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New Magnetic Materials and Their Application for Development of Prototype Mini-Electric Transport Components

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Abstract. A method has developed for obtaining soft magnetic materials based on ABC100.30 iron powder encapsulated by phosphides, which includes stages of powder preparation, pressing products of a given shape and sintering in air at a temperature of 870–900 ºC. The structure and morphology of the surface obtained composite materials have studied. The density value calculated from the X-ray diffraction data is about 3% higher than the directly measured values, which are 7.7 g/cm^3. The low porosity of the composites is confirmed by the SEM and EDX results. The results of magnetometric measurements and studies of the field dependences of the specific magnetization show that the synthesized composites based on ABC100.30 iron powder, the particles of which are encapsulated with phosphorus oxide, have the magnetic characteristics necessary for the manufacture of electrical components of electric motors.

INTRODUCTION

For the efficient operation of autonomous electrical devices, including electric vehicles, it is necessary to maintain a balance between the energy stored by the batteries and the power consumed by electric motors. Naturally, electromagnetic motors are used in electric vehicles, and in addition to traction motors, a large number of executive motors are used in rotation systems, control of scanning mirrors and cameras, climate comfort dampers, ergonomic positioning of seats, and so on. That is, for using in electric transport, a range of various engines is required, the energy costs of which will be appropriate and optimized in relation to the function performed.

The adopted programs for the development of electric transport in Belarus and Uzbekistan and the action strategy for the further development of the Republic of Uzbekistan for 2021-2025 define the development and the use of high-performance equipment, the creation and implementation of new technologies and production capacities, etc. With regard to electric motors, the scientific and technical task of developing new high-performance magnetic materials, the creation of motors of various sizes that will correspond to their functional purpose in the overall system of an electric vehicle. To achieve these indicators, it is important to improve technologies and create new technical means and their effective usage [3,4].

The results of development and research of magnetic materials and complex technology for constructing electric motors based on them [3,4] presented in the scientific literature are disparate and do not allow creating new approaches for their mass implementation. It is the integration, unification of sections of science and technology that will make it possible to develop the scientific foundations and the practical possibility of manufacturing and introducing engines for various purposes using powder magnetically soft materials in electric transport systems.

One of the methods for obtaining highly efficient materials for electrical applications is the encapsulation of particles of metal powders, for example, iron powders, with oxide coatings [3]. Known methods of encapsulation of iron powder with a thin oxide layer, namely mechanical deposition of the oxide layer, the formation of an oxide layer as a result of the decomposition of metal sulfates and nitrides, and the formation of an oxide layer from a gas oxide layer, create a poor-quality coating and are ineffective [6-8].

The proposed method of encapsulating iron powder with an oxide layer is a highly economical method that practically does not change the cost of the latter, and, from the standpoint of obtaining a given composition with given magnetic parameters and electrical resistivity, can be widely used in practice to obtain MDM alloys ("metal-dielectric- metal") with special magnetic and electrical properties [9].

Today, various electric vehicles for children have become widespread, designed for rent at playgrounds in parks, as well as for individual use. Entertainment in the form of riding children's electric cars has become popular with children of all ages. Most of the existing cars for children are imported, many of which are not sufficiently adapted to local climatic conditions, and some are obsolete. To solve the problem of manufacturing your own mini-electric transport, first of all, it is necessary to create and introduce into production the highest quality and safest machines based on new materials and new design solutions [10,11,12,13].

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Most children's electric cars have one or two motors. Models with one motor (power from 60 to 100 W) develop a maximum speed of up to 4.5 km / h. These vehicles are typically only able to climb up to 5% grade, so they can only be used on flat surfaces. All these characteristics make these models ideal for younger children.

Electric cars with two motors vary in power: from 140 to 170 W; from 170 to 240 W; and from 240 watts. Engines with a power of 140 to 170 W allow you to reach a maximum speed of up to 7.5 km / h and provide overcoming the climb angle up to 10%. Models equipped with motors from 170 to 240 W accelerate to 10 km/h, and electric vehicles with motors from 240 W are real SUVs, climbing up to 17%, with acceleration up to 17 km/h. These models can be used outside the city and on any uneven surfaces. Thus, electric transport for children does not require high engine power.

The purpose of this research is to obtain new composite materials for creating components of high-performance low-power electric motors and to study their structure and morphology.

MATERIALS AND METHODS

The coating technique included the stage of preliminary mixing of the initial ABC100.30 iron powder with a given amount of a reagent, which included an alcoholic solution of orthophosphoric acid in a ratio of 40%H_3PO_4 + 60% ethanol. At the next stage, the prepared powder was placed in a reactor for applying insulating coatings. The mixture was processed in a reaction drum at a pressure of 10^5 to 10^6 Pa, heated to a temperature of 150–200 ºC for 15–30 minutes. The manufacture of composites is carried out by hydrostatic pressing of encapsulated powders in manufactured molds under a pressure of 0.5–0.6 GPa under normal conditions. Compressed composites are subjected to heat treatment and normalization of physical parameters. Samples are annealed at a temperature of 400–450 ºC in special autoclaves, depending on the requirements [14,15,16,17,18].

The crystal structure of the composites was studied on a DRON-3 M diffractometer in CuK_α radiation in the angle range $20° \leq 2\theta \leq 90°$ at room temperature. The morphology and chemical composition of the powders were studied by scanning electron microscopy (SEM) using a Hitachi SEM, Zeiss microscope. Prior to the study, the surface of the composite was preliminarily ground and polished to remove the surface oxide layer.

Studies of magnetization of the initial ASC 100.30 iron powders and composites based on ASC 100.30 powders encapsulated with phosphorus oxide were carried out in the temperature range of 77–1100 K in a magnetic field of 0.86 T by the ponderomotive method. The field dependences of magnetization were studied using a vibrating magnetometer of the "Liquid Helium Free High Field Measurement System" (Cryogenic Ltd) at 300 K in a magnetic field up to 14 T [10,11,18].

RESULTS AND DISCUSSION

On figure 1. shows the X-ray diffraction pattern of the ABC100.30+P2O5 composite. The results of the analysis of the data obtained by the X-ray diffraction method showed that only one α-Fe phase of pure iron is present in the sample. The composite has a cubic unit cell with the space group $Im\bar{3}m$. The parameter is a ≈ 0.2867±0.0003 nm. In the region of small angles of 25–35°, an insignificant diffuse scattering is observed, which is inherent in the amorphous P_2O_5 phase. Based on the results of X-ray diffraction determination of the unit cell volume $V = a^3$, the theoretical density of composite materials was calculated. The calculated theoretical density value is approximately 3% higher than the density value obtained by direct measurement by hydrostatic weighing (7.7 g/cm^3). This is consistent with the fact that the press fill is about 95%. Such a difference in the density values is due to the low porosity of the synthesized composites.

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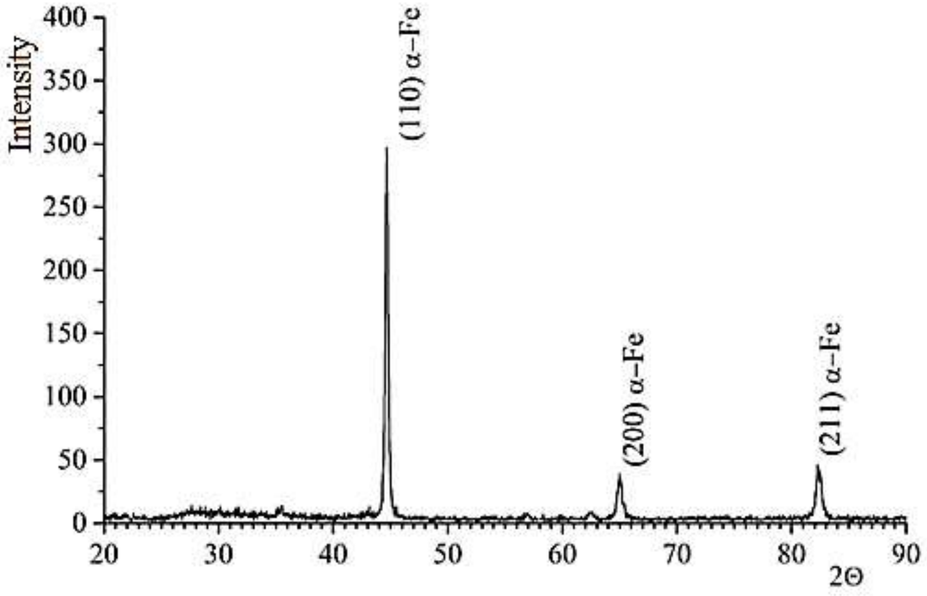

FIGURE 1. Experimental X-ray diffraction spectrum of a composite based on phosphide-encapsulated iron powder ABC100.30

The image of the surface of sintered composite is shown in figure 2. The figure clearly shows the grain boundaries of the composite consisting of encapsulated iron particles. The structure of the sample is dense with small inclusions of pores, which confirms the results of density studies.

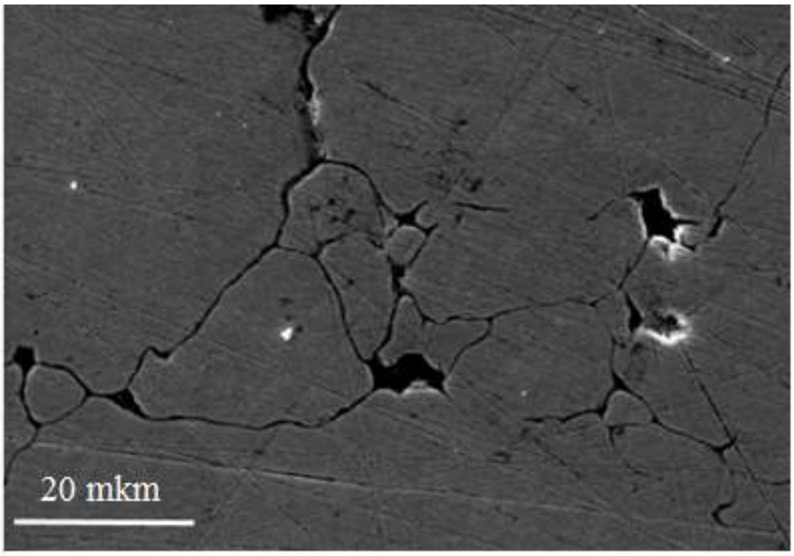

FIGURE2. SEM image of the surface of a composite based on phosphide-encapsulated iron powder ABC100.30

The results of chemical analysis by the method of energy dispersive X-ray (EDS) spectroscopy are shown in Figures 3 and 4, as well as in table 1.

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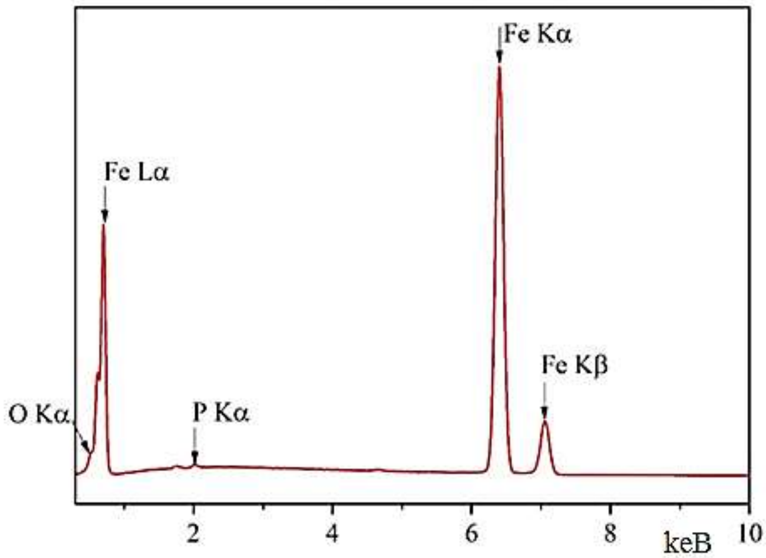

FIGURE 3. Spectrum of X-ray fluorescence analysis of the resulting composite

TABLE 1. The content of chemical elements in the sample

Chemical element	Weight, %	Atom, %
O	1.16	3.92
P	0.24	0.42
Fe	98.60	95.66
Total	100.00	100.00

The total EDS spectrum of the composite surface showed a complex composition consisting of the following chemical elements: iron (F), oxygen (O), phosphorus (P) (Fig. 4 and Table 1). The map of the distribution of elements showed that oxygen and phosphorus are distributed unevenly throughout the study area, but only along the boundaries of iron particles, where their increased concentration is observed. This proves the formation of a phosphide coating at the grain boundaries and its retention after pressing and annealing.

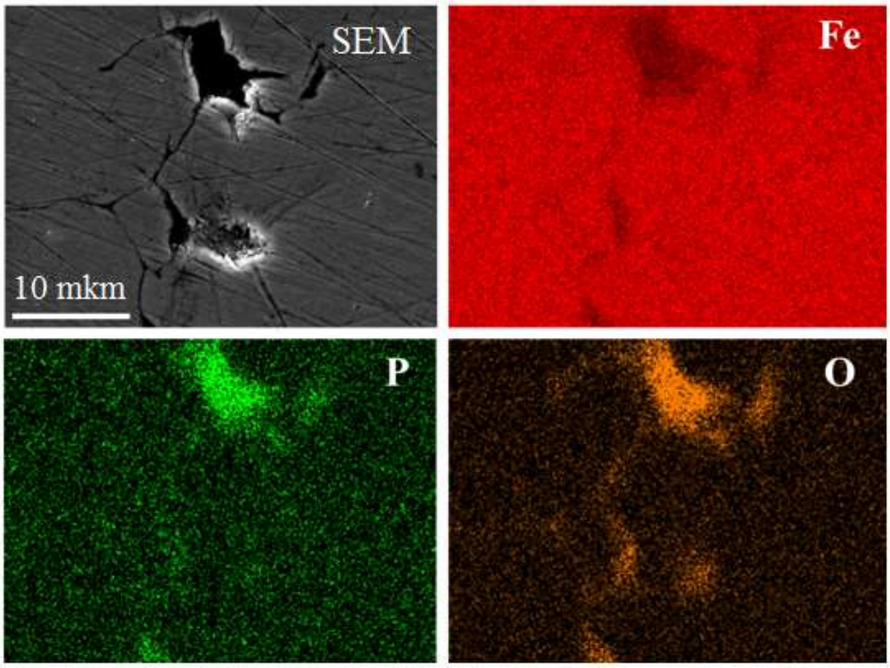

FIGURE4. Composite Chemical Element Distribution Maps

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On Figures 5 and 6 are shown the temperature dependences of the specific magnetization of initial ASC100.30 base powders and synthesized ASC100.30+P_2O_5 composites. At the temperature of liquid nitrogen, the value of the specific magnetization of the initial base powder is 216 $A \cdot m^2 \cdot kg^{-1}$ (Figure 5). The material is a ferromagnet, and the Curie temperature, determined from the maximum of the first derivative of the temperature dependence of magnetization ($\Delta\sigma/\Delta T$), is 1003 K. The magnetic moment of an iron atom in ABC100.30 powder at liquid nitrogen temperature is 2.16 μ_B.

From the analysis of the temperature dependences of the resulting powder composite (Figure 6), it was found that the deposition of the P_2O_5 oxide coating does not lead to change in magnetic characteristics within the measurement error. The value of the specific magnetization of the composite based on powder encapsulated by titanium oxide is 217 $A \cdot m^2 \cdot kg^{-1}$, and the Curie temperature is 1003 K. During temperature measurements in the cooling mode from 1060 K, in both cases (before and after encapsulation), a slight decrease in the specific magnetization value by ~ 10 $A \cdot m^2 \cdot kg^{-1}$ is observed, which can be explained by annealing of the samples during measurements.

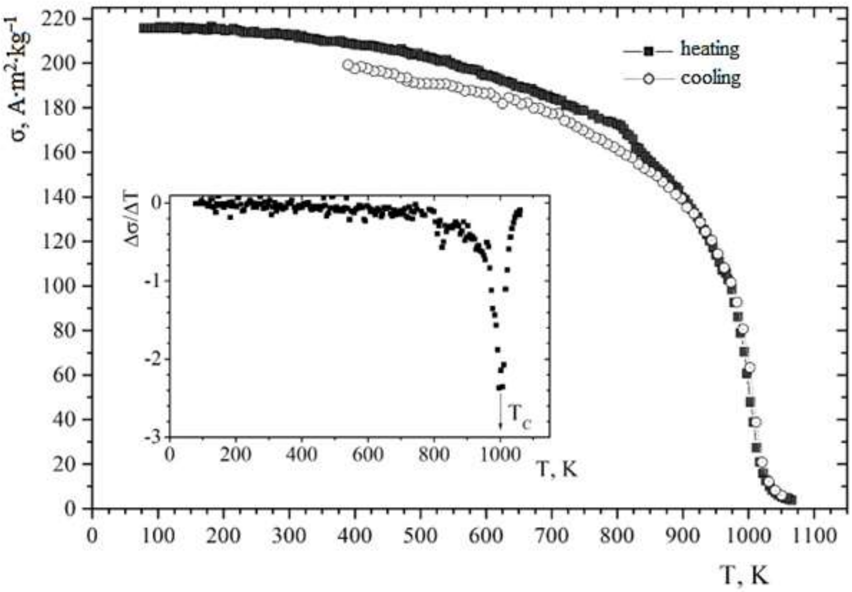

FIGURE5. Temperature dependences of the specific magnetization of the initial iron powder ABC100.30

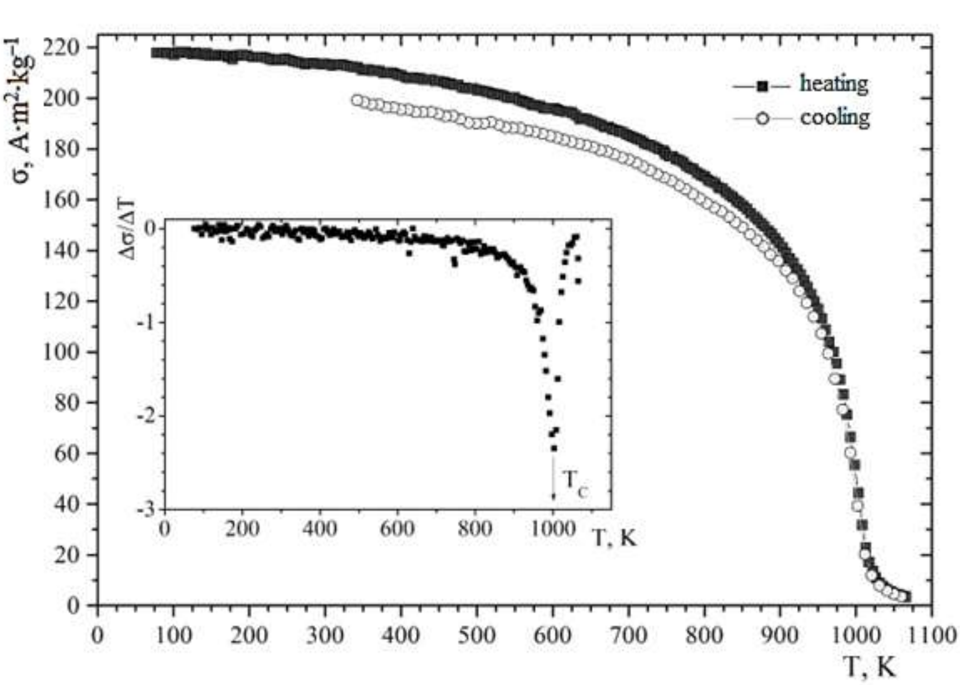

FIGURE6. Temperature dependences of the specific magnetization of the ASC100.30+ P_2O_5 powder composite

The results of magnetometric measurements are confirmed by studies of the field dependences of the specific magnetization at room temperature (Figures 7 and 8). The composite and base powder have a hysteresis loop characteristic of soft magnetic materials. The magnetization reaches saturation in low fields up to 1 T, and when the external magnetic field is removed, the spontaneous magnetization is practically zero.

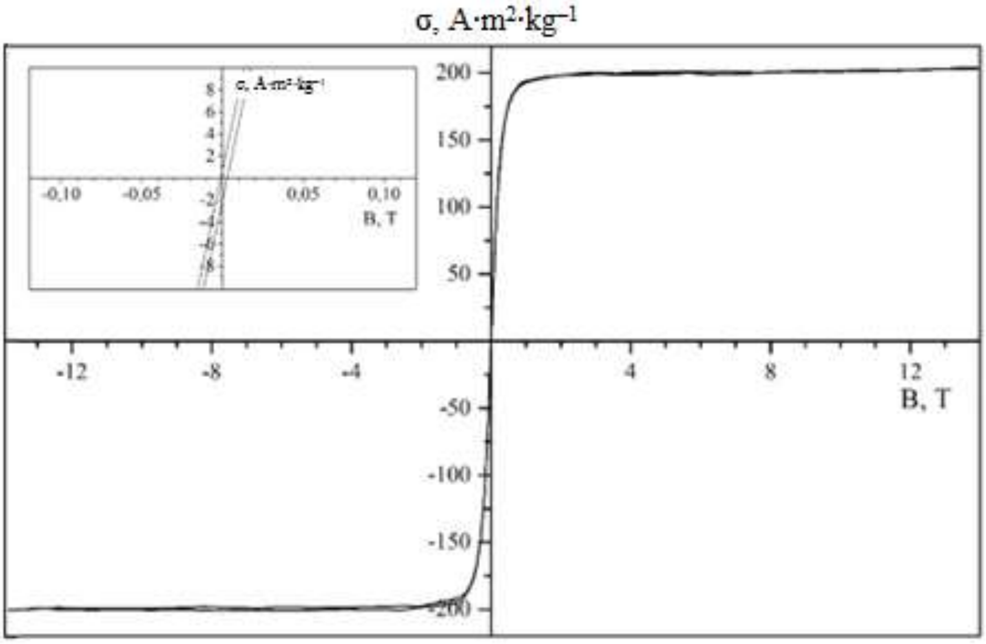

FIGURE7. Field dependences of the specific magnetization of the initial iron powder ABC100.30

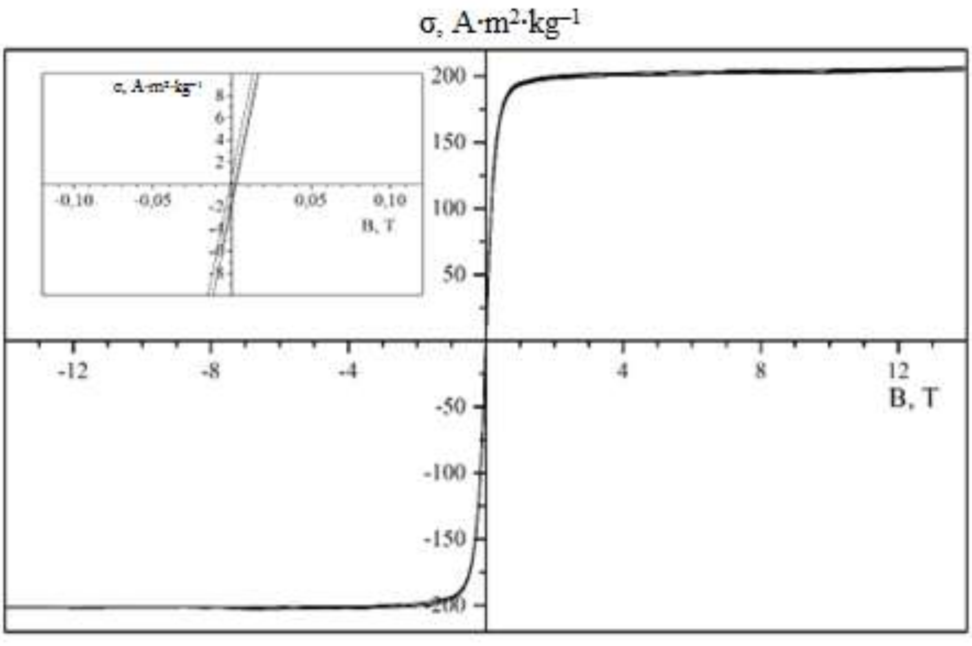

FIGURE8. Field dependences of the specific magnetization of the ASC100.30+ P_2O_5 powder composite

Thus, the synthesized composites based on ABC100.30 iron powder, the particles of which are encapsulated with phosphorus oxide, have the magnetic characteristics necessary for the manufacture of electrical components of electric motors.

CONCLUSION

A soft magnetic composite material with the required parameters was manufactured by encapsulating iron powder with a thin oxide layer based on P_2O_5. The structure and morphology of the surface of the obtained composite materials have been studied. The density value calculated from the X-ray diffraction data is about 3% higher than the directly measured values, which are 7.7 g/cm^3. The low porosity of the composites is confirmed by the SEM and EDX results.

The proposed method of encapsulation of iron powder with an oxide layer is a highly economical method for applying coatings of various chemical composition on metal powders, and can be widely used in practice to obtain electrical materials. Comprehensive studies of the properties of the obtained samples of powder composite materials based on ABC100.30 iron, the particles of which are encapsulated with phosphorus oxide, have been carried out.

It was found that the deposition of thin coatings did not change the magnetic characteristics of the initial iron powders, and therefore did not affect the exchange magnetic interaction. The value of specific magnetization at liquid nitrogen temperature is 216 A·m^2 kg^{-1} for pure powder and 217 A·m^2 kg^{-1} for composites based on iron powder encapsulated with phosphorus oxide. The temperature dependence $\sigma = f(T)$ is irreversible, which may indicate the annealing of the samples during measurements.

The composite and base powder have a hysteresis loop characteristic of soft magnetic materials, the magnetization reaches saturation in low fields up to 1 T. The synthesized composites based on ABC100.30 iron powder, the particles of which are encapsulated with phosphorus oxide, are magnetically soft materials with the characteristics necessary for the creation of electrical components.

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