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# INFLUENCE OF STRONTIUM FERRITE ON PROPERTIES OF COMPOSITES BASED ON POLAR AND NON-POLAR RUBBBER MATRICES

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In this work, rubber magnetic composites were prepared by incorporation of hard strontium hexaferrite in rubber blends based on polar and non-polar matrices. The aim was to investigate the influence of applied filler on magnetic and mechanical properties of rubber composites. Strontium ferrite was dosed in various concentrations in order to obtain the optimal characteristics of prepared materials. The results demonstrate that the presence of strontium ferrite in rubber matrices leads to significant increase of magnetic characteristics of composites. The mechanical properties of tested systems seem to be less dependent on the magnetic filler content, although the improvement of evaluated mechanical properties with doping content of ferrite was recorded.

Keywords: rubber composite, strontium ferrite, magnetic characteristics, thermal conductivity, physical-mechanical properties

## 1 INTRODUCTION

In the recent years a rapid interest in the development of rubber composites with magnetically polarisable particles has been shown [1-3]. The two different elements are attended to one structural unit what brings new properties and technological abilities. The advantage of such type of materials is that their properties can be modified for the requirements of specific applications. High flexibility, chemical resistance and easy moudability are the main attributes of rubber magnetic composites. Thanks to their versatility and good magnetic properties, there are widely used in many fields of technological and industrial applications: in clamps, bearing seals, memo holders, electromagnetic absorbers, variable impedance surfaces, in microwawe and radar technology, too [4-6].

Ferrites represent well established family of magnetic materials. The M-type of ferrites with general formula $MeO.6Fe_2O_3$, where Me is divalent metal such as Ba, Sr or Pb, have been extensively used as permanents magnets due to their low cost, high coercivity and remanent magnetic induction. They have domain structure, which terminates over the Currie temperature. High values of magneto-crystalline anisotropy and saturation magnetization, corrosion resistance and chemical stability are next benefits of these magnetic materials, which become very important materials as media for magnetic and magnetic-optical recording, components for reproducers, engines and generators in automobile industry [7, 8].

For manufacturing of rubber magnetic composites, different types of rubber matrices can be used, depending on the required properties of final products. The goal of the present was to investigate the influence of hard strontium ferrite content on the properties of rubber magnetic composites based on polar and non-polar rubber matrices.

## 2 EXPERIMENTAL

The two types of elastomers, butadiene rubber BUNA CB 24 (BR, Lanxess, Germany) as non-polar rubber matrix and acrylonitrile-butadiene rubber EUROPRENE N3330 (NBR, Polimeri, Italy) as polar rubber matrix rubber, were filled with hard strontium hexaferrite $SrFe_{12}O_{19}$ type FD 8/24 (Magnety, Světlá Hora, Czech Republic) in order to prepare rubber magnetic composites. Besides the rubber and the filler, the prepared rubber compounds contained only ingredients which support vulcanization process. The content of those ingredients was kept constant in all experiments. The content of magnetic filler was changed from 0 to 100 phr, which corresponds to weight fraction ranging from 0 to 50 wt%. The detailed specification of applied strontium ferrite is mentioned in Table 1.

**Tab. 1**. Characteristics of strontium ferrite

| Characteristics | Values |
|---|---|
| Density ($g.cm^{-3}$) | 4.13 |
| Specific surface area ($m^2. g^{-1}$) | 3.30 |
| Total porosity (%) | 54.94 |
| Coercivity ($kA.m^{-1}$) | 116 |
| Remanent magnetic induction (T) | 0.116 |
| Maximal magnetic polarization (T) | 0.205 |
| Maximal magnetic induction (T) | 1.150 |
| Curie temperature (ºC) | 455 |

The rubber compounds were prepared in the laboratory mixer BRABENDER in two mixing steps. In the first step the rubber and the filler were compounded (9 min, 90 °C), in the second step (4 min, 90 °C) the vulcanization system was added. The vulcanization process was performed at 150 ºC for the optimum vulcanization time under a pressure of approximately 20 MPa by using the hydraulic press FONTUNE.

Physical properties of the prepared composites were measured in accordance with the valid technical standards, on the double side blade specimens (width 6.4 mm, length 10 cm, thickness 2 mm). Magnetic measurements of composites on the magnetometer TVM−1 at room temperature and maximum coercivity of $H_m$ = 750 $kA.m^{-1}$ were determined. The basic principle of measurement is induction method of scanning of scattering magnetic flux $\Phi$ induced by magnetic

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vibrating sample. Magnetic field is generated by means of two cores of Weiss electromagnet at a minimum distance of poles adapters 7.5 mm. The specimens were of prism shape (8×4×4 mm). The evaluation of thermo-physical characteristics was carried out by means of the ISOMET appliance. The measurement is based on the analysis of time-temperature responds to the thermal flow impulses into analyzed material. The thermal flow is generated by dispersed electric power in probe resistor, which is thermal-conductively connected with tested specimen.

## 3 RESULTS AND DISCUSSION

Magnetic properties of both types of composites were evaluated at laboratory temperature and maximum coercivity of $H_m$ = 750 kAm$^{-1}$. First, the maximum magnetic flux $\Phi_m$ and remanent magnetic flux $\Phi_r$ were experimentally measured. The both characteristics showed the significant increasing tendency with increasing amount of ferrite.

The maximum magnetic polarization $J_m$ and the remanent magnetic polarization $J_r$ were evaluated on the basis of experimentally measured $\Phi_m$ and $\Phi_r$ values:

$$J_m = \frac{\Phi_m}{S} \cdot D \tag{1}$$

$$J_r = \frac{\Phi_r}{S} \cdot D \tag{2}$$

$S$ – surface area of the sample,
$D$ – constant of the used apparatus TVM-1 ($D$ = 16.4)

The maximum magnetic induction $B_m$ and the remanent magnetic induction $B_r$ were then determined:

$$B_m = \mu_o . H_m + J_m \tag{3}$$

$$B_r = \mu_o . H + J_r => B_r = J_r \tag{4}$$

$\mu_o$ – vacuum permeability
$H_m$ – maximum intensity of magnetic field ($H_m$ = 750 kA.m$^{-1}$)
$H$ – intensity of magnetic field ($H$ = 0 kA.m$^{-1}$)

From Figs. 1-2 it becomes clearly evident, that maximum $B_m$ as well as remanent $B_r$ magnetic induction of both types of composites were found to be strongly dependent on the content of applied strontium ferrite. In case of both types of composites, there was recorded nearly 500 % increase of the value $B_r$ by increasing of ferrite content from 20 to 100 phr. The type of rubber matrix has almost no influence on the values of these magnetic characteristics; the $B_r$ and $B_m$ are dependent only on the amount of magnetic filler regardless of the type of tested rubber. By contrast, the coercivity of studied materials seems not to be influenced by the magnetic filler content (Fig. 3).

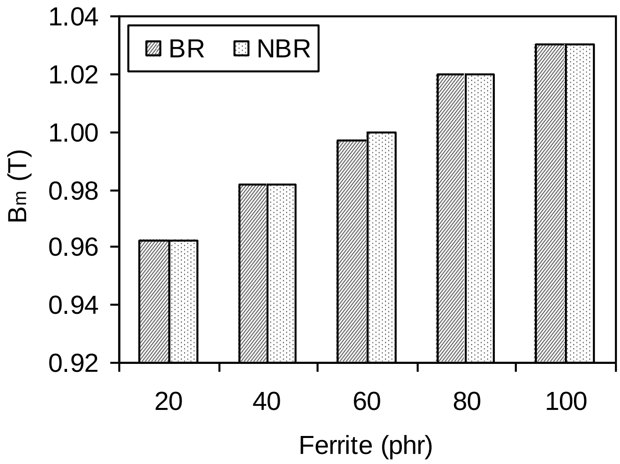


**Fig. 1.** Influence of strontium ferrite on maximum magnetic induction $B_m$ of BR- and NBR-composites

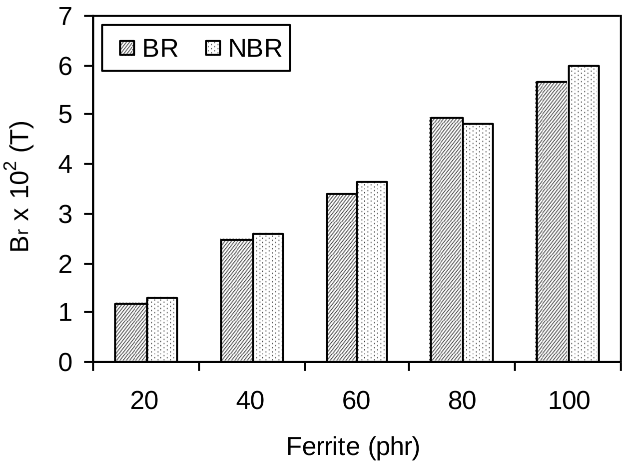


**Fig. 2.** Influence of strontium ferrite on remanent magnetic induction $B_r$ of BR- and NBR-composites

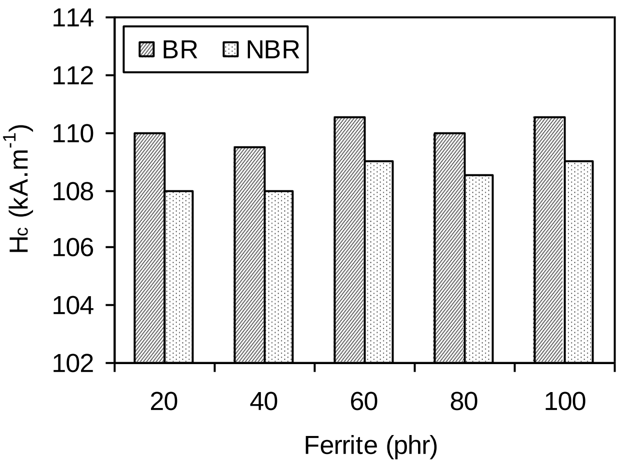


**Fig. 3.** Influence of strontium ferrite on coercivity $H_c$ of BR- and NBR-composites

The values of $H_c$ change only in the very low range, independently on the amount of strontium ferrite. The values of coercivity are higher in case of BR-composites, what is a bit surprising, as the above mentioned magnetic characteristics were found not to be affected by the type of rubber matrix.

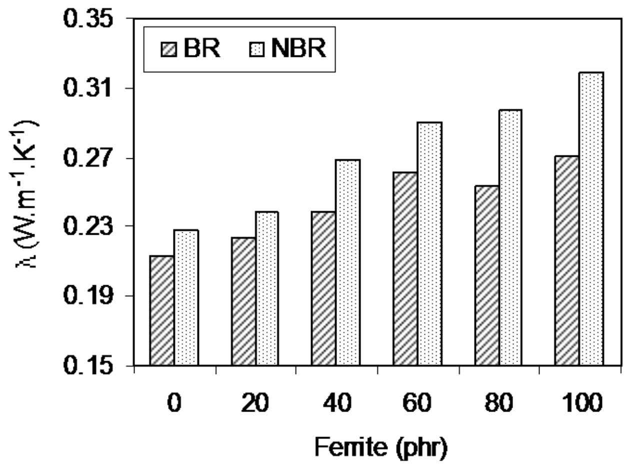


**Fig. 4.** Influence of strontium ferrite on thermal conductivity coefficient $\lambda$ of BR- and NBR-composites

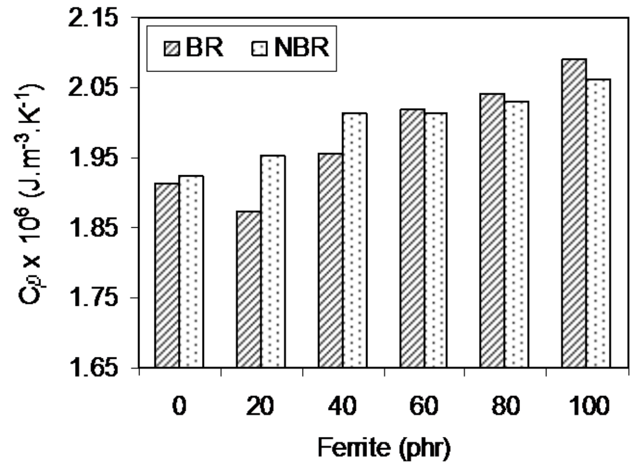


**Fig. 5.** Influence of strontium ferrite on volumetric heat capacity $C\rho$ of BR- and NBR-composites

The polymers, in generally, have low thermal conductivity. As metal ferrites belongs to the thermal conductive materials, there was expected, that the presence of ferrite filler in rubber matrices could influence thermo-physical properties of composites. Although ferrite incorporated in butadiene rubber matrix leads to the increase of thermal conductivity coefficient $\lambda$, at the maximum ferrite content, only about 30 % increase of $\lambda$ in comparison with ferrite free sample was spotted (Fig. 4). The results suggest that the percolation threshold of magnetic particles in the rubber matrix was not reached and therefore the increase of thermal conductivity is not considerable. The incorporation of strontium ferrite into the rubber matrix caused also the enhancement of thermal conductivity of NBR-composites (Fig. 4). The thermal conductivity coefficient of NBR-composites is higher in comparison with corresponding values of $\lambda$ of BR-composites. Also the increase of thermal conductivity of NBR-composites with doping content of ferrite is stronger and the difference between the $\lambda$ value of reference sample and sample with maximum ferrite content is bigger than in previous case (almost 40 %). This difference between BR- and NBR-composite could be attributed to the presence of polar functional groups in NBR matrix, which are supposed to contribute to the higher improvement of thermal conductivity when compared to the non-polar butadiene rubber matrix. From Fig. 5 it is seen the positive effect of applied magnetic filler on the volumetric heat capacity $C\rho$ of both types of composites. The values of $C\rho$ were found to slightly increase in dependence on magnetic filler content.

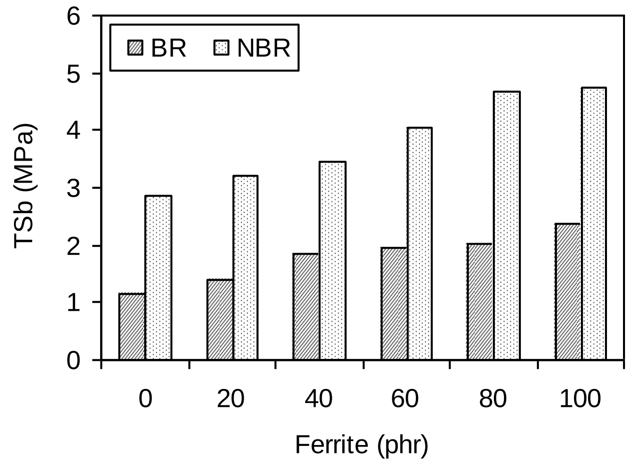


**Fig. 6.** Influence of strontium ferrite on tensile strength at break TSb of BR- and NBR-composites

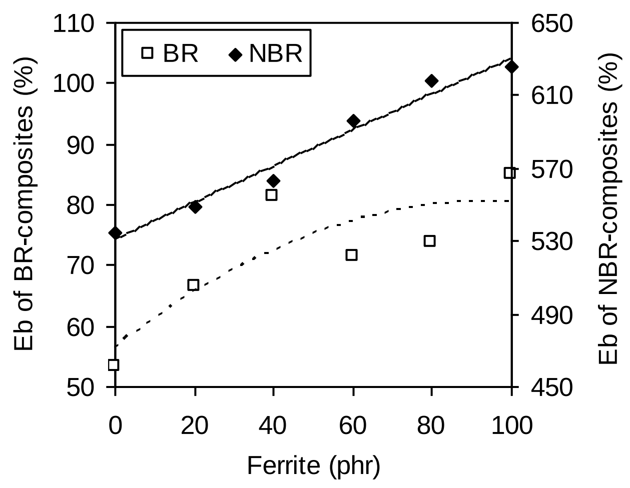


**Fig. 7.** Influence of strontium ferrite on elongation at break Eb of BR- and NBR-composites

The experimentally obtained values of physical-mechanical properties of both types of composites are illustrated in Figs. 6-8. The achieved result revealed that the presence of magnetic filler in rubber matrices leads to the enhancement of evaluated characteristics. The tensile strength at break of maximally ferrite filled composite based on butadiene rubber increased in more than 100 % in comparison with reference unfilled sample (Fig. 6). The similar non-linear increasing tendency of tensile strength at break with increasing of magnetic filler content was possible to observe also in case of composites based on acrylonitrile-butadiene rubber. The difference of tensile strength between the sample with 100 phr of ferrite and reference sample was almost 2 MPa (Fig. 6).

The elongation at break of both BR- and NBR-composites was also found to increase with ferrite loading increasing (Fig. 7). The both evaluated physical-mechanical properties were higher in case of NBR-composites what is attributed to the different physical properties of chosen rubber matrices. The obtained results demonstrate that ferrite incorporated in rubber matrices exhibits reinforcing effect as the evaluated properties are improved in dependence on ferrite content. Ferrite filler has no functional groups on the surface on its crystal structure, therefore it is expected that bonding forces between ferrite and the rubber matrix are of physical character. These physical interactions and adhesion between the two components get improved with increasing of magnetic filler content.

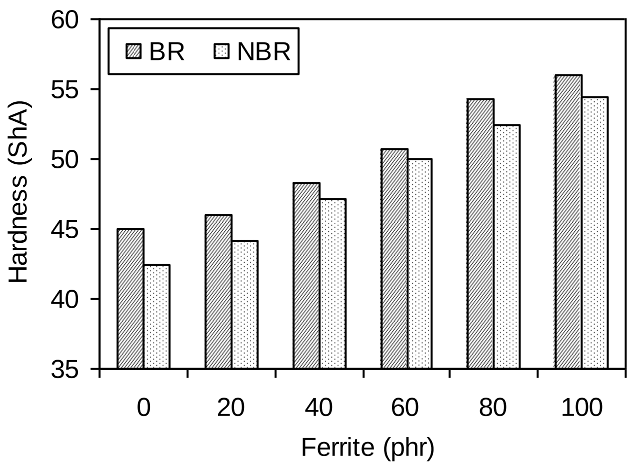


**Fig. 8.** Influence of strontium ferrite on hardness of BR- and NBR-composites

As shown in Fig. 8, the hardness of composites was enhanced with doping content of ferrite as the hardness of ferrite is much higher in comparison with the hardness of the rubber matrix. This physical-mechanical property is influenced not only by the amount of applied ferrite, but also by the hardness of rubber matrix seeing that the hardness of BR-composites is higher compared to the hardness of NBR-composites with equivalent content of magnetic filler.

## 4 CONCLUSIONS

The work was focused on the investigation of strontium ferrite content on the properties of rubber composites based on different rubber matrices. The obtained results revealed that ferrite incorporated in rubber matrices influences especially magnetic characteristics, which show significant increasing tendency in dependence on magnetic filler content. Thermo-physical and physical-mechanical properties of composites were also improved with doping content of ferrite. The type of rubber matrix was crucial in case of physical-mechanical properties. Although the dependences of physical-mechanical properties on ferrite content were similar in case of both types of composites, the differences in the values of evaluated properties of both BR- and NBR-composites were attributed to the physical properties of tested rubber matrices. This should be taking into consideration, when preparing rubber composites not only with good magnetic characteristics, but also with required physical-mechanical properties.

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