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Chapter

Composition and Structure Influence on Properties of Elastomeric Composites with Silicon Dioxide Fillers

*Yury V. Kornev, Hammat H. Valiev, Yuliya N. Karnet,
Alla A. Kornilova, Nikolay A. Semenov and Alexander N. Vlasov*

Abstract

The problem of finding effective polymer elastomer fillers now is actual task. This chapter presents experimental studies of composites based on industrial synthetic butadiene-styrene rubber with amorphous silicon dioxide filler particles, obtained from rice husk ash processing products. The new methodology was developed for producing highly dispersed fillers powders with micro- and nano-sizes using a planetary ball mill. The synthesized composites surface structure was investigated using scanning electron and atomic force microscopy. The composites elastic-strength properties were studied by tensile testing machine. The significant influence of the surface functionality and the carbon/silicon dioxide ratio in fillers on the elastomeric composites mechanical properties is shown. It is concluded that these new classes of reinforcing fillers can be recommended for practical use.

Keywords: elastomeric composites, amorphous silicon dioxide filler, rice husk ash, scanning electron and atomic force microscopy, mechanical properties

1. Introduction

Rubber materials belong to one of the main substances in modern industrial society [1, 2]. The main substitute of natural rubber synthetic styrene butadiene rubber (SBR) needs the proper fillers to attain the demanded performances [3]. Traditional reinforcement fillers such as black carbon and precipitated silica have many disadvantages. Black carbon produced from petroleum is toxic for environment, and as the precipitated silica have high cost in the production. Therefore searches to alternative fillers for SBR are the urgent task. Great interest aroused in the possibility to use as rubber fillers the multi-tonnage agricultural waste in rice production - rice husk ash (RHA), which contains amorphous silica. But many researchers conducted during decades in this direction yet were unable to create the SBR composites permissible for practical applications [4–24]. This Chapter summarizes our works in successful syntheses such

SBR composites based on RHA fillers and the conducted investigations demonstrate the promise possibilities for exploration these composites in rubber industry. Chapter includes the development in principles for creating composite materials based on polymer and elastomeric matrices and a new class of micro and nanostructured mineral fillers from rice husk ash (RHA) [25, 26], as well as the study of mechanical behavior features and reinforcement effects in such composites in order to directly regulate their properties. Based on experiments, it is proposed to use as a renewable raw material for the production of new types reinforcing fillers based on silicon dioxide – rice husk ash processing products (RHAPP). The main components of the obtained micro and submicron fillers are amorphous silica and carbon. This filler type differs in structure from the widely used carbon black and colloidal silica, but is similar to them in chemical composition and is obtained from renewable raw materials. In the course of obtaining highly dispersed fillers from RHAPP, the stage of ultrafine grinding is expected, which reduces energy costs and makes the technology more environmental safety in comparison with existing ones [27]. The technology was developed in our Institute and is used in the present work to obtain reinforcing fillers for investigated elastomeric composites. This Chapter presents a study of the filler particle size influence obtained from the RHAPP on the surface structure and mechanical properties of elastomeric composites based on a rubber copolymer butadiene - styrene SBR-30 ARK. In the proposed work, submicron particles of amorphous silicon dioxide were obtained for the first time by ultrafine grinding RHA. Also for the first time, the effect of reinforcing with mineral filler from RHAPP for elastomeric composites based on SBR-30 ARK was established. The relationship of the structure and complex of mechanical properties for elastomeric composites with a new class of strengthening mineral fillers has been established. These results are important not only for practical applications, but also for understanding the fundamental composition-structure–property relationships in rubber composites.

2. Experimental procedure and materials

The synthesized elastomeric composites were based on a copolymer butadiene - styrene SBR-30ARK with 30% styrene (Sibur, Russia, analogous SBR –1500). The rubber ingredients (in weight percentage) are shown in **Table 1**.

In **Table 1** rubber formulation presents various chemical additives to improve the vulcanization speed and efficiency and to control the cross-linking nature. Additives: Sulfur; Zinc oxide; Sulfenamides: N-Cyclohexylbenzothiazol-2-sulfenamide (CBS); Altax: Mercaptobenzothiazole disulfide (MBTS); Stearin technical – are the products Bina Group LLC, Moscow, Russia. NORMAN 346 - special process oils with the lowest carcinogen content, polycyclic aromatic hydrocarbon (PAH) normalized filler oil for TDAE synthetic rubbers (the type Vivatex 500) - the product AO GC Titan, Omsk, Russia.

Amorphous silicon dioxide microdispersed and submicron (nano) particles obtained from rice husk ash processing products (RHAPP) were used as the filler.

Substance	SBR-30ARK	Sulfur Sulfenamides C Altax	Zinc oxide	Norman 346	Stearin technical
%	100	4.7	3	7	2

Table 1.
The butadiene - styrene SBR-30ARK rubber ingredients.

It includes white amorphous silicon dioxide samples (up to 97%) and carbon impurities (3–5%) and one black RHAPP sample with 35% amorphous silicon dioxide and 60% graphite-like carbon (LTD Leader 2004, Russia). To increase the specific surface area of the rice husk ash and, consequently, its reinforcing activity in elastomeric composites, the initial fraction was subjected to additional grinding by a special method developed at the Institute of Applied Mechanics, Russian Academy Sciences (IAM RAS) (RU patent No. 2442657). The temperature of the initial mixture does not exceed 150°C. Submicron particles were also used in composites after oxidative surface treatment with hydrogen peroxide H₂O₂. For better filler particles dispersion in the elastomeric matrix volume was additionally used the coupling agent (1.5 mass % surface modifier) organosilane (bis (3-triethoxysilylpropyl) tetrasulfide) - TESPT - Sigma-Aldrich (Merck) as in [28]. The double modification – combination oxidized H₂O₂ submicron particles with TESPT was also used. The prepared and studied samples components of elastomeric composites are shown in **Table 2**.

In **Table 2** symbols correspond to the following composites: sample № 1: pure SBR-30ARK without fillers; sample № 2: filler RHAPP micro US— RHAPP micro particles, ultrasound treatment; sample № 3: filler RHAPP nano — RHAPP ultrafine grinding (sub micro- nano particles); sample № 4: filler RHAPP nano H₂O₂— as № 3, additionally processed by oxidation with H₂O₂; sample № 5: filler RHAPP nano TESPT – as № 3, additionally processed by TESPT; sample № 6: filler RHAPP nano H₂O₂/TESPT – as № 4 additionally processed by TESPT; sample № 7: filler RHAPP black micro US —RHAPP micro particles, ultrasound treatment.

For results comparison convenience, the mass concentration for all fillers was taken 65 phr (filler parts per hundred rubber parts in weight). The fillers dispersion and blending all elastomers ingredients was carried in a laboratory mixer Haake PolyLab 300 QC (Thermo Scientific, Dreieich, Germany). The mixing temperature did not exceed 150°C. Control of the particle size and morphology before and after grinding was performed using field emission scanning electron microscopy (SEM) JSM-6700F (JEOL, Tokyo, Japan) with a JED-2300F energy dispersive microanalyzer attachment. Tests were conducted in high vacuum mode. Preliminary platinum sputtering no thicker than 50 nm was applied on the surface of samples. The accelerating voltage during the experiments did not exceed 20 kV. Also was used transmission electron microscopy (TEM) (FEI Tecnai G2 F20 FEG). The atomic-force microscope (AFM) easyScan DFM (Nanosurf, Switzerland) operating in the semi-contact mode under normal conditions with additional phase contrast mode and SuperSharpSilicon probe (Nanosensors, Switzerland) with a tip radius of about 2 nm were used. Additional

The composite samples filler ingredients	№ 1	№ 2	№ 3	№ 4	№ 5	№ 6	№ 7
Pure SBR-30ARK	100	100	100	100	100	100	100
RHAPP micro US	0	65	0	0	0	0	0
RHAPP nano	0	0	65	0	0	0	0
RHAPP nano H ₂ O ₂	0	0	0	65	0	0	0
RHAPP nano TESPT	0	0	0	0	65	0	0
RHAPP nano H ₂ O ₂ /TESPT	0	0	0	0	0	65	0
RHAPP black micro US	0	0	0	0	0	0	65

Table 2.
The prepared and studied elastomeric composites samples components.

ACM protection from external excitations was provided by means a dynamic anti-vibration stage TS-150 (Fabrik am Weiher, Switzerland). The surfaces image processing was performed using the SPIP™ - advanced software package for processing and analyzing microscopy images at nano- and micro scale (Image Metrology, Denmark). The elastomeric composites mechanical characteristics were determined in accordance with ASTM [29] on the UTS-10 (Zwick Roell, Germany) universal testing machine. The tests were carried out at ambient temperature with a constant tension rate of 100 ± 10 mm/min. During the experiment, the engineering stress σ (MPa) – strain ϵ (%) curves were obtained. The complex effective component dynamic shear modulus G' (Pa) dependence on the relative strain for rubber compounds was carried out on a device HAAKE RheoStress RS 150 (Haake, Germany) at a frequency 10 Hz and temperature 60°C, in the deformation amplitude range 0.001–0.3.

3. Results and discussion

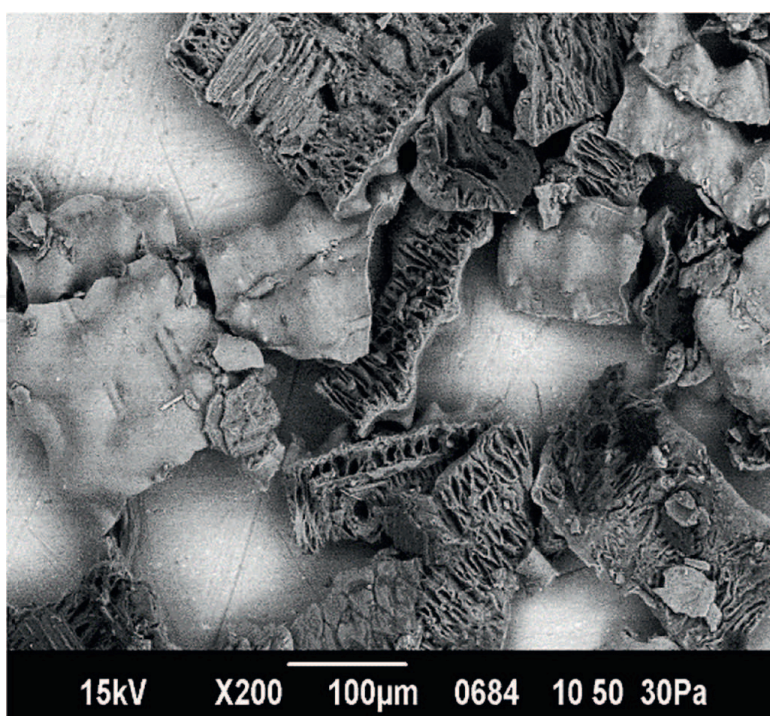
The particle size and morphology before RHA and after grinding RHAPP was performed using SEM (**Figure 1a,b**). It is noted that the initial particle size RHA was in range 10–300 microns and have a porous layered structure (**Figure 1a**). After grinding there is a significant decrease in the RHAPP (nano) particle size (**Figure 1b** compared to **Figure 1a**); and it is established that the nanosized particles are capable for strong agglomeration. It was found that the average particle size of the obtained highly dispersed fillers is up to 700 nm. The individual particles TEM images of rice husk ash processing products after grinding (RHAPP nano) are presented in **Figure 2**.

According TEM results the individual sizes RHAPP particles are in the range 10–20 nanometers. The surface scans of elastomeric composite sample № 3 (filler RHAPP nano) obtained during the SEM experiments are shown in **Figure 3**. The image visualize filler particles inclusions (lighter areas) in the elastomeric matrix volume (darker areas). The inclusion sizes in the samples filled with these sub-microfine fillers were much smaller and indicate markedly better filler particles dispersion in composite. Thus according the SPIP analysis for composite № 3 mean inclusion sizes are in the range 30 nm and mean distances between inclusions about 100 nm, while for example in composite № 2 (filler RHAPP micro) these are 200 nm and 450 nm accordingly.

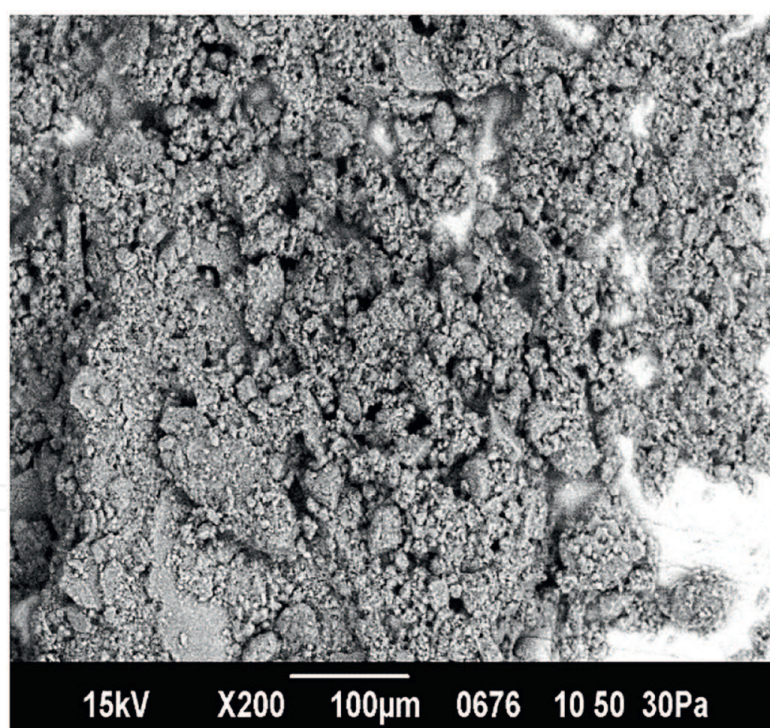
In **Figures 4–9** examples AFM surface images on samples № № 2–7 from the synthesized composites listed at **Table 2** is displayed. In topography scans the filler particles are visualized as light areas in the elastomeric matrix dark areas. In **Figure 4** the filler agglomerate sizes are in the range 300 nm – 3 μ m. Phase contrast image shows rather homogeneous microfiller distribution in rubber matrix with formation of certain filler structuring in matrix. It is visualized that the boundary layers of polymers adsorbed on the filler surface overlap. This testifies the filler ultrasound treatment success before its introduction into the elastomer, which provided the filler homogeneous size distribution in rubber. Thus, we can assume that the first condition for the emergence of the rubber reinforcement effect by the filler is fulfilled.

However, as will be shown by elastic strength characteristics studies of this composite, this condition is not sufficient, definitely due to the fact that the filler particles are micro-sized; this is the reason for poor adhesion of the filler to the matrix, and consequently, for the composite's physical and mechanical properties.

In **Figure 5** the filler agglomerate sizes are in the range 50 nm – 100 nm. The phase contrast image shows absence the filler coherent cooperative structuring: filler separately, matrix separately. Obviously, it is because the initial silica, even in the



(a)



(b)

Figure 1. SEM images rice husk ash particles before and after ultrafine grinding: a) RHA (micro) initial particles, b) RHAPP milled (nano) particles agglomerates.

nanoscale range, is hydrophilic whereas the rubber matrix is hydrophobic and hence there is very little interaction between them.

In **Figure 6** the filler agglomerate sizes are in the range 100 nm – 3 μ m. According to phase contrast image the cohesion, cooperation and structuring of filler is

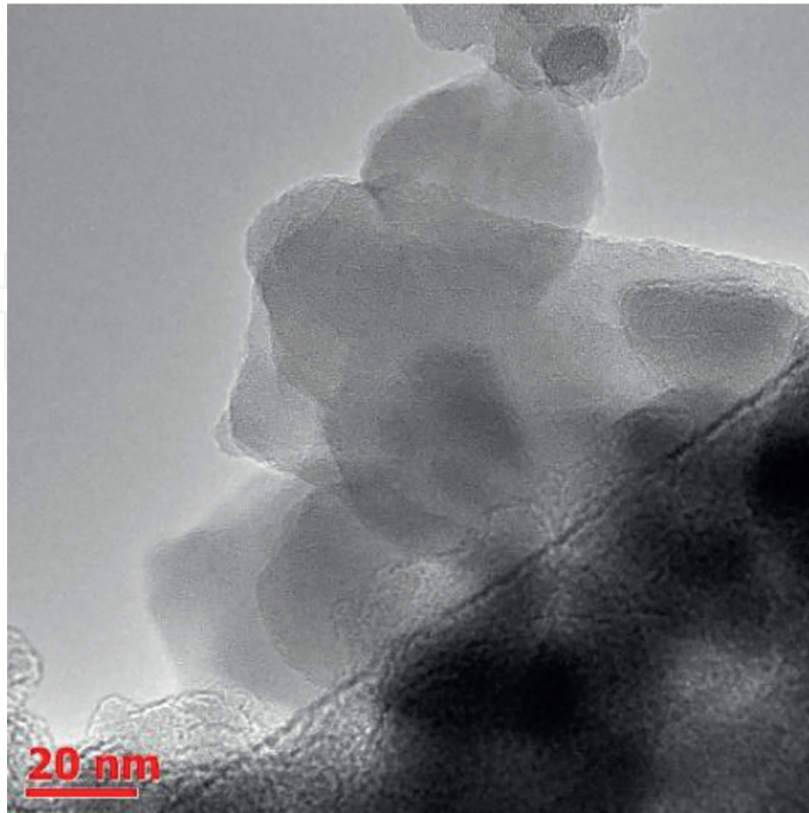


Figure 2.
The individual particles TEM images of rice husk ash processing products after grinding (RHAPP nano).

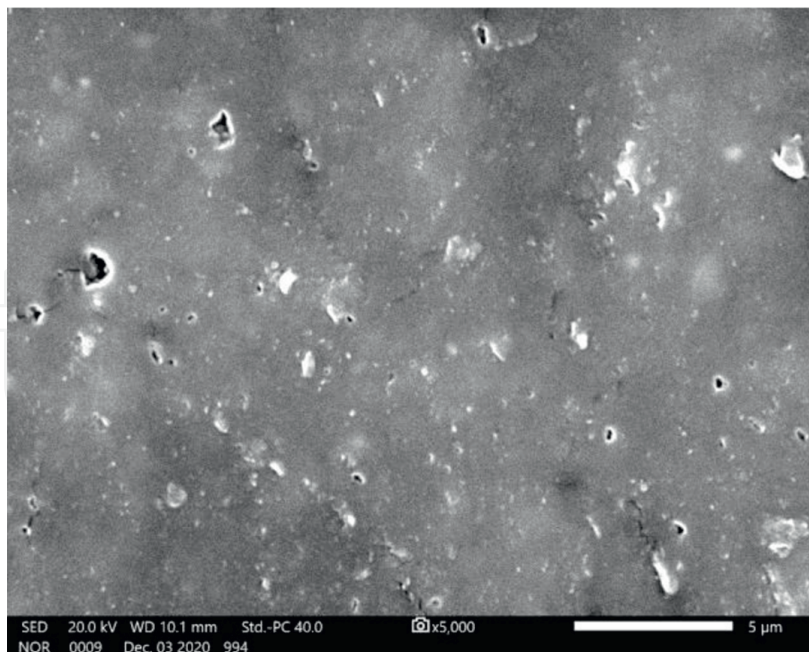


Figure 3.
The SEM surface morphology image of elastomeric composite with submicrodispersed amorphous silicon dioxide fillers. Sample N^o 3 (filler RHAPP nano).

observed; however, here large filler agglomerates down to micron size were formed, despite that the initial filler size introduced into matrix was in the nano range. This indicate that the silica-to-silica interaction is strong due to hydrogen bonding by

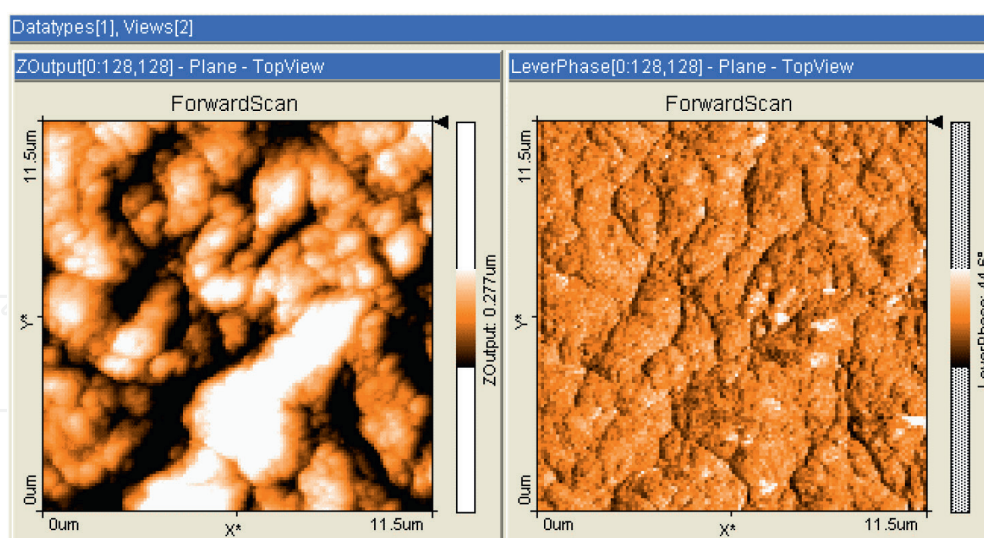


Figure 4.
AFM surface images composite № 2 (RHAPP micro). Scans $11.5 \times 11.5 \mu\text{m}^2$. Left - topography, right - phase contrast.

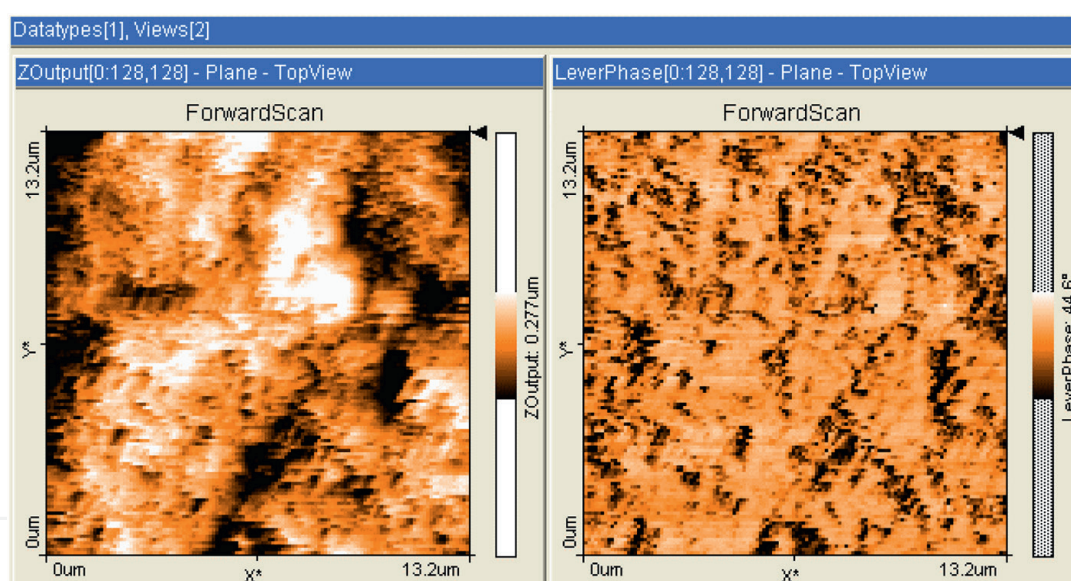


Figure 5.
AFM surface images composite № 3 (RHAPP nano). Scans $13.2 \times 13.2 \mu\text{m}^2$. Left - topography, right - phase contrast.

silanol groups on silica surfaces, which results in relatively more aggregation of silica particles in the rubber matrix.

In **Figure 7** the filler agglomerate sizes are in the range 100–700 nm. Phase contrast image showed good dispersion and distribution of nanofiller in matrix in a cooperative, coherent and structured manner. Obviously, this is due to the use of TESPT.

In **Figure 8** the filler agglomerate sizes are in the range 100–700 nm. Analogous to composite No. 5 pattern is visualized in this composite No. 6 phase image. Thus, in these composites No. 5 and No. 6 a significant increase in mechanical properties would be expected. All these conclusions were confirmed by direct examination of the mechanical properties of the composites on a tensile testing machine.

In **Figure 9** the filler agglomerate sizes are in the range 300 nm – 2.5 μm.

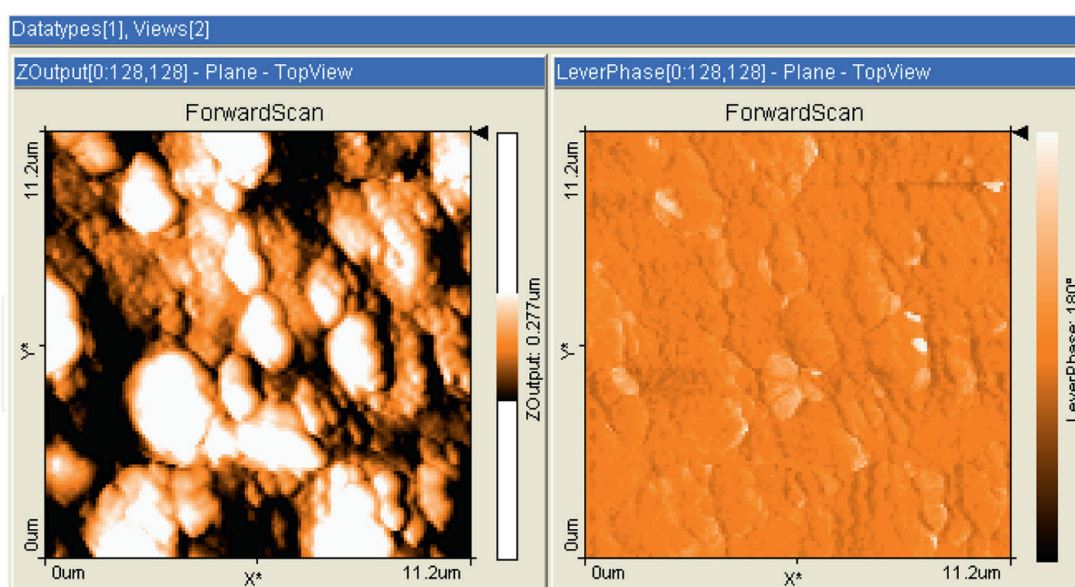


Figure 6. AFM surface images composite No 4. (RHAPP nano, oxidized). Scans $11.2 \times 11.2 \mu\text{m}^2$. Left - topography, right - phase contrast.

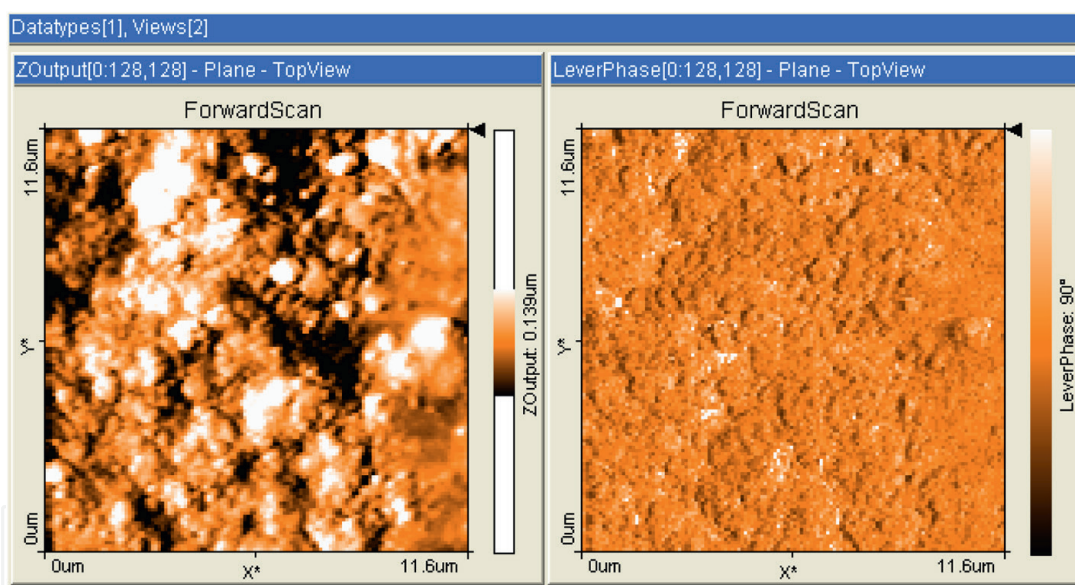


Figure 7. AFM surface images composite No 5 (RHAPP nano, TESPT). Scans $11.6 \times 11.6 \mu\text{m}^2$. Left - topography, right - phase contrast.

The topography and phase contrast image shows that the filler ultrasonic treatment prior to introduction into the elastomer failed to ensure a uniform size distribution of the filler in the rubber matrix as in composite No. 2. This is definitely due to a different chemical composition, which is not favorable for this filler effective interaction with the rubber matrix. From the data of **Figures 2–9** and the results of SEM and AFM images we can see that reducing the filler particles size leads to a marked decrease in the size of inclusions (particle agglomerates) and using the TESPT leads a better filler particles distribution in the elastomeric matrix volume. These results are important for understanding the synthesized composites physical-mechanical properties. The elastomeric composites stress – strain properties are presented in **Figure 10**.

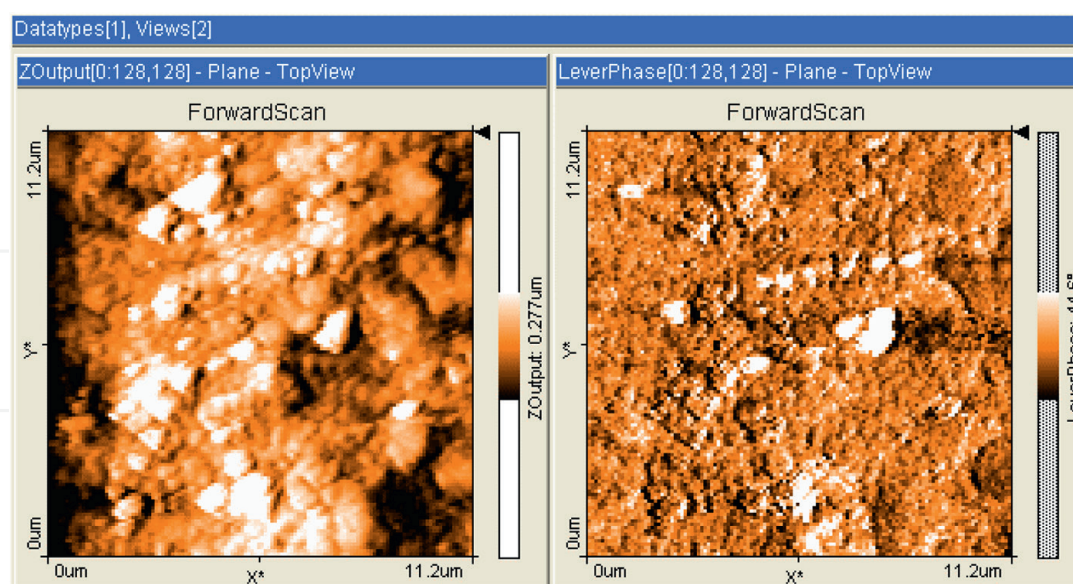


Figure 8. AFM surface images. Composite N^o 6 (RHAPP nano, oxidized/ TESPT). Scans $11.5 \times 11.2 \mu\text{m}^2$. Left - topography, right - phase contrast.

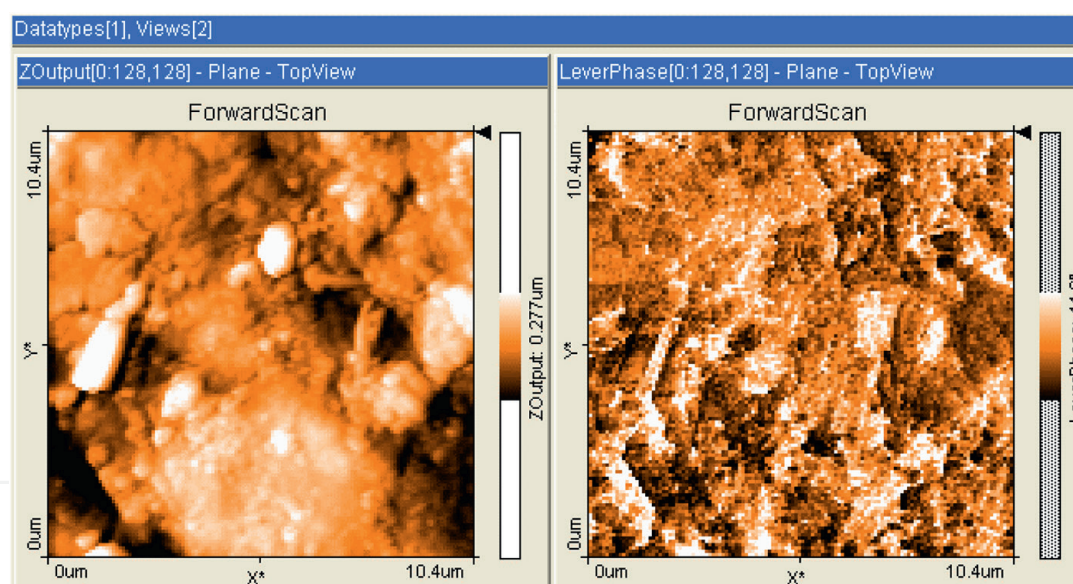


Figure 9. AFM surface images composite N^o 7 (RHAPP black micro US). Scans $10.4 \times 10.4 \mu\text{m}^2$. Left - topography, right - phase contrast.

For composites with micro particles, average strength values were obtained at the level no more than 4.0 MPa regardless of the fillers composition (samples N^o 2 (RHAPP micro US) and N^o 7 (RHAPP black micro US), therefore not presented in **Figure 10**. For composites with submicron particles the average strength reaches about 20 MPa: samples N^o 3 (RHAPP nano), N^o 4 (RHAPP nano H₂O₂), N^o 5 (RHAPP nano TESPT), N^o 6 (RHAPP nano H₂O₂/TESPT). For samples N^o 3 (RHAPP nano) there is a significant increase in composites elongation more than 700%. Oxidation of the submicron particle surface leads to a slight decrease in composite strength and elongation - sample N^o 4 (RHAPP nano H₂O₂). The TESPT combination agent addition to compositions with RHAPP submicron particles - samples N^o 5 (RHAPP nano TESPT) and N^o 6

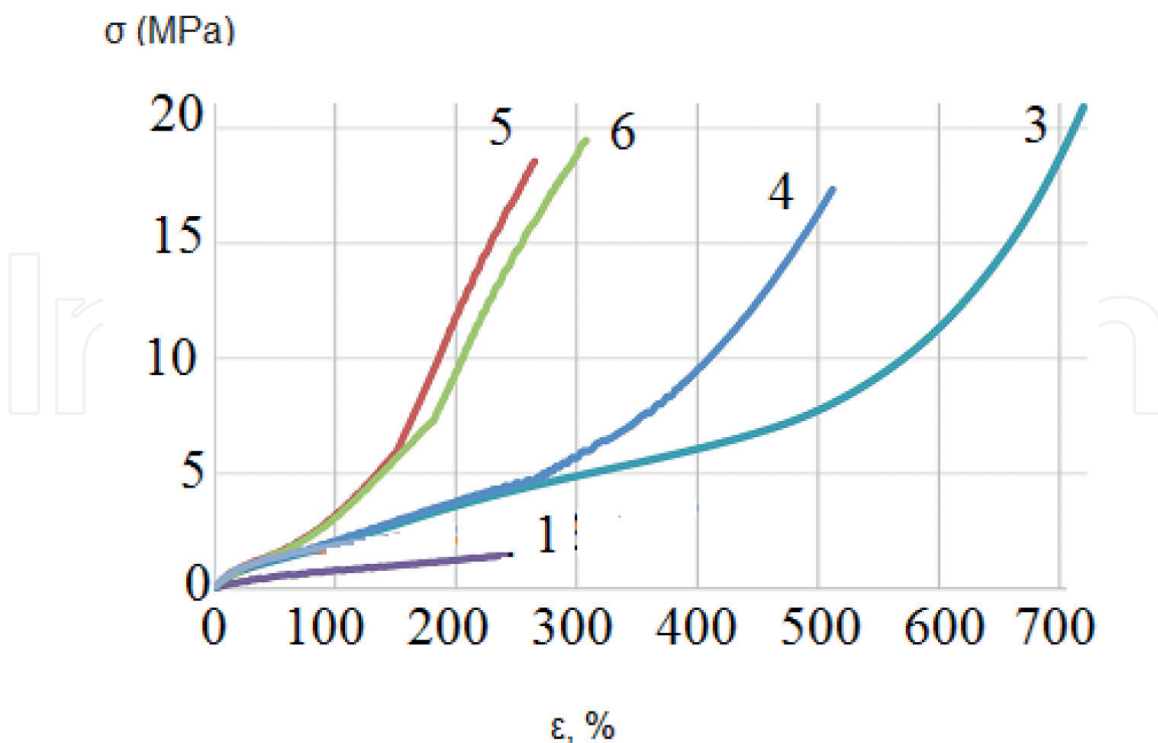


Figure 10. Engineering stress σ (MPa) – Strain ε (%) curves for elastomeric composites samples: № 1 (pure SBR-30ARK), № 3 (RHAPP nano), № 4 (RHAPP nano TESPT), № 5 (RHAPP nano H₂O₂/TESPT), № 6 (RHAPP nano H₂O₂/TESPT).

(RHAPP nano H₂O₂/TESPT), mainly leads to a decrease in elongation at break, and a significant increase in elongation stresses up to 20.0 MPa. The composite with an oxidized filler surface (sample № 6) is distinguished by a slightly higher relative elongation and somewhat higher strength. The coupling agent use in the case of non-oxidized submicron particles RHPP on the contrary, leads to a slight decrease in strength (comparison of samples № 3 and № 5). These effects show a significant effect of the surface functionality of submicron filler particles on the elastomeric composites mechanical properties with rice husk processing products. The strength values obtained in this work for samples № 3 (RHAPP nano), № 4 (RHAPP nano H₂O₂), № 5 (RHAPP nano TESPT), № 6 (RHAPP nano H₂O₂/TESPT) exceeding 20 MPa, are considerably higher than values about 13 MPa obtained in other investigations [23, 28, 30].

The mechanical behavior of elastomeric composites under dynamic loading conditions was further investigated. The elasticity dynamic modulus dependence on the amplitude of deformation (**Figure 11**) was obtained on a rheometer HAAKE RheoStress RS 150. This study was carried out to evaluate the Payne effect, which characterizes the interaction strength of filler particles with each other, as well as its change depending on the fillers crushing factor. The frequency was 0.5 Hz and the temperature 60°C. Tests were carried out on a rheometer in plane-plane mode, the amplitude of deformation is represented on the x-axis, and the y-axis represents the complex dynamic modulus. It can be seen from the data that the complex dynamic modulus value is significantly higher for sample № 3 (RHAPP nano) at all strain amplitudes. This indicates a strong particle-particle interaction (filler agglomeration) for sample № 3 (RHAPP nano) filled with submicron particles. For sample № 2 (RHAPP micro), these effects are significantly less pronounced due to the larger size of the inclusions.

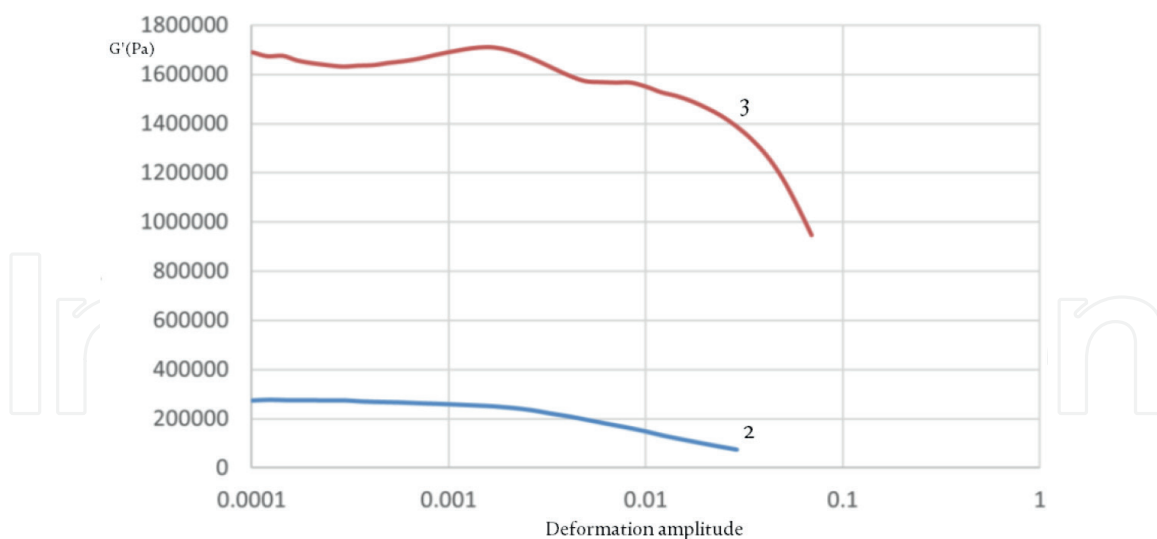


Figure 11. The real component of complex dynamic modulus G' (Pa) dependence on deformation amplitude for elastomeric composites: (sample N^o 2) micro-dispersed filler; (sample N^o 3) highly dispersed filler with submicron particles.

Thus, significant enhancement of physical and mechanical properties of composites of RAS rubber with rice husk ash fillers achieved in this study was possible due to two important components of composite fabrication. The first important component, as shown by synthesized composites SEM and AFM studies of the surface structure, is the filler dimensions transfer into the nanoscale. The second important component is the filler surface chemical modification to provide better adhesion to the elastomer matrix. SBR rubber matrix is hydrophobic while amorphous silica derived from rice husk ash is hydrophilic. In order to ensure their effective interaction and, consequently, a significant enhancement of physical and mechanical properties, it is necessary to use silanol-based adhesives, one of which is TESPT. Scheme of interaction of hydroxyls of amorphous silicon dioxide surface with TESPT is shown in **Figure 12** [31]. Alkoxy groups of TESPT interact with hydroxyls of the filler, whereas dissociating sulfur groups interact with the elastomeric matrix. This leads

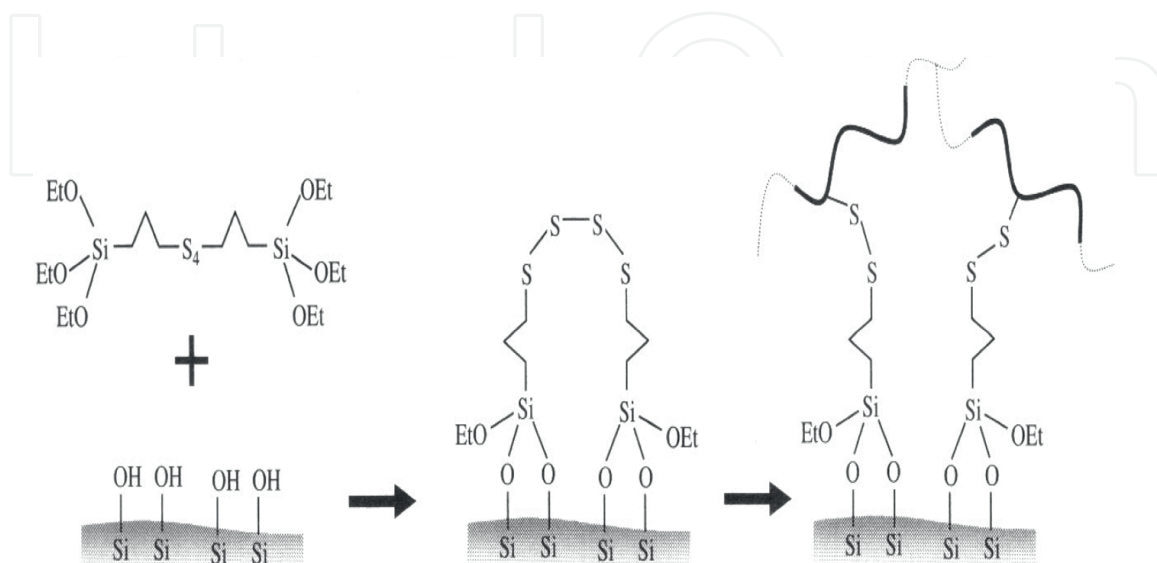


Figure 12. TESPT interaction mechanism with the silica surface [31].

to a synergistic interaction of the inorganic filler with the rubber, resulting in the composites enhanced deformation and strength properties.

4. Conclusions

The elastomeric composites study by electron and atomic force microscopy methods has been shown the influences of surface structure parameters of elastomeric composites on the complex of their mechanical properties. The directional control effectiveness over the initial particles size of amorphous silicon dioxide derived from renewable raw materials (rice husk ash) was shown. The Chapter demonstrates the efficiency of surface functionalization amorphous silicon dioxide particles and these particles application as promising reinforcing filler for composites with a complex of high elastic strength properties. In the proposed work, submicron particles of amorphous silicon dioxide were obtained for the first time by ultrafine grinding of rice husk ash processing products. Also for the first time the great effect of reinforcing with mineral filler from rice husk ash processing products for elastomeric composites based on rubber SBR-30 ARK was established. The relationship of the structure and complex of mechanical properties for elastomeric composites with a new class of strengthening mineral fillers has been established. For a sample filled with rice husk processing products with a surface modifier, the average strength value was obtained at the level 20 MPa, which was achieved for the first time for elastomeric composites with rice husk processing products as filler. It is shown that when grinding the rice husk ash particles by the method developed at IAM RAS and using them as filler, an elastomeric composite was obtained, approaching the elastic-strength properties of samples with precipitated silica as filler in the present rubber industry. The data obtained indicates the relationship between the size of filler particles and their reinforcing effect in the elastomeric composite. This dependence is known for fillers such as carbon particles and silica. It is shown that this dependence is also performed for mineral fillers of natural origin – rice husk ash processing products.

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Conflict of interest

The authors declare no conflict of interest.

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Author details


Yury V. Kornev¹, Hammat H. Valiev^{1*}, Yuliya N. Karnet¹, Alla A. Kornilova², Nikolay A. Semenov¹ and Alexander N. Vlasov¹

1 Institute of Applied Mechanics Russian Academy Sciences, Moscow, Russia

2 Physics Faculty, Moscow State University, Moscow, Russia

*Address all correspondence to: hhvlv@mail.ru

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References

- [1] Pereira AB, Fernandes FAO, editors. Renewable and Sustainable Composites. London: IntechOpen; 2019. p. 139. DOI: 10.5772/intechopen.77412
- [2] Saleh HEM, Koller M, editors. Characterizations of some Composite Materials. London: IntechOpen; 2019. p. 152. DOI: 10.5772/intechopen.80960
- [3] Yanovsky Y. Nanomechanics and Strength of Composite Materials. Moscow: IPRIM RAS; 2008 179 p
- [4] Bakar R, Yahya R, Gan S. Production of high purity amorphous silica from rice husk. Procedia Chemistry. 2016;**19**:189-195. DOI: 10.1016/j.proche.2016.03.092
- [5] Liu X, Chen X, Yang L. Mint: A review on recent advances in the comprehensive application of rice husk ash. Research on Chemical Intermediates. 2016;**42**:893-913. DOI: 10.1007/s11164-015-2061-y
- [6] Soltani N, Bahrami A, Pech-Canul M, González L. Review on the physicochemical treatments of rice husk for production of advanced materials. Chemical Engineering Journal. 2015;**264**:899-935. DOI: 10.1016/j.cej.2014.11.056
- [7] Kenechi N-O, Linus C, Kayode A. Utilization of rice husk as reinforcement in plastic composites fabrication – A review. American Journal of Materials Synthesis and Processing. 2016;**1**(3): 32-36. DOI: 10.11648/j.ajmsp.20160103.12
- [8] Zou Y, Yang T. Rice husk, rice husk ash and their applications. In: Rice Bran and Rice Bran Oil. AOCS Press, Elsevier; 2019. pp. 207-246. DOI: 10.1016/B978-0-12-812828-2.00009-3
- [9] Soltani N, Bahrami A, González L. Review on the physicochemical treatments of rice husk for production of advanced materials. Chemical Engineering Journal. 2015;**264**:899-935. DOI: 10.1016/j.cej.2014.11.056
- [10] Rout K, Satapathy A. Development and characterization of rice husk-filled glass fiber-reinforced epoxy biocomposites. Composites: Mechanics, Computations, Applications: An International Journal. 2012;**3**:95-106. DOI: 10.1615/CompMechComputApplIntJ.v3.i2.10
- [11] Arjmandi R, Hassan A, Majeed K, Zakaria Z. Rice husk filled polymer composites. International Journal of Polymer Science. 2015;**2015**:501471. DOI: 10.1155/2015/501471
- [12] Bilal A, Lin R, Jayaraman K. Optimal formulation of rice husk reinforced polyethylene composites for mechanical performance: A mixture design approach. Journal of Applied Polymer Science. 2014;**131**:1-10. DOI: 10.1002/app.40647
- [13] Bilal A, Lin R, Jayaraman K. Optimisation of material compositions for flammability characteristics in rice husk/polyethylene composites. Journal of Reinforced Plastics and Composites. 2014;**33**:2021-2033. DOI: 10.1177/0731684414552542
- [14] Chanda A, Neogi S, Neogi S. Optimization of plasma treatment for enhanced filler matrix adhesion in manufacturing green composites with rice husk. Indian Chemical Engineer. 2013;**55**:177-188. DOI: 10.1080/00194506.2013.832026
- [15] Chanda A, Hazra A, Kumar M, Neogi S, Neogi S. Chemical treatments of rice husk filler and jute fiber for

the use in green composites. *Fibers and Polymers*. 2015;**16**:902-910.

DOI: 10.1007/s12221-015-0902-3

[16] Nishata R, Sulong A, Yuliana N, Sahrim A. Effect of surface modified rice husk (RH) on the flexural properties of recycled HDPE/RH composite. *Advances in Materials and Process Technologies*. 2017;**3**:1-8. DOI: 10.1080/2374068X.2017.1340420

[17] Fernandes MRS, Maria FA, Furtado C. Rice husk ash as filler in tread compounds to improve rolling resistance. *Polímeros*. 2017;**27**:55-61. DOI: 10.1590/0104-1428.2385

[18] Lemessa Jembere A, Workneh FS. Studies on the synthesis of silica powder from rice husk ash as reinforcement filler in rubber tire tread part: Replacement of commercial precipitated silica. *International Journal of Material Science Appliences*. 2017;**6**:37. DOI: 10.11648/j.ijmsa.20170601.16

[19] Vishvanathperumal S, Anand G. Effect of nanoclay/nanosilica on the mechanical properties, abrasion and swelling resistance of EPDM/SBR composites. *SILICON*. 2020;**12**:1925-1941. DOI: 10.1007/s12633-019-00291-6

[20] Sintharm P, Phisalaphong M. Green natural rubber composites reinforced with black/white rice husk ashes: Effects of reinforcing agent on film's mechanical and dielectric properties. *Polymers (Basel)*. 2021;**13**:882. DOI: 10.3390/polym13060882

[21] Boonmee A, Sabsiroht P, Jarukumjorn K. Preparation and characterization of rice husk ash for using as a filler in natural rubber. *Materials Today: Proceedings*. 2019;**17**:2097-2103. DOI: 10.1016/j.matpr.2019.06.259

[22] Xiao Y, Zou H, Zhang L, Mint. Surface modification of silica

nanoparticles by a polyoxyethylene sorbitan and silane coupling agent to prepare high-performance rubber composites. *Polymer Testing*. 2020;**81**:106195. DOI: 10.1016/j.polymeresting.2019.106195

[23] Bach Q, Vu C, Vu H. Effects of co-silanized silica on the mechanical properties and thermal characteristics of natural rubber/styrene-butadiene rubber blend. *SILICON*. 2020;**12**:1799-1809. DOI: 10.1007/s12633-019-00281-8

[24] Dominic M, Joseph R, Sabura Begum P, Mint. Green tire technology: Effect of rice husk derived nanocellulose (RHNC) in replacing carbon black (CB) in natural rubber (NR) compounding. *Carbohydrate Polymers*. 2020;**230**:115-620. DOI: 10.1016/j.carbpol.2019.115620

[25] Kornev Y, Semenov N, Vlasov A, Valiev K. Reinforcing effects in elastomeric composites, filled with particles of mineral fillers, based on silicon dioxide and carbon. *Journal of Physics: Conference Series*. 2021;**1942**:012031. DOI: 10.1088/1742-6596/1942/1/012031

[26] Valiev H, Vlasov A, Kornev Y, Mint. Scanning probe microscopy of elastomers with mineral fillers. In: Pereira A, Fernandes F, editors. *Renewable and Sustainable Composites*. London: IntechOpen; 2019. pp. 39-50. DOI: 10.5772/intechopen.84554

[27] Garishin O, Shadrin V, Kornev Y. Mechanical studies of rubber micro and nanocomposites promising for the tire industry. Uniaxial and biaxial tests. *Materials Physics and Mechanics*. 2019;**42**:445-454. DOI: 10.18720/MPM.4242019_9

[28] Vilmin F, Bottero I, Travert A. Mint: Reactivity of bis[3-(triethoxysilyl)propyl] tetrasulfide (TESPT) silane

coupling agent over hydrated silica:
Operando IR spectroscopy and
chemometrics study. *Journal of Physical
Chemistry C*. 2014;**118**:4056-4071.
DOI: 10.1021/jp408600h

[29] ASTM D412-16. Standard Test
Methods for Vulcanized Rubber and
Thermoplastic Elastomers—Tension.
West Conshohocken, PA: ASTM
International; 2021. DOI: 10.1520/
D0412-16

[30] Ulfah I, Fidyarningsih R, Rahayu S,
Mint. Influence of carbon black and
silica filler on the rheological and
mechanical properties of natural rubber
compound. *Proceedings of Chemical
Society*. 2015;**16**:258-264. DOI: 10.1016/j.
proche.2015.12.053

[31] Donnet J, Custodero E. Reinforcement
of elastomers by particulate fillers.
In: Mark JE, Erman B, Roland M,
editors. *The Science and Technology of
Rubber*. 4th ed. Amsterdam: Elsevier;
2013. pp. 383-416. DOI: 10.1016/
B978-0-12-394584-6.00008-X

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