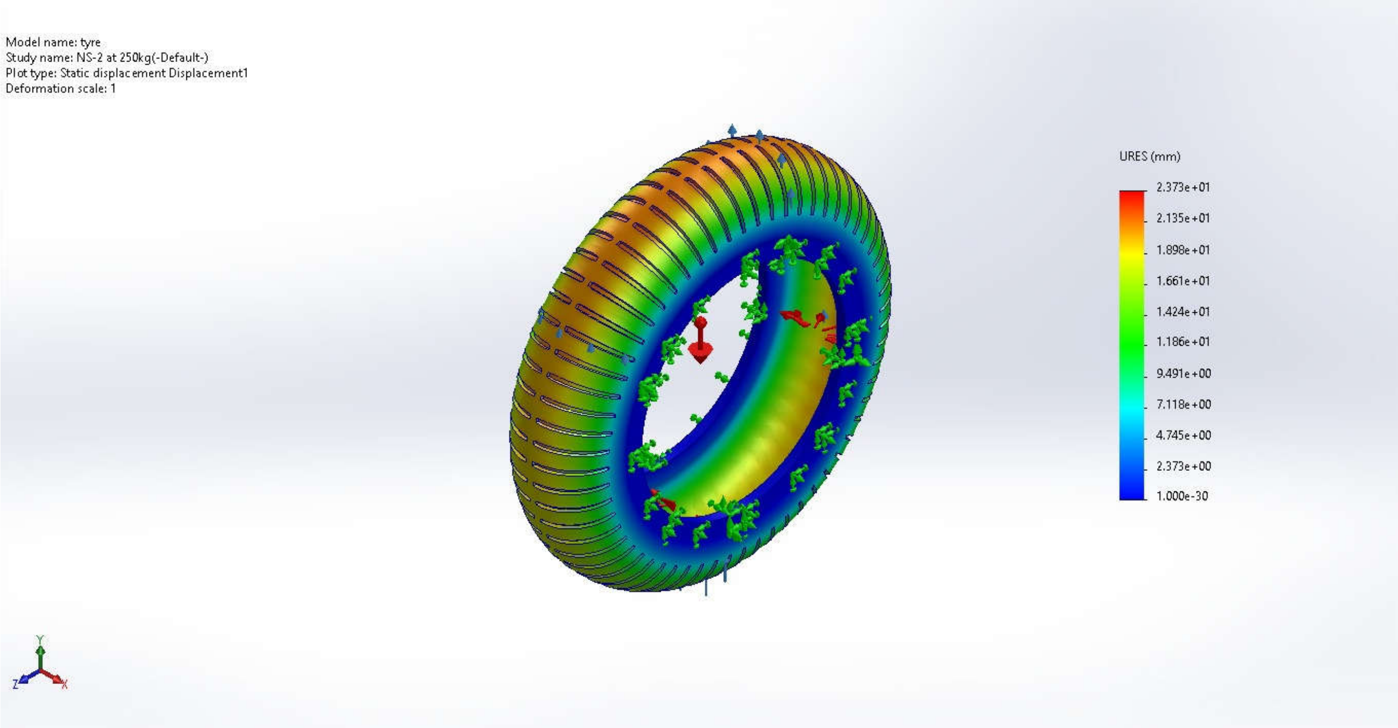
Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.983e-05N/mm^2 (MPa) Node: 4160	1.343e+00N/mm^2 (MPa) Node: 39791



tyre-NS-2 at 250kg-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 253	2.373e+01mm Node: 3959

Name	Type	Min	Max

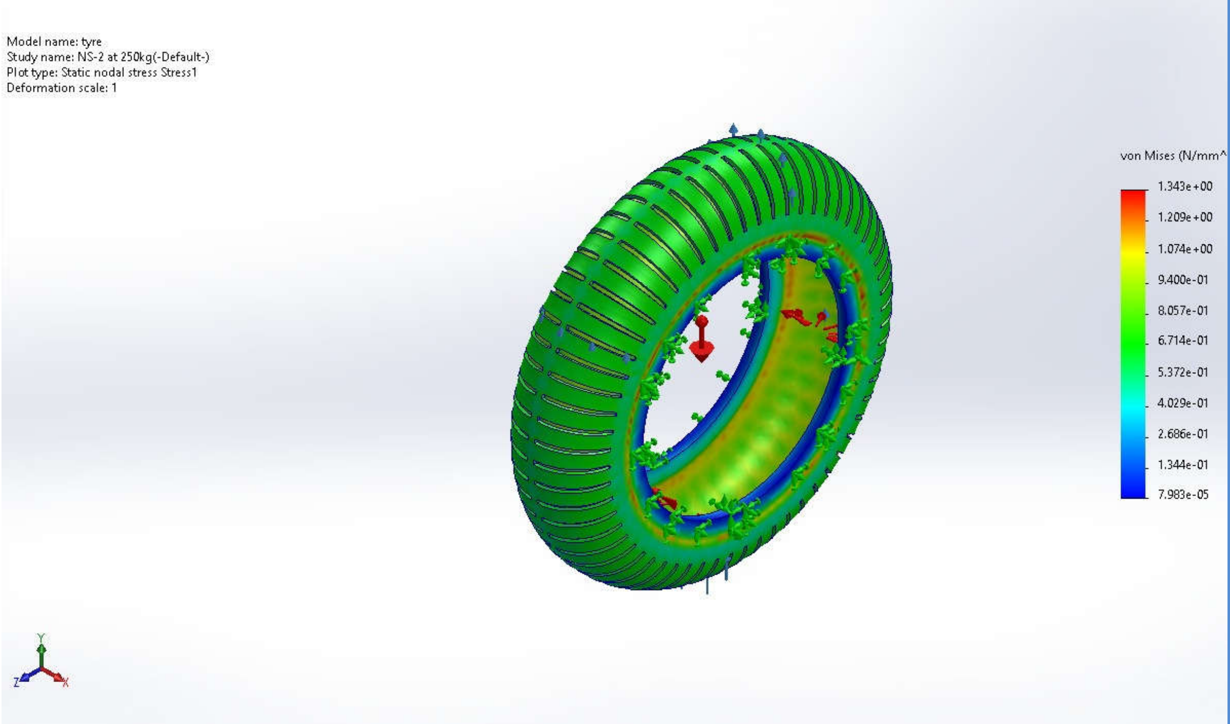


tyre-NS-2 at 250kg-Displacement-Displacement1

Name	Type	Min	Max

Study Results NS-3 Compound Rubber

Name	Type	Min	Max
Stress1	VON: von Mises Stress	7.983e-05N/mm^2 (MPa) Node: 4160	1.343e+00N/mm^2 (MPa) Node: 39791



tyre-NS-2 at 250kg-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 253	2.373e+01mm Node: 3959

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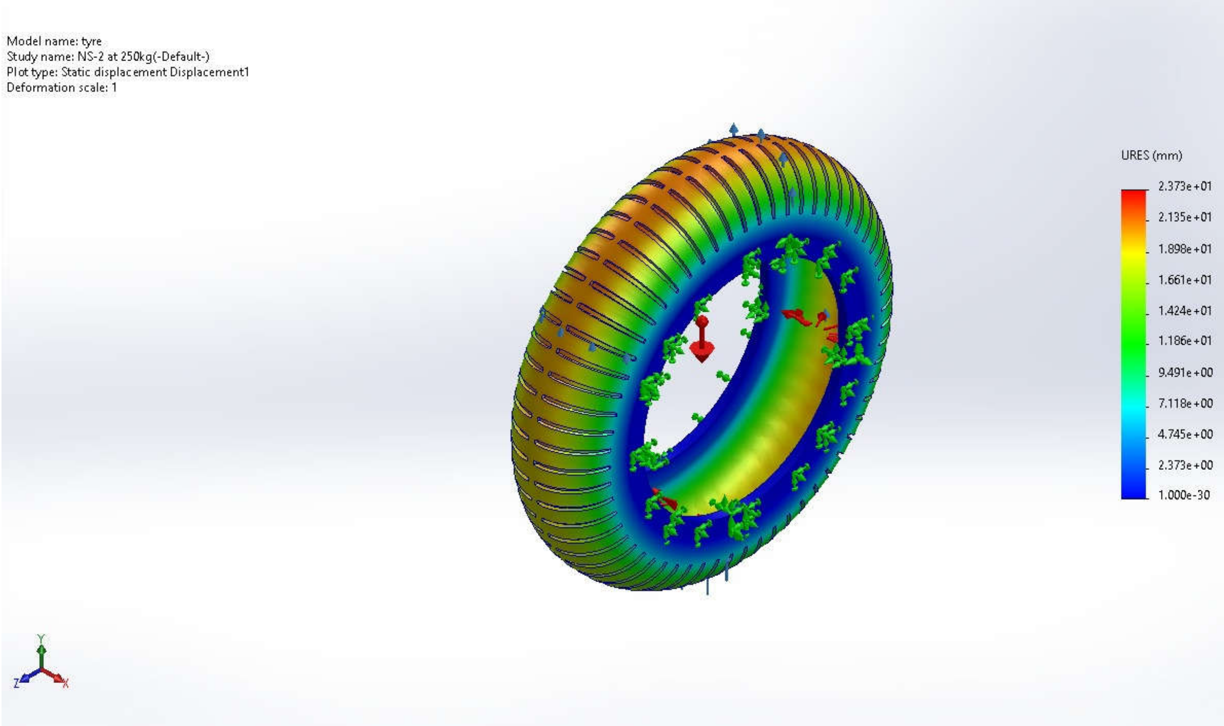
<tr><td colspan="4">

tyre-NS-2 at 250kg-Displacement-Displacement1</td></tr>
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Conclusions

In the present research, tire tread compound based on SBR/BR blend containing nano silica particle, with suitable silane modifier, i.e., TESPT, was prepared by the two-roll mill. With characterization investigation, it was found that replacing nano-SiO2 below 15 phr is very influential to improve per formance characteristics of the compounds and rolling resistance. Rolling resistance is regarded as a crucial objective within the industry. All these modifications were associated with the improved state of dispersion of the nano composite in presence of nano-SiO2.With further increase above 15phr the compound showed adverse effect. In summary, the present study showed that by adding few percent of nano-SiO2 with commercially well-prepared silica particles in tire tread compounds many Mechanical properties can be improved that would be great achievements for industry men working on tire tread compound formulation. The future scope lies can lie on further investigations of composition and proportion of nano particles to optimize properties in tire tread compounds.

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