IRON POWDERS WITH INSULATING LAYERS: STRUCTURE AND MAGNETIC PROPERTIES

ПОРОШКИ ЖЕЛЕЗА С ИЗОЛИРУЮЩИМИ ПОКРЫТИЯМИ: СТРУКТУРА И МАГНИТНЫЕ СВОЙСТВА

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Abstract: *The development and study of the composite magnetic soft material, the magnetic properties of which are close to the laminated metal magnets and the remagnetization losses is lower than that one of metal magnets is very relevant. The study of magnetic properties and magnitude of losses on the remagnetization of the developed low-frequency composite magnetically soft material, comprising separate iron 20 ÷ 100 mkm particles, covered by insulating layers (films) with thickness 3 ÷ 10 nm, in comparison with similar parameters of electrical steel 3412 (E320) was performed in this work.*
KEYWORDS*: SOFT MAGNETIC MATERIALS, COMPOSITES, CRYSTAL STRUCTURE, MAGNETIC PROPERTIES*

1. Introduction

The wide application of valve inverter drive type electric motors, for which the operating remagnetization frequency is significantly higher than the industrial frequency, required the development of new magnetic-soft materials.

Over the past few years, many research centers have been intensively conducting research on soft magnetic composite (SMC) materials based on the use of soft magnetic particles, usually based on iron with an electro-insulating coating on each particle.

In [1] the isolated powder is obtained by treating the iron powder with a solution containing phosphoric acid and chromic acid. The pressed product obtained from isolated powders is then subjected to heat treatment.

Another type of coating is described in [2]. In accordance with the patent, the core from magnetic powder is obtained by iron powder treating with an aqueous solution of potassium dichromate, drying, pressing the powder and heat treatment of the product at a temperature of 600°C approximately. In another known method, the particles of magnetically soft iron are coated with thermoplastic materials before pressing [3].

Significant progress in creating the composite soft magnetic material made up company “Hoganas” [4-7]. Individual products of this company, for example with the use of powder “Somaloy 500, 750”, approximate by the parameters of the device from electrical steel. However, the results of these studies do not allow to clearly speaking about the successful solution of the problem of developing a composite magnetic soft material.

2. Experimental technique

Further improvement of the properties of a soft magnetic material based on iron powders coated with a ferrite layer was achieved through the use of HF synthesis of metal-dielectric-metal (MDM)-structures. The fundamental difference between the HF synthesis of MDM-structures and the previously described method of rapid thermal sintering is the formation of MDM-structures. The process of forming thin-layer MDM-structures with the formation of channel effects at the interfaces is considered in paper [8].

When exposed on MDM-structure of high-frequency radiation, for which the depth of the skin-layer is comparable to the size of the sample, in the ferrite coating separating the iron grains, conduction channels are formed. The size of the channels is usually from one to several microns.

As a result of the formation of conduction channels in ferrite boundaries between iron grains in a two-phase crystalline system, a single electronic structure is formed, which corresponds to ferromagnetic ordering in the entire system (Fig.1).

Progress in magnetic properties improving of composite materials and reducing of the remagnetization losses has been achieved in this work by using of various magnetic oxides as insulating coatings, where the thickness of iron particle coatings has been reduced to a fraction of nanometers [8]. The technology of manufacturing powders of composite magnetically soft materials consisted in the reactive application of insulating coatings from the gas phase in a vacuum at a temperature of 150-200°C [9]. In this paper, we studied a low-frequency composite material based on ASC100.29 iron powder, with an average coating thickness based on phosphorus oxide d < 0.3-0.5 nm, marked in a work as SMC-LF.

Samples of the composite magnetic material were made by powder metallurgy method by pressing the prepared isolated iron powder with addition of zinc stearate in an amount of 0.25% of the total mass under pressure of 7-8 t/cm^2 and then were annealed by vacuum at a temperature of 400°C during 2 hours.

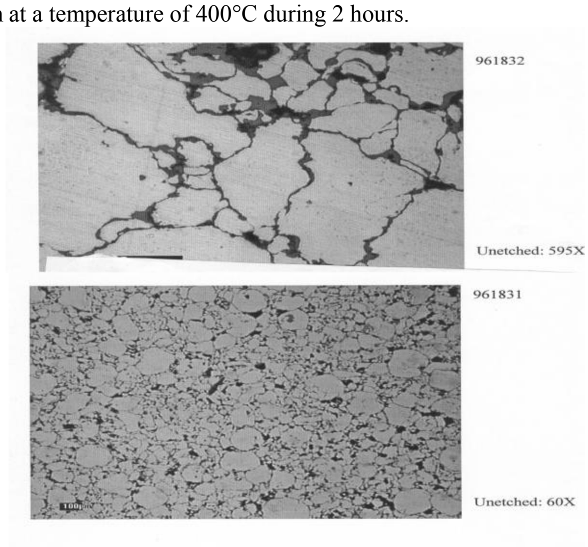

Fig. 1. *Results of metallographic study of the structure of the MDM-alloy*

Study of basic magnetic properties of composite magnetic materials using iron powders ASC100.29 (Hoganas) [10] is performed in comparison with the same parameters for electrical steel 3412 (Э320). With this purpose were made cores 24×13×10 mm from a set of tape drives electrically insulated steel and composite magnetic material of density ρ = 7.7 g/cm^3, were investigated the static, dynamic magnetic properties and hysteresis loss of the static characteristics were studied using microperimetry F5050, and dynamic performance and losses – by flaxmere and Express magnetometer in the frequency range up to 10 kHz and magnetic fields up to 30 kA/m.

3. Results and discussion

On Fig. 2 the static magnetization curves of a composite magnetic material based on iron powder ASC100.29 (curve 1) and electrical steel (curve 2) are given. The figure shows that the magnetic induction of the composite material in the fields up to

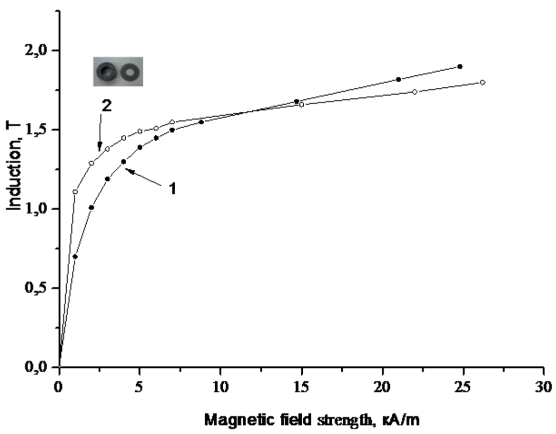

***Figure 2**. Curves of magnetization of the magnetic composite material based on powder ASC100.29 (curve 1) and on steel strip 3412(Э320) (curve 2)*

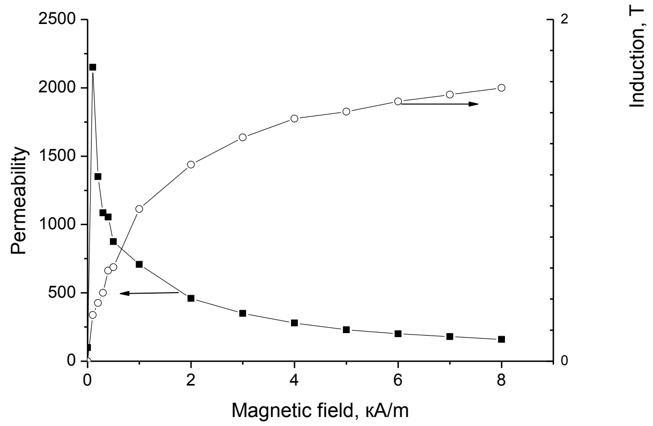

***Figure 3**. Magnetic permeability and magnetic induction depending on the field of composite magnetic material based on ASC100.29 powder*

H = 5 – 6 kA/m is inferior in value to the induction of electrical steel, and at higher fields it exceeds the parameters for electrical steel.

Magnetic induction at a strength H = 25 kA/m for a composite magnetic material is B_m = 1.95 – 2.0 Tesla, and for steel in the same field – B_m = 1.84 Tesla at the same density of samples ρ = 7.7 g/cm^3.

The initial magnetic permeability for the composite magnetic material is $\mu_м$ = 100-110, the magnetic permeability maximum is, respectively, μ_m = 2100-2300 (Fig. 3).

The dynamic reversal curves for a composite magnetic material at a frequency of 1 kHz are shown in Fig. 3 (curve 1). The induction of the composite material is higher than the induction of steel in the fields of large 5 – 6 kA/m.

In Fig. 4 is shown the dynamic curve of magnetization reversal at a frequency of 1 kHz in weak fields, from which it is possible to take the value of the coercive force of the composite material equal to H_c = 30 – 40 A/m.

The losses in steel increase quadratically with increasing magnetic induction. Losses in electrical steel are largely determined by eddy currents [4]:

$$P_c = (\pi B_m fh)^2 6\rho, \qquad (1)$$

where f – remagnetization frequency, h – grain size, ρ – resistivity, B_m – the magnetic induction.

At the same time in the composites losses on eddy currents are practically absent, only magnetic losses remain, which increase linearly with induction to the order of 1.5 Tesla. The losses in the composite material at a frequency of 1 kHz and induction b = 1.8 T are W = 120 W/kg, then for the steel under the same conditions the loss is 1.5 times higher W = 170 W/kg.

The iron particles have a size d > 100 mm and are multi-domain. Losses in the motion of the domain boundary occur when it is inhibited on defects in the structure and, first of all, on defects in induced anisotropy that occurs during uniaxial pressing of products. At high magnetic field values of order H = 15 – 20 kA/m the effect of anisotropy on the magnitude of the losses is affected to a lesser extent, and on the dependence of losses on the induction of the observed deviation from linearity with the transition to saturation.

Comparative data of the main characteristics of electrical steel 3412 (E320) and composite material SMC-LF based on iron powder ASC100.29 are summarized in table 1.

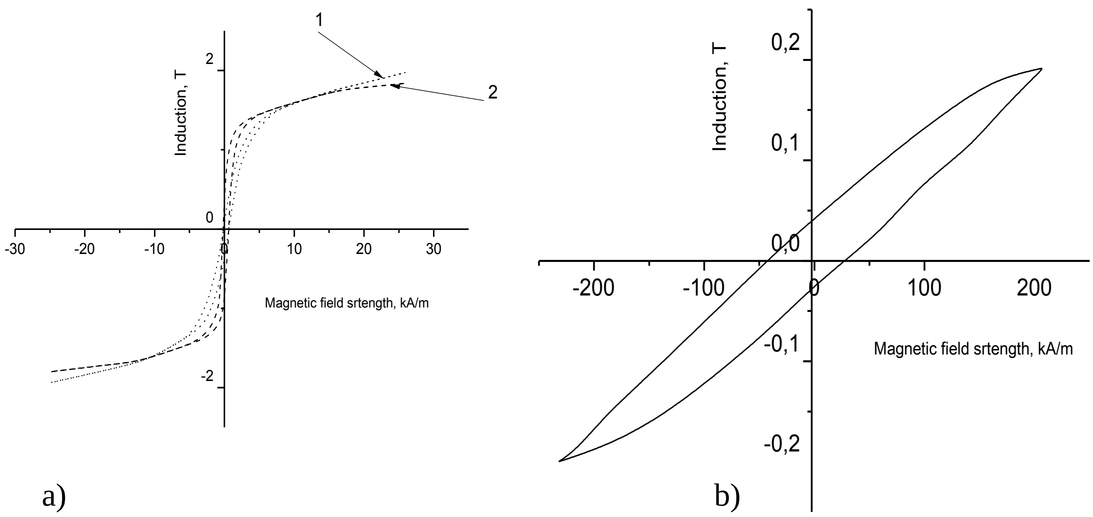

***Figure 4.** Dynamic hysteresis loops at the remagnetization frequency of 1 kHz: a-for composite material based on ASC100.29 (curve 1) and electrical steel 3412 (E320) (curve 2),*
b — for the composite material based on ASS100.29 in weak fields

Table 1. *Comparative data of the main characteristics of electrical steel 3412 (E320) and composite material SMC-LF based on iron powder ASC100.29*

Magnetic material	**Density, g/cm^3**	**HC, A/m**	**μм**	**B, T 10000 A/m**	**Losses, W/kg 1 T, 1000 Hz**	**Losses W/kg 1,75 T, 1000 Hz**
Steel 3412 0,35 mm	7,7	8 – 10	7000	1,59	100	170
SMC-LF	7,7	30 – 40	2000	1,59	60	110

Comparative studies of composite materials based on iron powders sprayed with air and water are carried out. For all selected iron powders the thickness of the phosphate insulation coating was 0.3-0.5 nm while maintaining identical conditions for their production. For example, an sprayed with air iron powder Laiwu Taidong Powder (China) significantly differs from water-sprayed ASC100.29 (Sweden) by the content of basic impurities such as manganese, carbon, phosphorus [10].

Table 2 shows the comparative data on losses for composite materials based on some iron powders, which shows the advantage of composite materials based on ASC100.29.

Table 2. *Comparative data on losses for composite materials based on iron powders*

Type of iron powder	**The relative losses in the field 2 kA/m**	**The relative losses in the field 10 kA/m**
PGR 2 (Russia)	1,33	1,27
LaiwuTaidon (China)	1,25	1,5
ASC100.29 (China)	1,01	1,12
ASC100.29 (Sweden)	1,06	1,17
ABC100.30 (Sweden)	1	1

4. Conclusion

As a result of the research it is shown that the magnetic induction of the developed composite material in the fields up to H = 5 – 6 kA/m is inferior in the induction value of electrical steel, and at higher fields it exceeds the parameters for electrical steel. Magnetic induction at a strength H = 25 kA / m for a composite magnetic material is B_m = 1,95-2,0 T, and for steel in the same field-B_m = 1,84 T at the same density of samples ρ = 7,7 g/cm^3

The advantages of the composite magnetic material over the electrical steel, first of all, is the reduction of remagnetization losses, for example at a frequency of 1 kHz and induction B =1,8 T with W=170 W/kg for steel to W=120 W/kg for the composite material, as well as the manufacturability of products, waste-free production, lower cost parameters, allow us to consider this material as an alternative product to metal magnets. In particular, the use of composite magnetically soft materials will have significant advantages due to lower losses in electrical machines, transformers and other products with increased specific power and high speed of rotation, where electrical steels have higher losses.

The study of remagnetization losses of composite materials showed that the hysteresis losses are 25 – 30% higher for composites based on iron powders sprayed with air (columns 1 and 2 of the table.2), compared with losses for composites based on powders, sprayed with water, such as the ASC100.29. First of all, this is due to the purity of the iron powder ASC100.29, for which the impurity content is less than 1.0%.

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5. Literature

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