

Magnetic and Mechanical Properties of Strontium Ferrite and Nd–Fe–B Rubber Bonded Permanent Magnets

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Application of permanent magnets bonded by rubber is still growing, especially in the automotive industry. Magnetic and mechanical properties of permanent rubber magnets can be tailored by a production's technology and a magnet's composition. Permanent magnets bonded by rubber are produced by a method called calendaring. Physical properties of rubber bonded permanent magnets depend on a type and amount of hard magnetic powder in a mixture with rubber. Anisotropic strontium ferrite powder and spherical isotropic Nd–Fe–B alloy powder were used in research. The results of measurements show that with an increasing amount of ferrite powder magnetic properties and Shore hardness increase whereas tensile strength decreases. Addition of Nd–Fe–B powder to the mixture instead of some ferrite slightly increases magnetic properties of magnets.

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1. Introduction

Application of permanent magnets is constantly growing. Permanent magnets can be produced by different methods. It may be casting, sintering, or bonding hard magnetic powder by a binding agent. The last method of producing magnets has a lot of advantages. One of them is a possibility of tailoring physical properties of permanent magnets. Permanent magnets can be prepared by compression moulding or injection moulding technology. Physical properties depend on a type and amount of hard magnetic powder, a type and amount of binding material, and a type and parameters of technology process. As hard magnetic powder, ferrite powder, Nd–Fe–B, Sm–Co, Alnico, or mixture of powders can be used. As dielectric bonding grain of powder, among others, epoxy resin, nylon, or rubber can be used.

One of industry branches where application of permanent magnets is constantly growing is the automotive industry. Permanent magnets in this industry are applied, among others, in rotary magnetic encoders for anti-lock braking system (ABS).

Multipole permanent magnets for rotating encoders for an ABS, are, among others, prepared by technology of bonding hard magnetic powder by rubber. Properties of this type of permanent magnets depend mainly on a type and amount of hard magnetic powder and kind of a cross-linker [1–6].

The aim of this investigation is to show influence of a kind and amount of hard magnetic powder on magnetic and mechanical properties of permanent magnets. This knowledge allows producers to prepare permanent magnets with physical properties adapted to a type of ABS device.

2. Experimental details and results

The technology of production permanent magnets from hard magnetic powder bonded by rubber consists of preparing a mixture of powder with rubber and a cross-linker with additives, and then a vulcanization process of this mixture is conducted. The last operation is magnetization of samples. In the experiment anisotropic strontium ferrite powder produced by TODA Ferrite (Japan) and isotropic Nd–Fe–B powder produced by Magnequench (USA) were used. Magnetic anisotropy in ferrite magnets are created mechanically.

The mixtures of powder and rubber with a cross-linker were prepared by a calendaring process. The first set of mixtures contains from 76.3 wt% to 88.1 wt% of strontium ferrite. The second set of samples with mixture of strontium ferrite from 83.3 to 69.0 wt% and spherical powder of Nd–Fe–B from 4.8 wt% to 19.0 wt% were prepared as well. The powder of Nd–Fe–B is a powder designed especially for the injection moulding technology.

A sheet of rubber with magnetic powder was prepared. Samples for measurement of magnetic and mechanical properties were prepared in a vulcanization process by pressing and heat treatment in an elevated temperature. Samples for measurement of magnetic and mechanical properties were prepared with the same parameters of a vulcanization process.

Metallographic investigations of prepared samples after a vulcanization process were carried out. Figure 1 shows a structure of samples with 88.1 wt% of strontium ferrite and Fig. 2 shows samples with 69 wt% of strontium ferrite powder and 19 wt% of Nd–Fe–B powder. Pictures were taken by scanning electron microscope model JSM–7600F produced by JEOL.

As Figs. 1 and 2 show that a small amount of strontium ferrite powder are evenly mixed with rubber, but powder of Nd–Fe–B has a round shape and a bigger size. Powder Nd–Fe–B for injection moulding technology has a value

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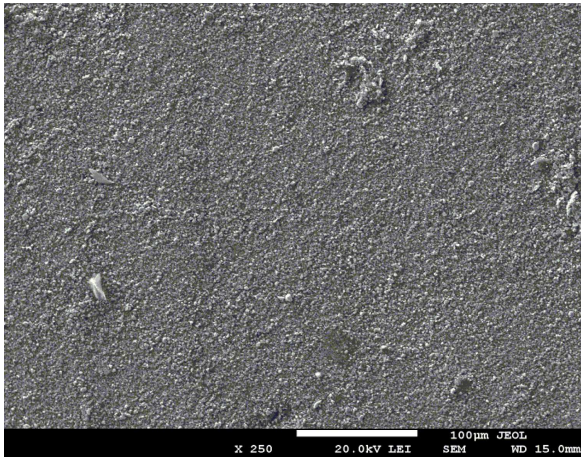


Fig. 1. Structure of a rubber bonded permanent magnet with 88.1 wt% of strontium ferrite powder, magnification 250 \times .

of medium particle size about 35–55 μm , but the average particle diameter of strontium ferrite powder is 1.05 μm .

Magnetic properties of samples were measured by a hysteresis-graph made by Laboratorio Elettrofisico Walker LDJ Scientific, model AMH-20K-HS according to IEC 60404-5 standard. Samples for measurement of magnetic properties consisting only strontium ferrite were composed from 3 cylinders with diameter 29 mm and *ca.* 2 mm thickness each. Samples for measurement of magnetic properties with Nd-Fe-B addition were cylindrical with diameter 23 mm and 13 mm in height. Samples with Nd-Fe-B powder before measurements were magnetized in pulse magnetic field with magnetic field strength 2400 kA/m to ensure magnetic saturation of samples. The results of investigation are shown in Table I.

As Table I shows, with an increase of the amount of strontium ferrite powder in the mixture of powder and rubber, density, remanence B_r , coercivity H_{cB} , and maximum density of magnetic energy BH_{max} of samples grow, whereas coercivity H_{cJ} remains approximately at the same level. It was impossible to prepare a mixture of rubber with a larger amount of strontium ferrite, because with larger amount of magnetic powder the mixture could

not be processed. The mixture of rubber with strontium ferrite and Nd-Fe-B powder were prepared for an increase in magnetic properties of magnets. The small increase of density, remanence, coercivity, and BH_{max} product is observed in samples with increasing amount of Nd-Fe-B powder.

Figure 3 shows, as an example, demagnetization curves of a bonded magnet with 88.1 wt% of strontium ferrite. As it can be seen, $B = f(H)$ is linear which is a typical property of ferrite magnets.

Mechanical properties of samples such as Shore hardness and tensile strength were measured. Shore hardness was measured according to ISO 37 standard, whereas tensile strength according to ISO 7619. Dimensions of samples are: for Shore hardness a cylinder with diameter 50 mm and 8 mm in height, for tensile strength the sample resembles a paddle with a centre part 25 mm length, 6.2 mm height, and 2 mm thickness. Measurement of tensile strength were carried out on tensor check profile produced by Gibitre Instruments srl., hardness was measured by hardness tester model Digi Test II produced by Bareiss Prüfgerätebau GmbH. The results of measurements are shown in Fig. 3.

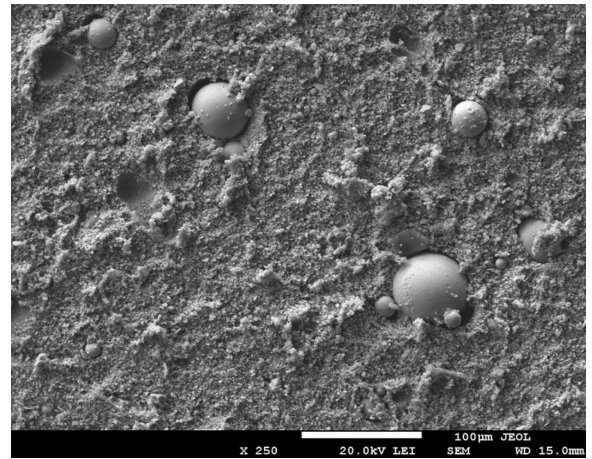


Fig. 2. Structure of a rubber bonded permanent magnet with 69.0 wt% of strontium ferrite powder and 19.0 wt% of Nd-Fe-B powder, magnification 250 \times .

Magnetic properties of rubber bonded permanent magnets.

TABLE I

An amount of ferrite and Nd-Fe-B powder [wt%], the rest is rubber, cross-linker and additives	Density [g/cm ³]	B_r [mT]	H_{cB} [kA/m]	H_{cJ} [kA/m]	BH_{max} [kJ/m ³]
strontium ferrite 76.3%	2.85	173	129	262	5.72
strontium ferrite 80.6%	3.03	190	141	258	6.85
strontium ferrite 86.5%	3.35	222	164	294	9.30
strontium ferrite 87.5%	3.40	227	167	288	9.70
strontium ferrite 87.8%	3.42	230	166	230	10.01
strontium ferrite 88.1%	3.44	234	170	249	10.33
strontium ferrite 83.3%, Nd-Fe-B 4.8%	3.48	237	158	222	10.44
strontium ferrite 78.5%, Nd-Fe-B 9.5%	3.52	240	159	239	10.54
strontium ferrite 69.0%, Nd-Fe-B 19.0%	3.60	251	175	318	11.46

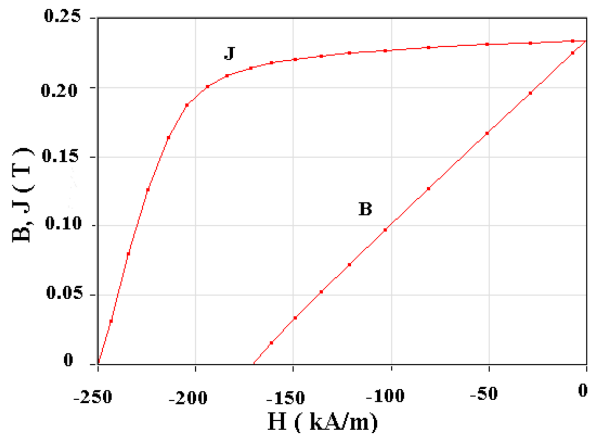


Fig. 3. Demagnetization curves for a ferrite bonded magnet with 88.1 wt% of strontium ferrite.

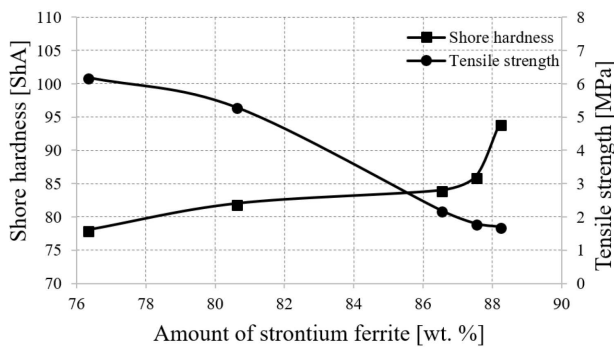


Fig. 4. Mechanical properties of rubber permanent magnets.

As Fig. 4 shows, with an increase in the amount of strontium ferrite powder hardness of samples increases, whereas tensile strength decreases. With increasing amount of ferrite powder samples are less plastic but more rigid.

3. Application of developed bonded magnets

Developed technology and material can be applied in an automotive industry practically for all car producers.

Permanent magnets for ABS system have a shape of a ring and are connected with a steel base, magnetized on 96 alternating magnetic poles. Different sizes and magnetic properties of permanent magnets are adapted to different systems of ABS in cars. The main parameter of ring permanent magnets is magnetic flux density in 1 mm distance from their surface.

The rings from prepared mixture of rubber and strontium ferrite powder with 88.5 wt% were vulcanized. Figure 5a shows an example of the ring and Fig. 5b — surface of a ring after pulse magnetization. The magnetization was conducted with use of pulse magnetizer and magnetizing fixture developed in a Tele and Radio Research Institute.

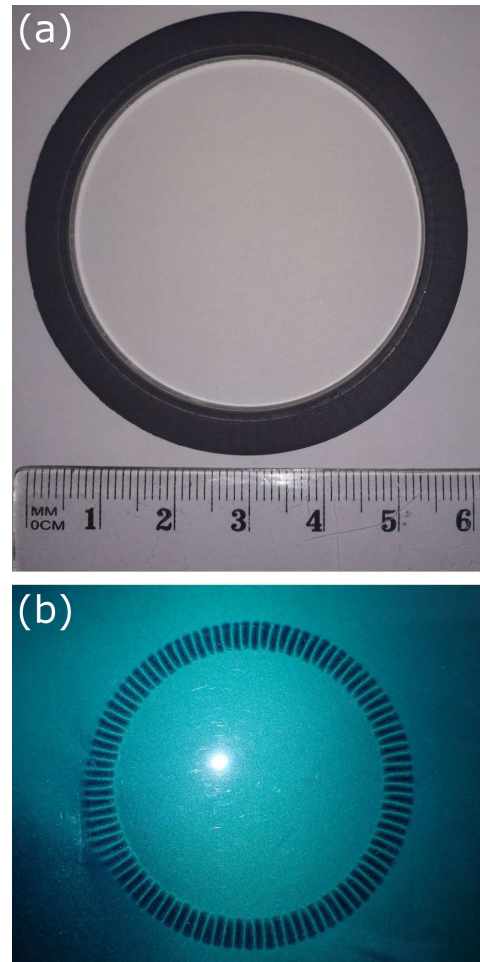


Fig. 5. (a) The ring with a rubber permanent magnet, (b) 96 magnetic poles of a rubber permanent magnet.

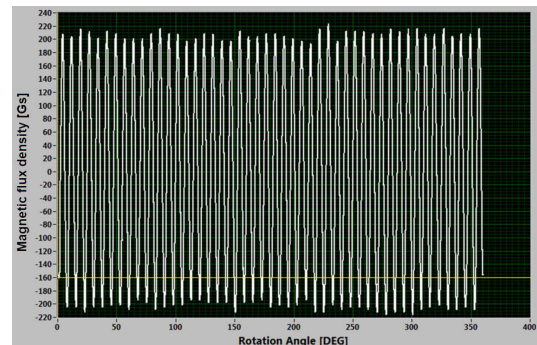


Fig. 6. Distribution of magnetic flux density in 1 mm distance from a ring with a permanent magnet.

As can be seen, magnetic poles change alternatively and are clear with regular neutral lines.

Measurements of magnetic flux density in 1 mm distance from surface were carried out. Measurements were conducted on a stand with use of a Hall sensor developed in Tele and Radio Research Institute. Figure 6 shows course of changes of magnetic flux density.

Maximum values of magnetic flux density in 1 mm distance from a surface of bonded magnet are in the range of 190 to 220 Gs (19–22 mT). Distribution of magnetic flux density in 1 mm distance from the magnet's surface is quite equal.

4. Conclusion

Results of research have shown that it is possible to tailor magnetic and mechanical properties of rubber bonded permanent magnets by a change of amount and type of powders used in the experiment.

A change of strontium ferrite from 76.3 to 88.1% by weight increases a magnetic energy density from 5.72 kJ/m³ to 10.33 kJ/m³. The increase is almost 81%. The Shore hardness increases for the same change of ferrite powder from 78 to 94 ShA, which is almost 21%. In turn, tensile strength decreases from 6.2 to 1.7 MPa with an increase of amount of ferrite powder from 76.3 to 88.1%. In this situation a decrease is equal to 73%.

In turn, a change of some strontium ferrite powder with Nd–Fe–B powder causes very little increase of a magnetic energy density. A change of ferrite powder with 19 wt% of Nd–Fe–B powder causes a slight increase of magnetic energy density from 10.33 kJ/m³ to 11.46 kJ/m³. Here a percentage increase is about 11%. Nd–Fe–B powder should be used with a different particle size and shape in future experiments.

Developed technology and material allows producers to make rings for ABS with different values of magnetic flux density adapted to different types of cars. For example, magnetic flux density required by Fiat is 145 Gs (14.5 mT), while prepared rings of strontium ferrite achieve 190–220 Gs.

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