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Influence of Vitrovac Content on Magnetic Properties in Composite Materials Based on the Mixture of Two Ferromagnets

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Soft magnetic composite materials play an important role in nowadays industry, replacing the traditional materials such as electrical steels and soft ferrites, especially at medium and higher frequency applications. The material can be tailored for a specific application by changing the composition of the material and by adaptation of the fabrication process. The aim of this work was to investigate the morphology, phase composition and magnetic properties of soft magnetic composite materials with various magnetic content to minimize the total magnetic losses. The prepared sample series was based on the mixture of two different ferromagnets Vitrovac 6155 and Somaloy 700 without addition of insulating material. The samples were prepared by conventional powder metallurgy with particular fraction of Vitrovac in the form of a ring for magnetic measurements in AC fields and electric resistivity measurements. The samples with 5 wt% and 20 wt% fractions of Vitrovac exhibit lower values of total losses in comparison with Somaloy heat treated at 530 °C.

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1. Introduction

Soft magnetic composite materials (SMCs) are frequently used in electrotechnology, electronics, computers, and telecommunication devices. Recently, a group of soft magnetic composites was extended by introduction of new materials which offer the possibility of production of components with significantly higher saturation induction, permeability, and lower losses [1–3].

One of the key properties characterizing magnetic material is the amount of energy dissipated in material during the magnetizing cycle. A lot of work has been done in this field up to the present time and the energy losses in various magnetic materials have been analyzed [4–6]. The main feature of SMCs is that an insulating layer between the iron powder particles minimises the eddy currents, finally resulting in lower total energy losses at medium and higher frequencies. Therefore, in an effort to extend the field of application of these materials, researchers are focusing on the detailed investigation of various factors influencing the magnetic properties of SMCs [7].

The goal of the work is the investigation of the structure and magnetic properties of SMCs composed of two types of ferromagnets: Somaloy® 700 and Vitrovac® 6155 (of various ratio), with an emphasis on the total energy losses and the components they consist.

2. Experimental method

We used two commercial available materials Somaloy® 700 [8] polycrystalline iron powder covered by insulating layer provided by Höganäs (AB Sweden) and Vitrovac® 6155 [9] amorphous Co-based alloy provided by Vacuumschmelze (GmbH & Co. KG, Germany) which feature excellent magnetic properties with unique combination of mechanical strength and hardness. The small pieces of Vitrovac ribbon were dry milled in a high-energy RETSCH PM-100 planetary ball mill for 12 h using hardened-steel vials and balls. The milling process was performed (ball-to-powder mass ratio of 31:1, speed of 200 rpm) to get a powder in amorphous state [10].

We prepared SMC sample series based on two ferromagnets in the form of a ring by mixing Somaloy with selected weight fractions of Vitrovac amorphous powder (0, 5, 20, 30, and 50 wt%) without addition of insulating material. Mixed powders were compacted in a cylindrical die at uniaxial pressure of 800 MPa and heat treated (at 450 °C, below crystallization temperature of Vitrovac) in an electric furnace for 60 min in air atmosphere. Sample SOM 530 was prepared from Somaloy® 700 powder (with mean value of the powder particle diameter of 120 μm covered by insulating film) by producer-developed technology (compaction at 800 MPa and heat treatment at 530 °C for 30 min in air). Sample SOM 450 was prepared with the same technology but it was heat treated at lower temperature (450 °C).

The structure of the milled Vitrovac powder was checked by X-ray diffraction (XRD, Philips XPERT PRO), to be in amorphous state. The morphology of the samples was investigated by scanning electron microscopy (TESLA BS 340).

The AC hysteresis loops were measured in the frequency range 10 Hz–1 kHz by AMH-1K-SAC hysteresis graph and in the frequency range 1 kHz–100 kHz by MATS-2010SA hysteresis graph at the maximum flux

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density of 0.1 T. We have respected a filling factor to measure hysteresis loop of an effective volume of ferromagnetic fraction samples. The impedance bridge (HP4194A) was used for complex permeability measurement in the frequency range from 1 kHz to 40 MHz.

The specific resistivity was measured by the Van der Pauw method. The porosity was calculated from the mass and dimensions of samples. Parameters of the samples are in Table I.

TABLE I

Parameters of the samples.

1	SOM 530	S95-5VIT	S80-20VIT
SOM [wt%]	100	95	80
VIT [wt%]	0	5	20
density [g/cm^3]	7.69	7.67	7.64
porosity [%]	4.62	5.36	10.06
resistivity [$\mu\Omega$m]	83.28	515.13	740.09
2	S70-30VIT	S50-50VIT	SOM 450
SOM [wt%]	70	50	100
VIT [wt%]	30	50	0
density [g/cm^3]	7.62	7.58	7.69
porosity [%]	14.90	20.58	4.73
resistivity [$\mu\Omega$m]	834.05	977.67	654.59

3. Results and discussion

The subjects of study were composite samples consisting of mixture of two ferromagnetic materials: Somaloy® 700 (SOM), polycrystalline iron powder covered by insulating film and Vitrovac® 6155 (VIT) amorphous Co-based powder. The morphology of two samples with different fraction after compaction is shown in Fig. 1. Vitrovac particles are impressed into Somaloy matrices, causing creation of the mechanical bond after heat treatment.

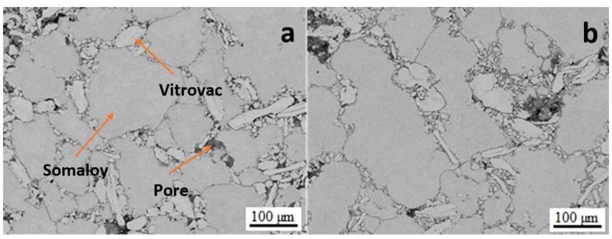

Fig. 1. SEM images of particles after compaction: (a) sample S80-20VIT versus (b) sample S70-30VIT.

Density measurement results exhibited a decrease in density with an increase of VIT content in composite. A high density specimen will be magnetically better because it improves flowing of magnetic flux between particles. Porosity acts as areas of demagnetization, reducing the saturation magnetization. It is assumed that increase of electrical resistivity is caused by increased amount of air gaps due to increased content of Vitrovac in composites.

The total energy losses dependences versus frequency (from 10 Hz up to 100 kHz) at maximum flux density of 0.1 T (in magnetic material) of all samples are depicted in Fig. 2.

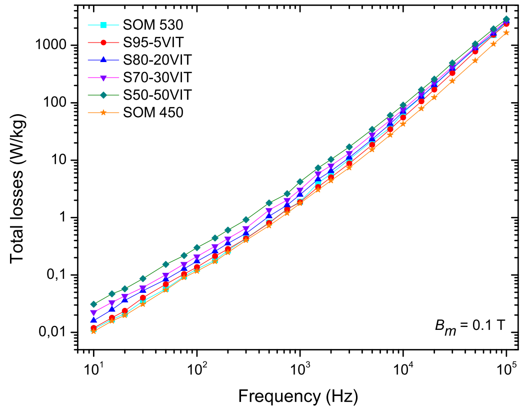

Fig. 2. Total losses P_t as a function of the frequency f measured at maximum flux density $B_m = 0.1$ T.

We can observe that the dependences are not linear, which means that numbers of moving domain walls are not constant with frequency [11].

The increase of VIT content causes the energy losses increase and also sample S95-5VIT and partly sample S80-20VIT exhibit lower losses than the SOM 530 material but on the other hand it has higher losses than sample SOM 450. The possible explanation of this fact could be that the increase of porosity of material is dominant to weakening the interaction between magnetic particles. Also numerous pinning centers hinder the domain walls motion which causes further increase of the energy losses.

We assume that lower values of losses of S-VIT samples are caused by lower contribution of the eddy current losses to the total losses due to higher specific resistivity of these samples in comparison to the specific resistivity of sample SOM 530. The hysteresis loops measured for all samples at maximum flux density of 0.1 T and frequency of 20 kHz are compared in Fig. 3. Hysteresis loops with increasing Vitrovac fraction are tilted down having lower permeability. Two of Vitrovac samples (S95-5VIT, S80-20VIT) have lower core loss than SOM 530 material, but their permeability is less favorable.

This argument is confirmed by the frequency spectra of real $\mu\prime$ and imaginary μ'' part of the complex permeability in powder cores of SMC samples prepared from different powders, Fig. 4. The real part of permeability decreases with rising content of VIT in the composite. The steepest drop in permeability begins with frequency of 15 kHz for sample SOM 450 and continues in similar slope for all other samples (with different initial values). Permeability is decreasing less steep for samples with

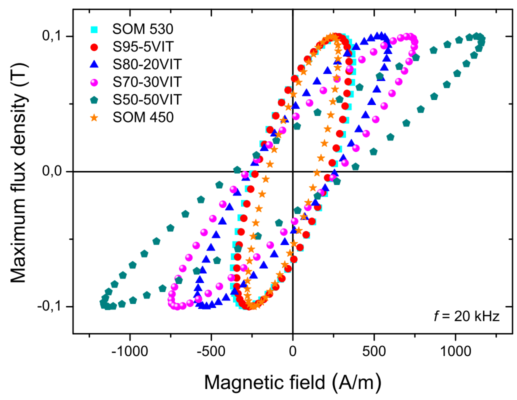

Fig. 3. Hysteresis loops of the S-VIT samples measured at the maximum flux density of 0.1 T and frequency of 20 kHz.

larger content of Vitrovac. The eddy current between particles can be reduced by higher volume of insulating material and pores.

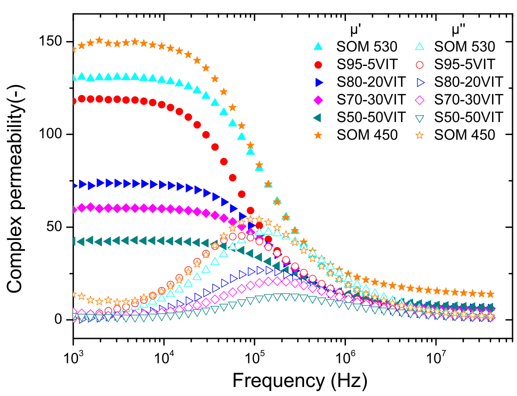

Fig. 4. Frequency dependences of real and imaginary parts of the complex permeability of S-VIT samples.

The real part of permeability depends on non-magnetic phase, fraction of pores, magnetic anisotropy and size of particles [12]. Imaginary part of the complex permeability which reflects the power loss due to eddy currents and hysteretic response has peak at different frequencies depending on VIT content.

4. Conclusions

In this work we dealt with the structure and magnetic properties of SMC based on the mixture of two ferromagnets Somaloy 700 and Vitrovac 6155 in order to study their magnetic properties.

We observed that the slope of the hysteresis loops is different for each sample which is explained by inner demagnetizing fields at the scale of magnetic particles. By adition of Vitrovac, mean size of the particles decreases, the porosity increases, resulting in higher inner demagnetizing field causing less steep hysteresis loops. Similar influence on the slope of hysteresis loop has the VIT content increase, leading also to of the electrical resistivity rise lowering of the contribution of eddy current loss to total energy losses.

We can conclude that samples with 5 wt% and 20 wt% fractions of Vitrovac exhibit the lower value of total losses in comparison with Somaloy heat treated at 530 °C, but on the other side they have lower permeability.

Acknowledgments

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