Remagnetization Core Losses In The Massive Amorphous FeCoYb Alloy

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In this paper were studied the influence of magnetic field frequency and induction on the total core power loss – which is divided into eddy current loss, hysteresis loss and anomally losses of the bulk amorphous alloy. The total core power loss of the investigated bulk amorphous alloy increases with magnetic field frequency and peak induction. It follows a power relation similar to what has been observed in classical ribbons. In the investigated alloy in addition to losses due to magnetic hysteresis and eddy currents, other additional losses are present. However additional losses, emerging simultaneously to the component associated with migration relaxations are very weakly dependent on the frequency and temperature.

Keywords: bulk amorphous alloy, the total power loss, hysteresis loop, eddy current loss

Massive amorphous alloys are characterized by unique magnetic and mechanical properties, that result from their structure [1-6]. With respect to the domain structure found in amorphous materials which is in general heterogeneous, there are four types of magnetization processes. In contrast to magnetic materials with crystalline structure, amorphous materials are characterized by a chemical disorder, topological and magnetic inhomogeneity and structural defects that are sources of stress. It is these local stresses play an important role in the process of magnetization and can be divided due to the extent of their impact: short and long range. It is known that described stresses are directly related to the arrangement of the atoms in the amorphous volume of the material. Therefore, amorphous materials should be first of all considered as the short-range ordering between atoms (SRO) [7- 9]. Due to the construction of the structure of amorphous materials and its nature the movement of the constituent atoms occurs stably, and diffusion distance can be adjusted by providing the corresponding portions of energy, typically as heat. As the results contained in scientific papers show, generally improvement of the properties of amorphous alloys is obtained by the heat treatment performed below the crystallization temperature [10-17]. It should be added that the shape of the magnetic hysteresis loop is strongly associated with the structure of the alloy and its heterogeneities. In the case of crystalline materials, point or linear defects are treated as an anomaly of the structure. In the amorphous material the atoms are arranged randomly and it is difficult to characterize the anomaly of such a structure. However, using the magnetic properties of these alloys, one can specify two types of defects: the free volume (point defects) and pseudo-dislocation dipoles (linear defects) [18-23]. These defects are the centers of internal stress and as a result of magnetoelastic interactions they cause the heterogeneous distribution of magnetization and have an impact on the coercivity field, initial permeability and saturation. The free movement of the domain walls in the amorphous materials is blocked, inter alia, under the influence of long-range stresses which are generated by a pseudo-dislocational dipoles. In the amorphous alloys there can also occure fluctuations of parameters such as local anisotropy or exchange interactions, which lead to the creation of additional braking centers of domain walls movement [24]. Domain walls are also blocked by structural relaxation responsible for magnetic delays. The other factor influencing the domain structure in amorphous materials is *free volume*. Centers which are blocking domain walls movement, present in amorphous alloys, are influencing the shape op magnetic hysteresis loops an on their parameters. One of the basic parameters describing the usefulness of magnetic material to be used, is the total core losses on remagnetization. The phenomenon of magnetic hysteresis is observed when in the material exist irreversible magnetization processes. In the case of magnetically soft amorphous transition metal alloys, this phenomenon occurs in the magnetic fields of the intensity of a few tenths of the value of coercive field [25].

According to the theory loss distribution [26, 27], total losses P_t von remagnetization in magnetic materials consist of three main components: hysteresis losses (P_{his}) eddy current loss (P_{cl}) and anomally losses (P_{exc}):

$$P_t = P_{\text{his}} + P_{\text{cl}} + P_{\text{exc}} \tag{1}$$

Magnetic hysteresis loss is defined as the surface area of the quasi-static hysteresis loop. These losses are a function of the thickness of the sample and are related to the irreversible remagnetization processes, which are influenced by inhibiting the movement of the domain walls blocking centers.

The second component of losses is related to the eddy current, generated during magnetization of the sample. These currents have a direction determined by Lenz's law and the field produced by them is in opposition to changes that produced them. Assuming a sinusoidal shape of the magnetic induction vs time and assuming that the thickness of the sample is d, eddy current losses can be described by the equation:

$$P_{\text{cl}} = \frac{\pi^2}{6} \sigma d^2 B_{\text{peak}}^2 f^2 \tag{2}$$

where:

σ- electrical conductivity;

B_{peak} - the maximum value of the induction;

f- frequency.

For amorphous materials contribution to the total losses from the component described as eddy current losses is

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much smaller. It should be noted that the resistivity of the amorphous materials is more than three times higher than that of crystalline materials of the same chemical composition, which shall significantly reduce eddy currents. Of course, the calculation of the total contribution of eddy currents is difficult due to their microscopic nature when moving the domain walls.

Additional losses can be expressed by the approximate formula [28]:

$$P_{exc} = 8{,}76\sqrt{\sigma GSV_0}B_{peak}^{3/2}f^{3/2} \qquad (3)$$

where:

G- dimensionless factor;

S- the cross-section area of the sample;

V_0- Constant associated with the impact of braking centers of the domain walls.

The additional losses, in addition to the component associated with migration relaxations, loss are very weakly dependent on the frequency and temperature. The first type of losses included in the additional losses could reach very high values, and the loss of the second kind are very weak and they are assigned to so-called. fluctuating viscosities.

Core losses of solid amorphous alloys also depend on the conditions of their preparation and heat treatment [29]. The paper presents the results of structural and core losses investigation for massive amorphous alloy $Fe_{64}Co_{10}Y_6B_{20}$ in as cast state.

Computational details

The investigated samples were made from components having a purity: Fe – 99.99% at, Co – 99.98% at, Y – 99.98% at. Boron was added as a $Fe_{56.4}B_{43.6}$ compound. Components of the alloy have been remelted in the arc furnace in the protection of argon. After the first melting an ingot was prepared, which was then remelted several times on each side. In addition before each remelting a piece of titanium was also melted to bound oxygene molecules from the chamber. The working current was set to 400 A. Ingots thus prepared were divided into smaller portions, which were placed into a quartz capillary and then have been remelted in an induction furnace. Rods for the research were prepared using the method of injection casting in a protective gas atmosphere. The resulting rods were examined by X-ray diffraction using Bruker D8 Advance. Diffactometer was equipped with CuKα tube. The samples were irradiated at an 2Θ angle ranging from 30 to 120° with an resolution 0.02° and exposure time 5 s/step. Powdered sample was used in this measurement.

Total core losses were measured in the frequency range from 50 Hz to 1000 Hz using transformer method. Measurements were made at room temperature. The rod samples were placed in the yoke made of super permalloy.

Results and discussions

Figure 1 shows the X-ray diffraction images of the samples in the form of a rod in a state after solidification.

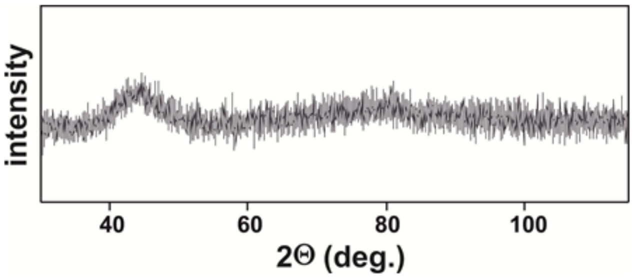

Fig. 1. X-ray patterns obtained for examined samples in the state after solidification

The X-ray diffraction patterns for investigated sample consist only of a broad peak, which is typical of amorphous materials.

In the magnetizing fields above about 0.4 H_c [30], during magnetization of alloy the existence of irreversible processes is observed and magnetic hysteresis loops are recorded (fig. 2).

The area of quasi-static hysteresis loop made from one full cycle is a measure of core losses. The shown histeresis loop is typical for the soft magnetic materials. In figure 3a the relationship between core losses and maximum induction of magnetizing field for amorphous $Fe_{64}Co_{10}Y_6B_{20}$ alloy, in as cast state is presented. The investigated sample has higher core losses than classic amorphous ribbons, which is related to its lower electric resistance. Lower electrical resistance value is related to thickness of the investigated material. This leads to higher losses on eddy currents [29]. Figure 3b shows the relation of core losses in the function of the square of the magnetizing field

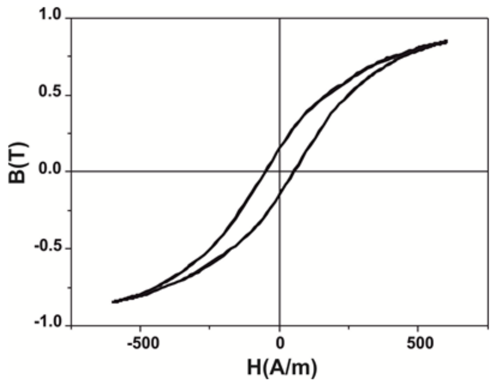

Fig. 2. Dynamic hysteresis loop for massive amorphous $Fe_{64}Co_{10}Y_6B_{20}$ alloy for the magnetic field frequency of 50Hz

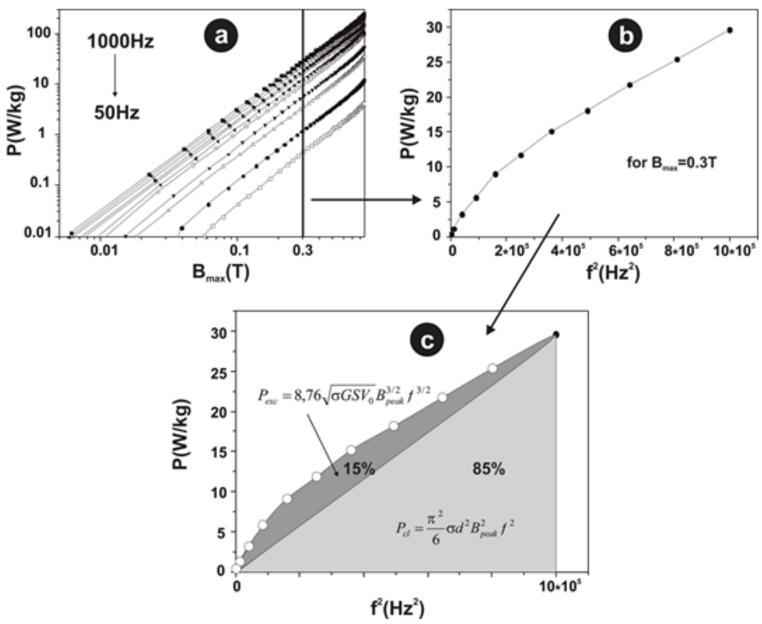

Fig. 3. Core losses in function of: maximum induction (a), frequency aquared (b, c) for massive $Fe_{64}Co_{10}Y_6B_{20}$ alloy

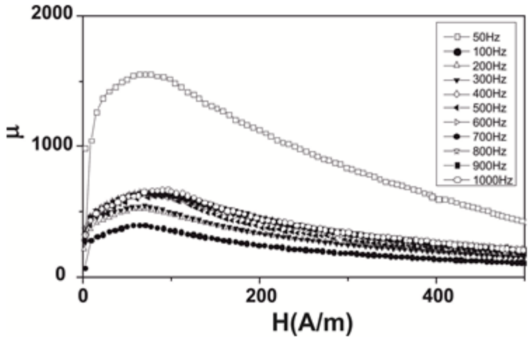

Fig. 4. Dependence of the magnetic susceptibility on the amplitude of the magnetic field, for $Fe_{64}Co_{10}Y_6B_{20}$ alloy

frequency, for a constant magnetic induction [27, 29, 31-35]. This relation is typical. The increase in core losses with the square of the magnetizing field frequency is consistent with the relation 2. It should be noted that the core losses are not linear function of the square of the magnetizing field frequency for a fixed value of magnetic induction. This shows that in addition to core losses from magnetic hysteresis and eddy current, also additional losses are present (P_{exc}) while magnetizing of alloy. Figure 3 c graphically depicts decomposition of core losses for the investigated alloy in the state after solidification.

The share of additional losses associated with the magnetic viscosity, small changes in temperature and changes in the frequency of measurement is quite significant and is about 15%.

Figure 4 shows dependence of the magnetic susceptibility on the amplitude of the magnetic field, measured at room temperature.

On the curves μ(H) the maximum which corresponds to the maximum permeability is visible [29, 35]. With further increase of the amplitude of the magnetizing field magnetic susceptibility decreases. It can be seen decrease in the maximum susceptibility while frequency of magnetizing field increases.

Conclusions

In the case of crystalline materials analysis of core losses allows for a close correlation between the domain structure and the losses due to the fact that the domain structure is determined by magnetocrystalline anisotropy. In the amorphous alloys there exist a very complex domain structure and loss analysis can only determine the relationship between microstructure of alloy and core losses.

In the amorphous alloys there is no such defects that can be observed in the crystalline materials, which leads to a small hysteresis loss. The cross section of amorphous samples is comparable with the crystalline samples, but they are characterized by large internal resistance, which leads to small eddy current [24, 28].

The results of investigation shows that during the magnetization process for $Fe_{64}Co_{10}Y_6B_{20}$ alloy in addition to the core losses and eddy currents also additional losses associated with migration relaxations occures. Those losses are 15% of total core losses for investigated alloy. It was also found that, that the value of total losses is comparable to the total losses which are observed for classic FeSi alloys. The maximum permeability of the investigated alloy is about 1500 for the 50 Hz frequency. However, detailed analysis revealed that low total losses for massive amorphous alloys are mainly associated with small eddy current losses [29].

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