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XII SAVJETOVANJE

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ZBORNIK RADOVA

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ПОДРУЧНА ПРИВРЕДНА КОМОРА БАЊА ЛУКА

University of Banja Luka

CONTENTS

Original scientific article – Originalni naučni rad

EFFECT OF SILICA ON THE PROPERTIES OF ELASTOMERIC MATERIALS BASED ON NR/BR/SBR TERNARY RUBBER BLEND

Slaviša Jovanović[1], Vojislav Jovanović[2], Gordana Marković[3], Milena Marinović-Cincović[4], Miladin Gligorić[5], Nevena Vukić[6], Suzana Samaržija-Jovanović[2], Jaroslava Budinski-Simendić[6]

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Abstract

The effects of pyrogeneous silica on the mechanical properties of elastomeric materials based on natural rubber (NR), polybutadiene rubber (PB) and styrene-butadiene rubber (SBR) are reported. For sample preparations the content of network precursor was constant (25:25:50), but the content of filler was varied (0, 40, 60, 80, 100 phr). Curing behavior was assessed using oscillating disc rheometer. Results indicated that the minimum torque and maximum torque increase with increasing filler loading in the compounds, whereas scorch time shows a decreasing trend. Cure time of obtained composites increases with increasing filler loading. Mechanical properties were evaluated before and after thermal ageing (during 72h or 168h at 100^{o}C) of obtained composite materials. Incorporation of silica has improved the tensile modulus. However, elongation at break exhibited a different trend. For tensile strength, optimum values were obtained at 60 phr silica content

Key words: elastomers, mechanical properties, silica, thermal ageing

INTRODUCTION

The use of blends of rubber is widespread, the purpose being to obtain a balance of properties, including cost, which one elastomer alone cannot supply. Synthetic rubbers may, therefore, be added to each other as binary mixtures to improve the inferior properties of one of the components (THONGPINA, 2013). Elastomeric materials based on polyisoprene rubber (NR) have a certain advantages, such as flexibility. Nevertheless, some of its properties fall short in certain applications, such as oil resistance, air permeability, ozone resistance, compression set, and thermal aging resistance. Polybutadiene is classified as general purpose rubbers intended for the manufacture of tires and general mechanical products. However, one type of rubber may not possess all the physical properties desired in a finished product. For example, in tire tread the high abrasion resistance under certain conditions conferred by the use of BR is desirable, but the poor road holding and rib tearing properties are not, hence blends of BR with NR and (SBR) styrene-butadiene rubber are employed. Compatibility is the fundamental property, deciding the practical utility of a polymer blend (Ngudsuntear, 2014). If the two elastomers in a blend are incompatible, it will exist in the form of two separate phases and the cured blend will show inferior properties (Marković, 2015). SBR is widely used as one of the network precursor for automotive tires, wire and cable applications due to its high elongation, but unfortunately it has low elastic modulus and durability and needs some additives such as; antioxidants, accelerators,

softeners and fillers to improve its properties (Camargo, 2009). The phenomenon of reinforcement of elastomers is of great importance for the structuring of materials in new technologies. The nanoparticle addition to the elastomers based on different network leads to an increase in the modulus and to an improvement of key properties such as tensile strength, elongation, as well as abrasion resistance (Nawawi, 2012). The silica surface hydroxyl groups including isolated, vicinal, and geminal silanols play a key role in most of the applicative properties (Samaržija-Jovanović, 2013). The presence of silanol groups on the silica surface induces particle–particle interaction which tends to favor filler agglomeration in the rubber matrix. This highly polar surface makes it poor compatible with most rubbers due to weak rubber–filler interactions. The addition of nanoparticles influences the cross-linking regime as well, especially in some types of rubbers. Reinforcement of elastomers is a particularly complex process if material contains more than one type of network precursor. By creating a multi-phase system, characteristics of individual phases can be partly preserved or significantly changed due to the influence of intermolecular interaction (Marković, 2012). Materials which have a satisfactory thermal stability and mechanical properties required in the specific exploitation conditions are obtained by addition of the optimum content of active fillers. If elastomers are compressed over a long time, it loses its capability to return to its original thickness. The compression set values are expressed as a percentage. The lower the value, the better material resists permanent deformation under a given deflection. In this study the goal was to dtermine the influence of silica.on the properties of sulfur cured elastomeric materials based NR/BR/SBR ternary rubber blends which has been widely used in ***rubber*** industry, particularly in tire ***applications.***

MATERIAL AND METHODS OF WORK

Polyisoprene rubber, NR SMR-20 (0.92 g/cm3) was supplied by Malaysia; polybutadiene rubber, BR SKD N (0.91 g/cm3), with 94% of 1,4 *cis* content, Mooney viscosity Ml (1+4) 100°C=44 M – was supplied by Njižnjekamsk (Russia); Styrene butadiene rubber, SBR Europa Intol 1783 (density=0.94g/cm3), is an emulsion styrene-butadiene rubber with 23.5% bound styrene, obtained by cold polymerization extended with 37.5% RAE oil, was supplied by Versalis (Italy). News 175G, Wuxi (China)(ρ = 2.0 g/cm3) was used as nano silica had 22 nm average size of primary particles Content of filler was 0, 20, 40, 60, 80, and 100 phr. The curing system was: N-cyclohexyl-2-benzothiazolsulfonamide *-CBS((1,4 phr); diphenyl guanidine, DPG, (1 phr); N-(cyclohexylthio)phthalimide, CTP 100 (0.2 phr) and sulfur (2 phr). In rubber compounds the network precursor ratio was 25/25/50 (w/w/w). Content of zinc oxide was 3 phr. The stearic acid content was 2 phr. Naphthenic process oil is used throughout a mix of rubber compounds (content 10 phr(. These facilitate in rising the dispersion of fillers and flow characteristics of the compound throughout more process All samples are mixed in a laboratory mixer K-0 INTERMIX (Francis Shaw), volume 1 L, and laboratory roll mill (14201-Buzuluk Komarov) at a speed of rollers n1/n2 = 17.4/14 and a temperature between 60-70°C, according to the procedure ASTM D318489. The sheeted rubber compound was conditioned at 23 ± 2° C for 24 h prior to crosslinking behavior assessment at 160 °C using Monsanto Moving Die Rheometer (model 100S). All test specimens were compression molded at 160 °C during the determined optimum curing time (t_{c90}). The scorch time, t_{s2} is the time to 2 units of torque increase above minimum torque. The optimum cure time, t_{c90} is the time to 90% of maximum torque evaluated from the following expression:

$$M_{t90} = (M_h - M_l) \times 0{,}9 + M_l \quad (1)$$

where M_h is the maximum torque, and M_{t90} a new torque reading corresponding to 90% cure in the rubber were determined from the cure traces generated at 160 ± 2 °C by oscillating disc

rheometer at an angular displacement of ±3 and a frequency of 1.7 Hz .The cure rate index (CRI) is the measure of rate of vulcanization based on the difference between optimum cure time of vulcanization t_{c90} and the scorch time t_{s2}. It can be calculated from the relation:

$$CRI = 1/t_{c90} - t_{s2} \times 100 \quad (2)$$

The sheets were cut and vulcanized in polished molds in a press at 160 C and after that.were cut into dumbbell-shaped specimens (five replicates from each sample) for the assessment of mechanical properties using an electronic tensile testing machine (Zwick 1425, Germany) at speed of 500 mm/min. Samples of at least 0.12 mm in thickness with flat surface were cut for hardness meauserements according ASTM D 2240 using durometer of model 306L type. The unit of hardness is expressed in (Shore A). The compression set was assessed using the measurement according ASTM D395 procedure. Test procedures of aging consist in exposing samples to the effect of harmful factors in a given time interval.

RESULTS AND DISCUSSION

Crosslinking of rubber macromolecules represent topologically critical phenomenon, when the ensemble of chains forms a three-dimensional network. In order to design the compounds formulation the representative combination of network structure should be managed for specific exploitation conditions of obtained materials. In the case of nano silica as reinforcing filler the strong filler/filler interactions resulting from polar surface functional groups such as siloxane are believed to be primarily responsible for the mechanical properties. The influence of .silica loading on the crosslinking characteristics of the compounds based on NR/BR/SBR (25/25/50) rubber blends is show in the Table 1.

Table 1. Determined crosslinking characteristics of rubber comounds based on NR/BR/SBR and different content of silica

Silica content (phr)	ML (dNm)	MH (dNm)	ts_1 (min)	t_{C90} (min)	CRI (min^{-1})
0	0.49	5.28	0.65	1.03	263.16
20	0.83	6.38	0.63	1.07	227.27
40	1.53	8.22	0.49	1.37	113.64
60	10.57	22.42	0.47	1.36	112.36
80	19.51	32.3	0.44	1.26	121.95
100	21.60	48.68	0.22	1.04	121.95

Generally, acidic compounds retard the crosslinking of rubber compounds. For this reason, precipitated silica, which contains a large number of acidic silanol (Si–OH) groups, is not added without an activator in elastomeric materials based on natural rubber. The surface of silica is acidic and therefore the strong hydrogen bonds with functional groups at network precursor are forming. For materials based on SBR due to the existence of phenyl groups the hydrogen bonding of the silica silanol group are influencing the strong silica/SBR interactions. Silica particles also can adsorb molecules of polar curative agents, rendering the deactivation of crosslinking process. Physical ageing which occurs as the gradual process may greatly affect many applicativeproperties depending on ageing temperature. Heat aging stability is a substantial for use in severe conditions. Retention of mechanical properties after accelerated heat aging is a specification for such long-term uses. Values of elongation at break are explained by the nature of filler (mainly the shape of the filler particles), but a very important factor is the bond strength between matrix and filler, which reduces the mobility of the polymer phase (better "wetting" of filler rubber macromolecules), the dispersion of fillers and agglomerates of filler particles. Tensile strength is a complex function depending on crosslinks type, concentration of elastically active network chains and chemical structure of

used network precursor. It is well known that if rubber is deformed by an external force, part of the input energy is stored elastically in the chains and is available (released upon crack growth) as a driving force for fracturing. The remaining energy is dissipated through molecular motions by heat; and as such, is made unavailable to break the chains. At higher crosslinking densities the chains motions become restricted, and the network is incapable of dissipating as much energy. The tensile strength increased with silica content. The optimal rubber reinforcing it is assumed that all filler agglomerates are dispersed to the aggregate. Generally silica particles tend to agglomerate due to formation of hydrogen bond between the hydroxyl group interactions and thereby enhanced the tendency for agglomeration. At lower loading of silica the nano particles are well dispersed and thereby increased the surface area for interaction. When silica content increases, the values of the elongation at break and hardness values increase. Rubbers are susceptible to oxidative aging because of unsaturated carbon–carbon double bonds in the backbone. Elevated temperatures usually promote oxidative ageing. In some elastomeric materials the tensile strength increases after ageing as a result of the further process of cross-linking. It was found that the sulfur of polysulfide -C-S_X-C- bond lead to further cross linking. The resistance of the elastomeric materials to thermal aging is considered as an essential requirement for the product service life. The ageing process is defined by a set of irreversible physical and chemical changes in the material. Tensile strength is reduced and for longer ageing process, the greater are the changes. However, elastomeric materials thermal ageing can be very complex due to the two competitive processes taking place simultaneously: cross-linking and chain scission. Crosslinking will lead to an increase in the elastic modulus and a consequent decrease in the extensibility of the material, whereas chain scission will result in the loss of the elastic modulus. In sulfur cured elastomers the bond energy between the sulfur and the polymer backbone greatly differ. There are three types of crosslinks: polysulfidic, disulfidic, and mono-sulfidic. For rubbers cross-linked with sulfur systems under elevated temperature, conversion of polysulfide bonds in mono-sulphidic is observed. The reaction is followed by separation of low molecular weight groups such as hydrogen sulfide, sulfur dioxide, and carbon disulfide. The tensile strength of prepared materials before and after thermal ageing (100°C for 72 h and 168 h) are shown in the Figure 1. The influence of silica content on the elongation at break before and after ageing is shown in the Figure 2. We can observe that there is a marginal decrease in the tensile strength and elongation at break after aging during 72 h and 168 h for samples which contain 80 phr and 100 phr silica. The reductions of the properties are due to partial crosslinking of the elastomer backbone and degradation of the rubber taking place upon ageing. Values of elongation at break decrease with ageing time increase. Elongation at break decreases with tightening of the conditions of accelerated ageing process. The influence of silica content on the hardness before and after ageing of prepared elastomeric materials is shown in the Figure 3. It was determined that hardness for all composite materials increases with tightening of the conditions of accelerated ageing process. Well-dispersed nano particles are barrier for heat transfer through the material, thereby preventing fast degradation and are acting as a mass transport barrier to oxygen and volatile decomposition products.

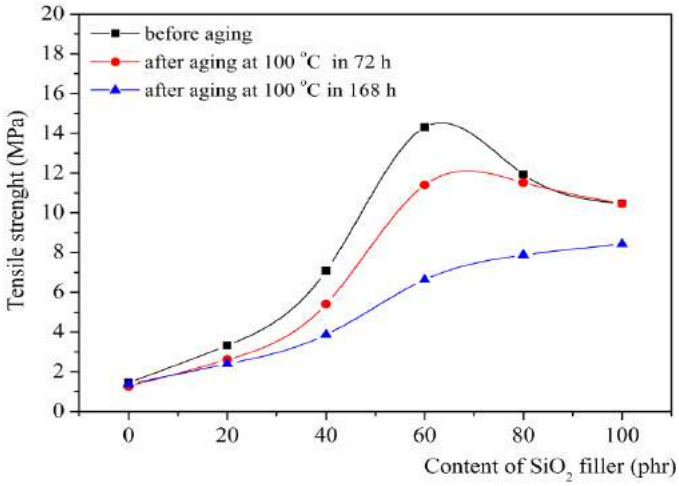

Figure 1. The influence of silica content on tensile strength of NR/BR/SBR composites before and after ageing during 72h or 168 h at 100 °C.

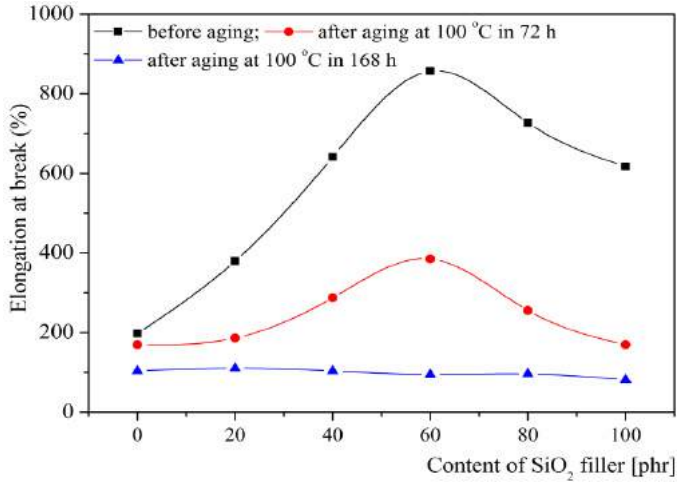

Figure 2. The influence of silica content on the elongation at break before and after ageing during 72h or 168 h at 100 °C for composites based on NR/BR/SBR.

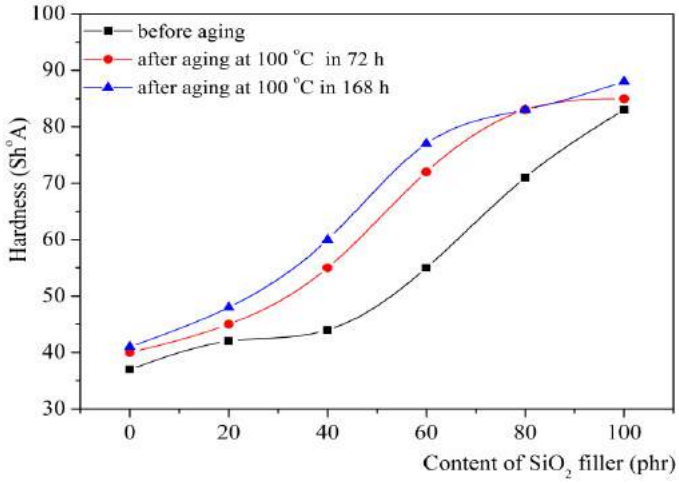

Figure 3. The effect of silica content on hardness of composites based on NR/BR/SBR ternary rubber blends after ageing at 100 °C during 72h or 168 h.

In the figure 4 is shown the influence of silica content on the compression set of prepared materials. This characteristic of materials is important as spontaneous stress release of the elastomeric materials and is the indicator what could occur due to the external forces or internal pressure changes during elastomeric product exploitation.

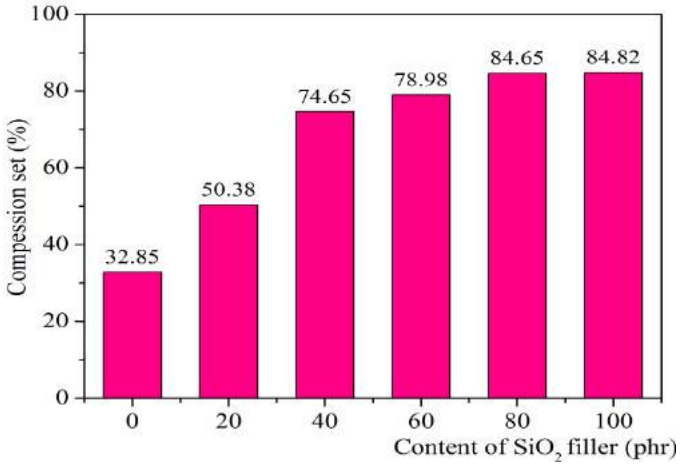

Figure 4. The influence of silica content on compression set of materials based on NR/BR/SBR ternary rubber blend

It was determined that the compression set of prepared elastomeric materials increases linearly with the content of used silica. The introduction of reinforcing fillers into the rubber blends reduces its elasticity, which in turn increases the compression set. This performance is attributed to non-crosslinked areas that do not contribute to the permanent network structure and relax during the compression stage. This permanent deformation is of particular concern when elastomers are used to for seals fabrication. Decreasing seal force has the potential to create leaks over time

CONCLUSIONS

The aim of this work was to assess the influence of silica nano particles on ageing of elastomeric materials based on NR/BR/SBR ternary rubber blends in order to find the best formulation of rubber compounds. Elastomeric materials based on this three network precursor are used for tire tread fabrication**.** Thermal stability and ageing is the primary characteristics for processing and application of elastomeric products. It was assessed that after ageing during 72h or 168 h at 100 °C the mechanical properties of prepared materials decreases (changes in the morphology; degradation of rubber; changes in interaction between components at elevated temperatures). The resistance of the elastomeric materials to thermal ageing is considered as an essential requirement for the service life of elastomeric materials. When silica content increases, the values of the elongation at break and hardness values increase. It was determined that the compression set increases linearly with nano-silica content. It was estimated that values of the compression set obtained for 25% of deformation are appropriate for application of prepared materials.

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LITERATURE

1. Camargo P., Satyanarayana K., Wypych F., (2009) Nanocomposites: Synthesis, Structure, Properties and New Application Opportunities, *Materials Research*, 12(1), 1-39
2. Nawawi M., Har S., Han C., (2012) Miscibility of Polymer Blends Comprising Poly (Ethylene Oxide) - Epoxidized Natural Rubber, *International Journal of Chemical Engineering and Applications* 3(6) 410-412. doi: 10.7763/IJCEA.2012.V3.230
3. Ngudsuntear C., Limtrakul S., Vatanatham T., Wichien. A., Rempel G., Arayapranee W., (2014) Effect of Blend Ratio on Cure Characteristics, Mechanical Properties, and Aging Resistance of Silica-filled ENR/SBR
   Blends, *International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies* 5(1) 11-24. doi: 10.14456/rjas.2015.7
4. Marković G., Jovanović V., Samaržija-Jovanović, Marinović-Cincović M., Budinski-Simendić J., (2012) Hybrid materials based on brominated copolymer isobutylene isoprene/chlorosulfonated polyethylene rubber blends reinforced by nano- and micro-silica, *Journal of elastomers and plastics* 44(4) 335–351 2012 DOI.ORG/10.1177/0095244311428895
5. Thongpina C., Santawitee O., (2013) The Effect of Rubber on Morphology, Thermal Properties and Mechanical Properties of PLA/NR and PLA/ENR Blends, *Energy Procedia* 34, 888-897 doi.org/10.1016/j.egypro.2013.06.826
6. Samaržija-Jovanović S., Jovanović V., Konstantinović S., Marković G., Marinović-Cincović M., (2013) Radiation stability of nanosilica-based urea-formaldehyde composite materials, *Journal of Thermoplastic Composite Material*s 26 (6) 747-761 Doi.org/10.1177/0892705711428661