DEPENDENCE OF THE MAGNETIC PROPERTIES OF Fe–Si AND Fe–P ALLOY POWDERS ON THEIR INTERPARTICLE SPACING

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Ferromagnetic powders constitute the principal raw material in the production of magnetic materials by powder metallurgy methods. Power losses in such materials can be reduced by providing them with dielectric interlayers between their particles. A knowledge of the magnetic characteristics of individual particles and particle assemblies representing a wide range of stacking densities will create a basis for the manufacture of parts of predetermined properties.

In the present work a study was made of iron and Fe–Si (2 and 6% Si) and Fe–P (1% P) alloy powders whose interparticle spacings were varied by the addition of a nonmagnetic filler. The alloy powders were prepared by diffusional impregnation of iron particles with silicon or phosphorus at a temperature of 800°C in a hydrogen atmosphere, involving the decomposition of salts containing silicon and phosphorus, respectively [1]. The mean alloy powder particle size was 50 μm. In the course of the investigation the particle packing was varied from very close (one-half the density of the solid material) to open, in which the spacing between adjacent particles was two to three times larger than their mean linear size.

A vibrating-sample magnetometer [2] was used for constructing curves of magnetization in solenoid (up to 70 kA/m) and electromagnet (1.6 kA/m) magnetic fields and for measuring residual magnetization intensity Jr and coercive force Hc. The specimens for these measurements were mixtures of ferromagnetic powders and a nonmagnetic filler, which were packed into Perspex vessels with inner cavities in the form of 8-mm-diameter, 4-mm-thick disks.
Fig. 1. Magnetization curves for close-packed particles: 1) Fe; 2) Fe–Si (2% Si); 3) Fe–P (1% P); 4) Fe–Si (6% Si).

Fig. 2. Magnetization curves for Fe–Si (2% Si) alloy with different particle packing densities. Ferromagnetic concentration: 1) 50; 2) 40; 3) 25; 4) 20; 5) 2.5; 6) 0.5%.

To ensure that results were not affected by possible segregation of the ferromagnetic particles during vibration and during the action of magnetic fields, comparisons were made of measurements of the magnetic characteristics of particles distributed in various media (metallic, with densities close to the density of iron, and nonmetallic). As fillers, copper, lead, niobium, paraffin wax, and epoxy resin were used. For all Fe–Si alloy particles distributed in the different media with a given packing density, results of measurements matched, which was indicative of uniform packing. Calculations showed that at a ferromagnetic concentration of 0.5% the distance between adjacent particles was more than three linear particle sizes.

To determine the effect of nature and concentration of an addition on magnetic properties, magnetization curves for the materials investigated were constructed using specimens with close-packed particles (50% of the vessel volume was occupied by a ferromagnetic and 50% by air interlayers between its particles) (Fig. 1). As can be seen from the figure, curves 2 and 3 — for the Fe–Si (2% Si) and Fe–P (1% P) alloys, respectively — fully coincide in the whole range of magnetizing fields. The saturation magnetization intensity $J_s$ for these alloys was 1700 kA/m, and for the iron powder 1720 kA/m; for the Fe–Si (6% Si) alloy particles $J_s = 1550$ kA/m (Table 1). For the particles of the alloys of low addition content the values of $H_c$ and $J_F$ were smaller than those for the iron particles. For the particles of the Fe–Si (6% Si) alloy the values of $H_c$ and $J_F$ were the same as for the iron particles.

As the iron powder had been annealed at 800°C in a hydrogen atmosphere, the iron and alloy particles were free from mechanical stresses, and any differences in their magnetic characteristics were linked with the nature of the alloying addition, its concentration, and character of distribution within the particles.

Microscopical examinations established that the mean inclusion diameter did not exceed 0.1 μm in the particles of low addition concentration (1-2%), but grew to 1-2 μm when the latter was raised to 6%.

Since the presence of inclusions in real ferromagnetics is a common phenomenon, their theory of magnetization is based on the uniformity of distribution of magnetization intensity [3]. A small inclusion (or cavity) does not alter the direction of spontaneous magnetism in the surrounding volume of ferromagnetic material when its linear size is not greater than the domain boundary thickness. For iron the domain boundary thickness is 0.1 μm. An inclusion of this size cannot form a secondary structure around itself, as this would increase the free

*Ferromagnetic concentrations are expressed in percentages of the relative volume of the vessel filled with close-packed particles.