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Magnetic Viscosity in Amorphous Alloys Showing Magnetically Soft Properties

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The phenomenon of magnetic viscosity can be observed when measuring losses on remagnetization. During magnetization of a ferromagnetic with alternating current, apart from the losses caused by magnetization and eddy currents, an additional component can be observed, which is referred to as additional losses. Such losses can be divided into two groups, i.e., strongly and weakly dependent on frequency and temperature. The paper presents tests of losses in the frequency range from 50 to 1000 Hz. Exact calculations of the share of additional losses caused by magnetic viscosity were made.

topics: magnetic viscosity bulk amorphous alloys, injection casting, total loss cores, additional losses

1. Introduction

Bulk amorphous alloys have been known for several dozen years [1, 2]. Initially, scientists encountered great difficulties in obtaining reproducible results when producing amorphous alloys. Many chemical compositions with high glass forming ability have been developed by trial and error. Only the works of A. Inoue systematized the process of producing bulk amorphous alloys. It was then that it was found that the alloy will have a good glass forming ability if it has a high viscosity [3, 4]. Most bulk amorphous alloys are characterized by excellent mechanical properties [5, 6] and corrosion resistance [7]. Amorphous alloys based on iron are additionally characterized by good soft magnetic properties [8, 9]. Due to the lack of long-range organization of atoms, these alloys are relatively easily magnetized. Moreover, due to the lack of a crystal structure, these materials can be used to build the cores of transformers operating at high frequencies. Amorphous alloys are characterized by losses on remagnetization comparable to conventionally used materials [10, 11].

Core losses are related to various physical phenomena occurring during the magnetization process: eddy currents, magnetic hysteresis or magnetic delays — in other words, magnetic viscosity [12].

In approximation, additional losses might be represented by the following formula

$$P_{\mathrm{exc}} = 8.76\sqrt{\sigma\, G\, S\, V_0}\,(B_{\mathrm{peak}}\, f)^{3/2}, \qquad (1)$$

where B_{peak} is the maximum value of induction, f — frequency, σ — electrical conductivity, G — dimensionless factor, S — cross-section area of a sample, and V_0 — constant associated with the impact of braking centers of domain walls.

The additional losses are related to the magnetic retardation — the so-called magnetic viscosity. This phenomenon is still poorly described, especially for bulk amorphous alloys.

The study investigated the phenomenon of magnetic viscosity occurring in alloys with an amorphous structure. Loss analysis was performed for frequencies from 50 to 1000 Hz. The correlation between the level of additional losses and the value of the maximum induction was investigated.

2. Materials and methods

The polycrystalline $Fe_{70}Y_5Nb_3Mo_2B_{20}$ alloy was produced in an arc furnace in an argon protective atmosphere from components of the following purity: Fe — 99.99%, Mo — 99.99%, Nb — 99.99%, Y — 99.95%, B — 99.95%. The charge was melted with a non-consumable tungsten electrode at the intensity of 180–300 A. The charge was melted before the titanium getter was melted. The process was repeated 5 times in order to obtain a homogeneous ingot structure. The charge was mechanically cleaned, divided into smaller pieces, and subjected to cleaning in an ultrasonic cleaner. The alloy prepared in this way was used to produce rapidly quenched samples. The alloy was made by the injection casting method. The charge was melted using eddy currents and forced into a water-cooled copper mold. The samples were made in the form of bars with a diameter of 1 mm and a length of 20 mm.

Loss curves as a function of maximum induction and magnetic permeability were measured using the Ferrometr measuring system. The alloy samples were placed in a yoke made of superpermalloy. Loss measurements were carried out at room temperature in the range 50–1000 Hz.

3. Results

Figure 1 shows the curves of permeability as a function of the amplitude of the magnetising field. The permeability curves show a maximum for the magnetizing field value of about 20 A/m, which corresponds to the maximum permeability. For the tested alloy it is about 6800. The magnetic permeability measured for the $Fe_{70}Y_5Nb_3Mo_2B_{20}$ alloy sample decreases with increasing frequency of the magnetizing field. The measured values are typical of amorphous alloys showing soft magnetic properties.

Figure 2 shows the loss curves as a function of maximum induction.

Losses measured for the tested alloy are comparable to those for materials used conventionally [10, 11]. The loss process is related to three factors. The first concerns eddy currents. They are formed during the induction of eddy currents due to the application of an external magnetic field. The induced field has the opposite direction to the applied one, therefore some of the energy is used to compensate for this phenomenon. For amorphous alloys, this component is less important than the losses associated with the magnetic hysteresis loop. The low conductivity of amorphous alloys significantly reduces the induction of eddy currents. This is due to the lack of ordering of the long-range atoms, and consequently, much lower conductivity of these materials. The losses from the hysteresis loop area have the greatest impact on the generation of losses. The irreversible remagnetization processes related to the centers that inhibit the movement of domain walls generate hysteresis loops. These components, in the case of amorphous alloys, are quite difficult to determine. In fact, the third component, namely additional losses, can be determined from the loss curves as a function of the square of the frequency. The analysis for the investigated alloy was carried out for various values of the maximum induction, and the results are presented in Fig. 3.

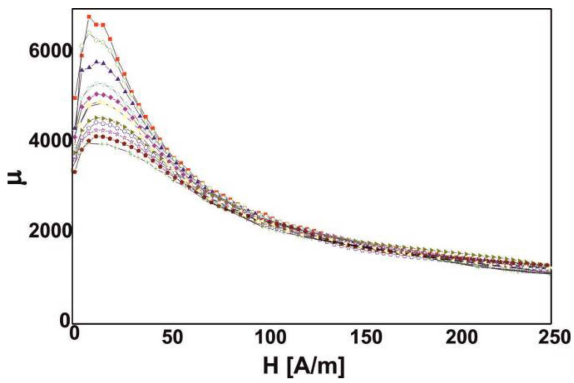

Fig. 1. Dependence of magnetic permeability on the amplitude of the magnetising field.

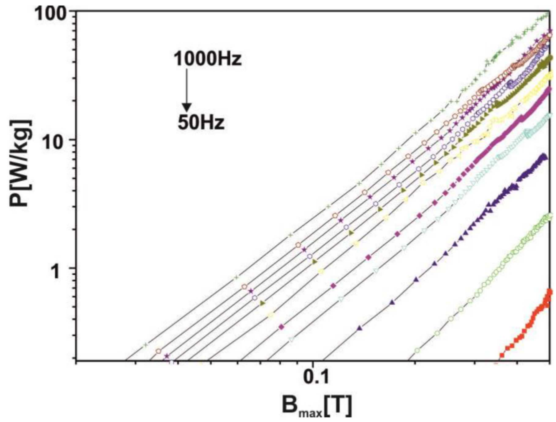

Fig. 2. Remagnetization losses as a function of the maximum induction for the produced alloy in the 50–1000 Hz frequency of the magnetizing field.

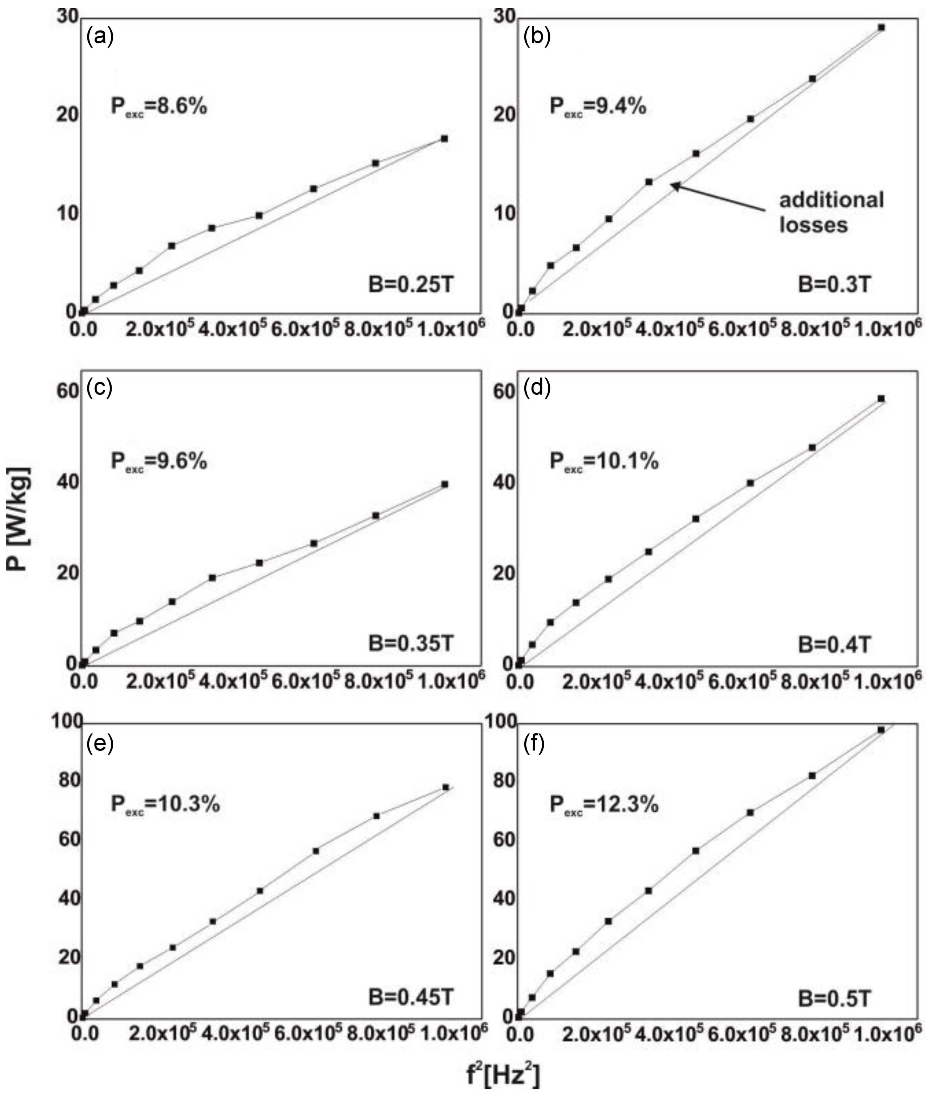

Fig. 3. Additional losses determined for $Fe_{70}Y_5Nb_3Mo_2B_{20}$ alloy for B_{peak} equal to: (a) 0.25, (b) 0.3, (c) 0.35, (d) 0.4, (e) 0.45, (f) 0.5 T.

The losses due to the magnetic hysteresis loop and eddy currents are a linear function of the square of the frequency. Part of the losses above the linear function are additional losses. Figure 3 presents the loss analysis for the maximum induction value from 0.25 to 0.5 T. The percentage share of additional losses was determined, ranging from 8.6 to 12.3% of the total losses. Therefore, when designing the cores, the presence of this component (additional losses) should be taken into account. As the maximum induction increases, the level of additional losses increases slightly. It is related to the metastable state of this material and fluctuations in its chemical composition. In the volume of the alloy there are areas with different concentrations of Fe atoms and with different degrees of packing structure. These inhomogeneities show up with different intensity depending on the applied magnetic field, and thus are indirectly related to the maximum induction.

4. Conclusions

Magnetic viscosity has a significant influence on the loss of magnetization in the case of alloys with an amorphous structure. The paper shows that with the increase of the maximum induction, the level of additional losses slightly increases. This proves the existence of differences in the phenomenon of remagnetization of these materials depending on the maximum value of induction. As the induction value increases, the magnetic delays have a greater influence on the level of total losses.

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