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On the Correlation between Domain Size and Coercive Force in Grain-oriented 3.25 % Si-Fe

Abstract: A method is described for measuring the size of the largest spike-shaped magnetic domains on surfaces of grain-oriented 3.25% Si–Fe. Values of coercive force, obtained by using measured spike-domain size in a previously derived empirical expression correlating spike size with the coercive force in silicon-iron, are in close agreement with coercive force values obtained from *B–H* loop measurements. This technique makes it possible to measure the coercive force on non-toroidal magnetic components used in data processing machines.

Introduction

An inverse relationship reported by Pesch [1], between a domain size parameter measured at the base of the largest spike domains and the coercive force in demagnetized specimens of iron and 2.5% Si–Fe, has been used to correlate the largest spike domain size with the coercive force in grain-oriented 3.25% Si–Fe. This correlation makes it possible to determine the coercive force in small components for which the measurement of magnetic properties is not possible by electrical methods.

Experimental procedure

The materials used in this study were AISI M-5 and M-6 grade commercial grain-oriented 3.25% Si–Fe transformer sheet. M-5 has a thickness of 0.030 cm and M-6, 0.036 cm. Two batches of each material were cut into 3 cm × 30.5 cm Epstein strips, with 96 strips of M-5 and 88 of M-6 material per batch. One batch of each material was heat treated at 815°C for 2 hours in a vacuum of 10^{-6} Torr. The second batch of each material was heat treated at the same temperature for the same length of time in hydrogen. Both treatments produce near-optimum magnetic properties in these materials. The average grain size of each grade is about 1.5 mm. Magnetic tests were performed using an Epstein frame. Maximum induction in the dc *B–H* loop measurement was 19,000 G.

To measure the magnetic domain size, eight strips were randomly selected from each of the four batches of material. Two areas, each 2.7 cm^2, were electropolished on each strip by means of the technique developed by Morris [2]. One of the areas was near the center and the other near one end of the strip.

Domains were observed by the Bitter solution technique [3, 4]. The method for measuring the domain size is the same method as was used previously [1] on 2.5% Si–Fe; the spike domains to be measured were selected from those that exhibited a closed pointed end and a continuous observable curved boundary at the broad end.

The size of the measurement area from which we chose the largest domain was determined by observation. Area size had to be optimized to obtain a reasonable number of large domains and to minimize the standard deviation. Variables other than impurities and stresses, which affect the domain size and shape, are grain size and grain orientation [5]. After examining thirty 2.7-cm^2 areas, we concluded that there were less than eight well-shaped spike domains in each area. Four domain measurements were therefore considered adequate for an area. To avoid having all four measurements made on domains in one grain, the areas were divided into quadrants and the largest domain in each quadrant was measured. About one grain in every 32 was measured by this method. This limited measurements to grains larger than the average grain size and to grains with the [001] crystallographic direction within 2° of the surface [5].

Values of the four domain sizes from an area were averaged to give an S value [1] for each area. The two area values for each specimen were averaged to give an S value for each specimen, and the S values for the eight specimens were averaged to give an S value for the batch. Ninety-percent confidence limits were calculated from the last eight averaged values.

Results

Average S values with 90% confidence limits and coercive force values for each batch are listed in Table 1. Also shown in the table are the values for the coercive force

Table 1 Coercive force from *B–H* loop and from Eq. (1).

Material (AISI)	*Heat treatment atmosphere at 815°C*	*Domain size parameter S(cm × 10³)*	*H_c from B–H loop (Oe)*	*H_c from Eq. (1) (Oe)*
M-5	Vacuum (10^{-6} Torr)	7.90 ± 0.67	0.090	0.081
M-6	Vacuum (10^{-6} Torr)	7.90 ± 0.96	0.084	0.081
M-5	Hydrogen	7.30 ± 0.82	0.102	0.088
M-6	Hydrogen	6.99 ± 0.32	0.092	0.091

as calculated from the empirically derived expression [1] for 2.5% Si–Fe,

$$H_c = 6.4 \times 10^{-4}/S. \quad (1)$$

Values of H_c from the above relationship are in good agreement with the electrically measured coercive force.

Conclusions

A method is described for measuring the size of the largest spike domains in grain-oriented 3.25% Si–Fe. The correlation between spike size and coercive force which was found previously for iron and 2.5% Si–Fe is also found for grain-oriented silicon iron. Although good correlation has been found between spike domain size and coercive force over a range of compositions, a detailed model explaining the coercivity is yet to be developed.

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