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COMMUNICATIONS

Influence of manufacturing parameters on magnetic parameters of soft magnetic composites cores

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The paper presents results of investigations of powder composites made of magnetically soft iron powder and dielectric - PVC - insulating and bonding molecules of this powder. The research was done on self-developed cylindrical samples. The study was aimed to determine the effect of molding pressure and the grain size of Fe on the magnetic properties of the samples. The studies have showed that an increase in core forming pressure obtaining higher induction B values at a lower H field intensity. It was also found that better parameters were obtained in the case of samples with a larger iron particle size.

K e y w o r d s: soft magnetic composites, grain size, magnetic properties

1 Introduction

Soft magnetic composites (SMCs) are recently a topic of interest for the scientific community and industry [1, 2] due to their interesting physical and chemical properties. The main advantages of such materials are isotropic behavior, waste-free production and the ability to adapt to specific applications. Selecting the right components of SMC makes them attractive as the sum of the material, manufacturing process and design of the electrical machine. Research on the properties of SMC can be found in, inter alia, Gilbert *et al* [3] who tested available commercially available SMC materials. Other researchers have focused on the influence of heat treatment methods and particle size and packing of iron-based particles on energy losses and mechanical properties of produced cores [4, 5]. Kollár *et al* [6] and Lauda *et al* [7] have focused on studying the dynamic properties of magnetic Fe-based composites in a wide range of excitation frequencies. Ślusarek *et al* investigated the correlation of SMC density and magnetic properties of finished cores [8]. The ideal construction of composite magnetic materials assumes the occurrence of magnetic material covered by a layer of insulating material as shown schematically in Fig. 1.

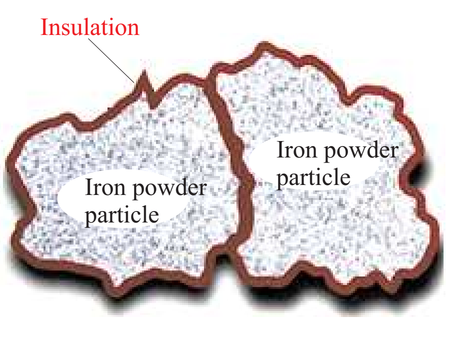

Fig. 1. The construction of magnetic composite material [1]

Because of the imperfections in the composite materials manufacturing process, short circuits between isolated areas may occur, which may affect the losses associated with the eddy currents in SMC [9].

2 Materials and measurements

Table 1. Comparison of saturation induction values of the samples made (FeP05x65) for each fraction, $f = 50\,\mathrm{Hz}$, $B_{\max} = 1$ T

Sample	Grain size (μm)	B_s (T)	$H_{\max}$, (A/m)	B_r B_r	H_c H_c
FeP05A65	$s \leq 50$	1.2	4720	0,31	507
FeP05B65	$50 < s \leq 100$	1.3	3267	0,35	441
FeP05C65	$100 < s \leq 150$	1.4	2873	0,35	396

The samples were made of iron powder (99.5% purity) with the addition of suspension polyvinyl chloride (PVC-S). The iron and PVC were mixed, maintaining a weight ratio of 99.5% Fe and 0.5% PVC. For all made samples the PVC fraction was within the range of $100 < s \leq 150$ μm. On the other hand, the size of iron fraction of irregular particle shape was in the intervals according to Tab. 1.

The mixture was molded into cylindrical shape samples which were then compacted at 165 °C for 15 min, Fig. 2. The method of manufacture is a subject of patent application - P.420850.

Research was done in several stages. In the first step described in detail [10], the optimal PVC content was determined at which samples could maintain good magnetic properties while at sufficient mechanical strength. The determined value was 0.5% of PVC in the total weight of the sample. In the next steps, the impact of the molding parameters and the influence of the grain size (s) of the powder material was investigated.

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Fig. 2. The prepared sample of SMCs

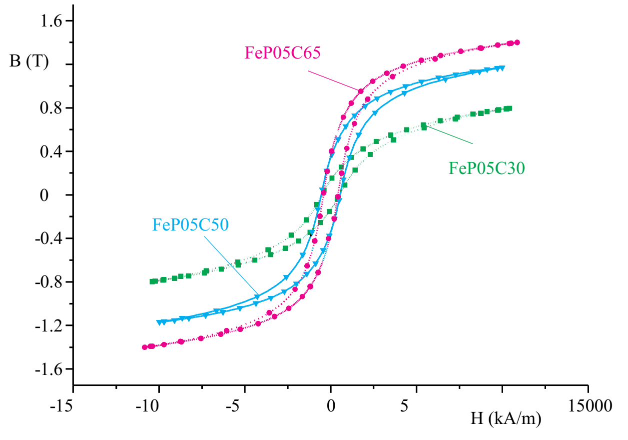

Fig. 3. The typical B_s values of SMCs tested according to molding pressure ($100 < s \leq 150$ μm)

In order to investigate the effect of the formation conditions of the samples, the powder pressing pressure was changed at constant temperature and particle size (s). The dimensions of the samples were $D_i = 30$ mm, $D_0 = 50$ mm, $h \approx 9$ mm each. The samples were made using a hydraulic press for pressures of 234 MPa (FeP05x30), 390 MPa (FeP05x50), 507 MPa (FeP05x65).

Studies of the magnetic properties of composite materials were carried out using the Remacomp C-200 measuring system. The sinusoidal shape of the induction was preserved, which results from the requirements of the relevant standard IEC 60 404-6.

Both stages of the impact study of the compacting pressure and grain size were carried out in two phases. In the first one, the value of induction saturation was determined, while in the second one, the magnetic parameters of the samples were compared for the induction value $B_{\max} = 1$ T. For this value of induction, the remanent induction and coercivity values of the samples were measured In Figure 3 are shown the saturation induction B_s values obtained by FeP05x65 samples depending on the formation pressure for the excitation frequency of 50 Hz. The highest B_s value = 1.4 T was obtained for the FeP05C65 sample.

The obtained values of B_s are strongly dependent on the pressure at which the samples were made. For the selected pressure (507 MPa), the effect of iron particle size was investigated and the results are given in Tab. 1 and in Fig. 4 and Fig. 5. During the preliminary investigation it was found that the magnetization frequency has small-effect on the shape of the hysteresis loop for $f \leq 50$ Hz. Accordingly, the characteristics shown in Fig. 5 at 50 Hz, be treated as quasi-static.

Based on the measurements results shown in Fig. 4, it can be stated that the magnetization curves for 50-100 μm and 100-150 μm are close to each other, while the 50 μm sample has significantly worse magnetic characteristics. For an increased frequency of magnetization ($f = 400$ Hz), the observed effect of magnetic deterioration on a sample of small grain size becomes even more apparent, Fig. 5. At the next stage of research, the influence of excitation frequency on magnetic parameters of SMC samples was investigated. The results are shown in Tab. 2.

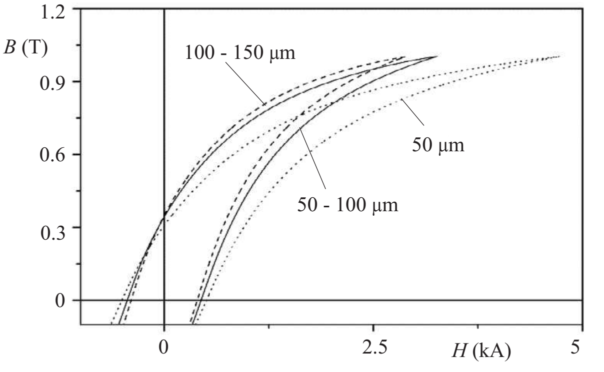

Fig. 4. The hysteresis loops for each fraction at $f = 50$ Hz, $B_{\max} = 1$ T, FeP05x65 samples

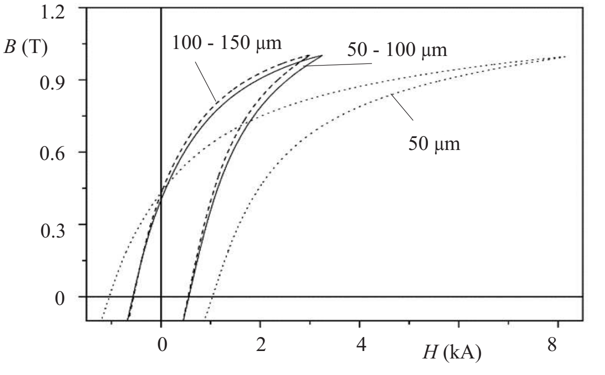

Fig. 5. The hysteresis loops for each fraction at $f = 400$ Hz, $B_{\max} = 1$ T , FeP05x65 samples

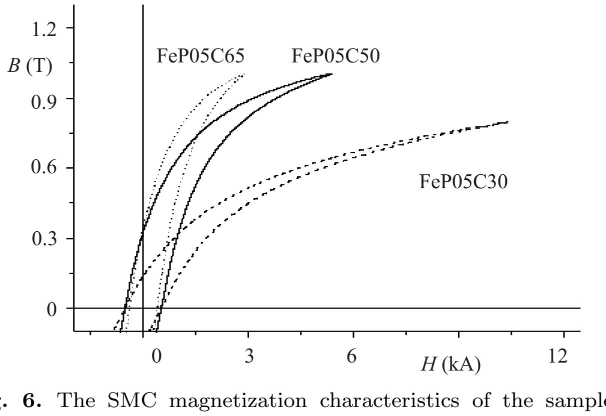

Fig. 6. The SMC magnetization characteristics of the samples made of $100 < s \leq 150$ μm grains at a frequency of 50 Hz

Analysing the measurement data presented in Figures 3, 6 and in Tab. 2, a significant relationship between the SMC sample forming parameters and their magnetic properties can be observed.

Table 2. Set of measurement data for the samples (FeP05Cxx) at different excitation frequencies

Sample	f (Hz)	$B_{\max}$ (T)	$H_{\max}$ (A/m)	B_r (T)	H_c (A/m)
	20	0.772	10421	0.134	505
FeP05C30	50	0,796	10410	0.137	519
	400	0.8	10686	0.147	565
	20	0.996	4991	0.302	459
FeP05C50	50	1	5415	0,325	518
	400	0.989	5637	0.528	1108
	20	1	2959	0.329	381
FeP05C65	50	1	2874	0,349	395
	400	1.0	2984	0.426	550

3 Conclusions

The paper presents the results of investigations of magnetic properties in MPCs samples made of different grain size and at different compacting pressures. It has been found that the change of grain size has a significant effect on the magnetic properties of the produced cores (loss, coercivity, remanence induction). It has been also found that better properties have samples with larger iron particles (100-150 μm). The effect of the compacting pressure is also very important. As the compacting pressure increased, the magnetic parameters improved and the hysteresis loops became steeper. With the increase of the compacting pressure in core, it was also possible to achieve higher induction values B at lower magnetic field H.

In addition, the influence magnetization frequency on the shape of characteristic $B(H)$ was investigated. It has been found that the measured characteristics at the technical frequency $f = 50$ Hz do not deviate from the characteristics obtained at lower frequencies. For high frequency $f = 400$ Hz, the benefits of using larger grain sizes are already significant.

The presented measurements show how important is the control and selection of the optimal parameters for of composite cores.

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