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Influence of the Production Method on Magnetization Processes of the $Fe_{61}Co_{10}Y_8Mo_1B_{20}$ Bulk Amorphous Alloys

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The aim of this paper was to show the influence of the manufacturing method of bulk amorphous alloys on the resulting magnetization processes. Samples in the form of plates were prepared by the injection or suction of liquid alloy into a copper mould. In order to determine the type and quantity of structural defects present in the bulk amorphous alloys, the indirect method, i.e. the approach to the ferromagnetic saturation, was applied. Studies revealed the presence of conglomerates of point defects, for both alloys. These defects were pinning sites of domain walls and their number, size and type was found to have a direct impact on the coercive field. Alloy produced by the suction-casting method was found to possess the highest number of these defects, and thus a higher coercive field value.

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1. Introduction

There are many methods for producing bulk amorphous alloys [1, 2]. However, until now, the improvement of their magnetic properties has been achieved by minor changes in the alloy composition or through isothermal annealing [3-5]. The results of investigations carried out in this new work suggest that improvement of the properties of these materials could also be achieved by an appropriate production method.

Due to difficulty in describing structural changes in the amorphous materials, the indirect method is used. This method gives the possibility of identifying the structural defects playing the main part in the magnetization processes within strong magnetic fields [6-10].

In this paper, the analysis of the initial magnetization curve according to the H. Kronmüller theory is presented, as well as the type of the structural defects and their influence on the formation process of the magnetic properties, i.e. coercive field.

2. Material research

The samples of $Fe_{61}Co_{10}Y_8Mo_1B_{20}$ alloy used in the investigations were manufactured in the form of plates, using two different production methods: injection- (IC) and suction-casting (SC) of the liquid material into a water-cooled copper die. All elements used in the production process were of high purity ~ 99.99 at.%. The ingots of the base alloy were made in an arc-furnace under a protective gas atmosphere. Samples in the form of plates were made under these same manufacturing conditions irrespective of the used production method, in order to maintain similar range of cooling speeds. The structure of the resulting alloy samples was investigated by means of X-ray diffractometry (CuK_α), and the static hysteresis loops were taken using a vibrating sample magnetometer (VSM). The ingots of the base alloy were produced by arc-melting.

3. Results and discussion

In Fig. 1, X-ray diffraction patterns for the samples are presented; the patterns reveal only one, broad, maximum in each case. This pattern is typical for amorphous materials.

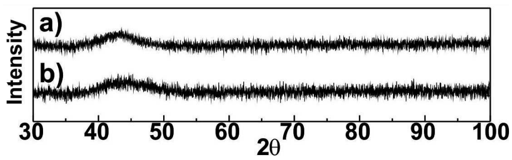

Fig. 1. X-ray diffraction patterns for the samples, in the form of plates, made using: injection-casting (a), suction-casting (b).

TABLE I

Magnetic parameters obtained from the analysis of the static hysteresis loops.

$Fe_{61}Co_{10}Y_8W_1B_{20}$	$\mu_0 M_S$ (T)	H_C (A/m)
Injection-casting	1.17	42
Suction-casting	1.20	113

The static hysteresis loops for samples of the $Fe_{61}Co_{10}Y_8Mo_1B_{20}$ alloy are presented in Fig. 2; soft magnetic properties are clearly indicated by these results. Magnetic parameters, such as saturation magnetization ($\mu_0 M_S$) and coercive field (H_C), obtained from the analysis of the static hysteresis loops, are gathered in Table I.

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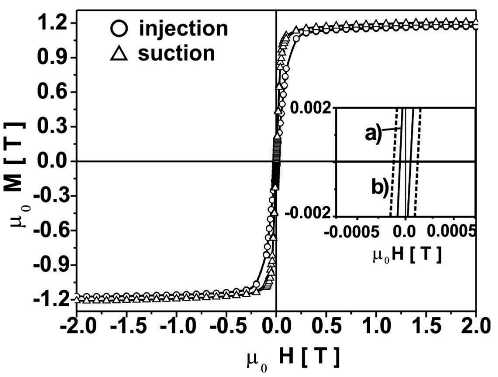

Fig. 2. Static hysteresis loops for the samples, in the form of plates, made using: injection-casting (a), suction-casting (b).

The influence of the structural defects existing in the samples on the magnetization process when approaching ferromagnetic saturation, according to H. Kronmüller theory [6–9], could be described by the following relationship:

$$\mu_0 M(H) = \mu_0 M_s \left[1 - \sum_i \frac{a_{1/2}}{(\mu_0 H)^i}\right] + b(\mu_0 H)^{1/2}, \quad (1)$$

where M_s – spontaneous magnetization, μ_0 – magnetic permeability of vacuum, H – magnetic field, a_i ($i = 1/2$, 1, 2) – gradient coefficients of the linear fit, depending on the type of defect (free-volume and linear defects) assigned in accordance with [5–12], b – gradient coefficient of the linear fit, related to thermal dumping of the spin-waves by the strong magnetic field. Results of the analysis of the initial magnetization curves (Fig. 3), according to (1), were found to indicate, that samples in the form of plates made by both suction- and injection-casting methods, obey the relationship of the approach to ferromagnetic saturation for $i = 1$, under the assumption $D_{dip} < l_h$ (where D_{dip} – the width of the quasidislocational dipole, l_h – exchange length) [6–9].

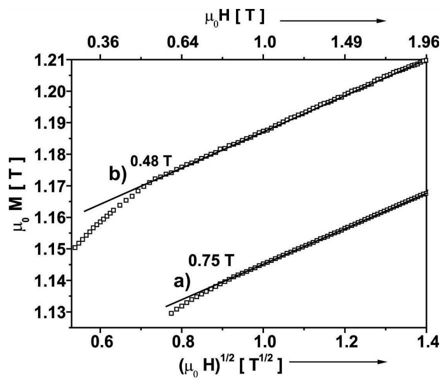

Fig. 3. Magnetization as a function of $(\mu_0 H)^{-1}$ and $(\mu_0 H)^{1/2}$.

This means that the main role in the magnetization process in the investigated area is played by linear defects, the so-called quasidislocational dipoles [7–9]. In stronger magnetic fields, where the domain structure vanishes, a further increase in the magnetization is caused by dumping of the thermally-excited spin-waves.

The parameters obtained from analysis of the initial magnetization curves are gathered together in Table II.

TABLE II

The parameters obtained from analysis of the initial magnetization curves: D_{sp} – spin-wave stiffness parameter, A_{ex} – exchange constant, l_h – exchange length, N_{dip} – surface density of the linear defects.

	b (10^{-2} $T^{1/2}$)	D_{sp} (10^{-2} meV nm^2)	A_{ex} (10^{-12} J m^{-1})	l_h (nm)	N_{dip} (10^{16} m^{-2})
IC	5.65	45.11	1.71	2.24	19.93
SC	5.72	44.74	1.75	2.77	13.03

4. Conclusions

It was found that both production methods facilitated the production of material exhibiting amorphous structure. The values of the saturation magnetization of both samples of the $Fe_{61}Co_{10}Y_8Mo_1B_{20}$ alloy in the form of plates, produced by the different methods, were found to be similar. However, the value of the coercive field H_C for the sample made by injection-casting was less than half than that of the sample made by suction-casting. This is connected with the smaller size of the defects in the form of the quasidislocational dipoles, described indirectly through the exchange length (l_h) in proportion to the size of the defects. The smaller size of the defects means a lower barrier for the movement of the magnetic domains within the volume of the material under the influence of the applied magnetic field and is the cause of the decrease in the value of the coercive field [9–12].

References

[1] N.M. Hong, N.H. Dan, N.X. Phuc, *J. Magn. Magn. Mater.* **242-245**, 847 (2002).

[2] H. Lee, W.T. Kim, D.H. Kim, Y.B. Kim, *Mater. Sci. Eng. A* **375-377**, 336 (2004).

[3] T. Kulik, *J. Non-Cryst. Solids* **287**, 145 (2001).

[4] A. Van Den Beukel, S. Radelaar, *Acta Metall.* **31**, 419 (1983).

[5] K. Sobczyk, J. Świerczek, J. Gondro, J. Zbroszczyk, W.H. Ciurzyńska, J. Olszewski, P. Brgiel, A. Łukiewska, J. Rzącki, M. Nabiałek, *J. Magn. Magn. Mater.* **324**, 540 (2012).

[6] H. Kronmüller, *J. Appl. Phys.* **52**, 1859 (1981).

[7] N. Lenge, H. Kronmüller, *Phys. Stat. Sol. A* **95**, 621 (1986).

[8] H. Kronmüller, *IEEE T. Magn.* **15**, 1218 (1979).

[9] M. Nabiałek, M. Dośpiał, M. Szota, P. Pietrusiewicz, *Mater. Sci. Forum.* **654-656**, 1074 (2010).

[10] M. Nabiałek, M. Szota, M. Dośpiał, P. Pietrusiewicz, S. Walters, *J. Magn. Magn. Mater.* **322**, 3377 (2010).

[11] A. Łukiewska, J. Zbroszczyk, M. Nabiałek, J. Olszewski, J. Świerczek, W. Ciurzyńska, K. Sobczyk, M. Dośpial, *Arch. Met. Mater.* **53**, 881 (2008).

[12] T. Bitoh, A. Makino, A. Inoue, *J. App. Phys.* **99**, 08F102 (2006).