MAGNETIC PROPERTIES OF ANNEALED $Fe_{85}B_{15}$ AMORPHOUS ALLOY

[*]Ladislav CENIGA, [**]Anna STANČÁKOVÁ
[*] Institute of Materials Research, Slovak Academy of Sciences,
Watsonova 47, 043 53 Košice, Slovak Republic, tel. 095/63 381 15, E-mail: ceniga@saske.sk
[**]Department of Physics, , Faculty of Electrical Engineering and Informatics,
Technical University of Košice, Komenského park 2, 042 00 Košice, tel. 095/602 3206, E-mail: Anna.Stancakova@tuke.sk

SUMMARY

The paper deals with microstructural changes of the as-cast and isothermally annealed $Fe_{85}B_{15}$ amorphous alloy, indirectly observed by measurements of microstructure-sensitive magnetic properties as the coercivity, the energy of total and stress induced anisotropy, the demagnetisation factor, and the Barkhausen noise parameters. The microstructural changes were observed in such temperature range within which the $Fe_{85}B_{15}$ amorphous alloy was characterized as a soft magnetic material.

Keywords: annealing, amorphous alloy, magnetism.

1. INDRODUCTION

An investigation of amorphous alloys has been performed for several years due to their excellent soft magnetic properties [1]-[3]. The magnetic properties are strongly influenced by internal stresses. The change of the internal stresses, as a consequence of an annealing process, can be indirectly observed by measurements of the microstructure-sensitive magnetic properties.

2. EXPERIMENTAL

Samples of the $Fe_{85}B_{15}$ amorphous alloy were prepared at the Research Institute of Solid State Physics and Optics in Budapest by the planar flow casting technique in a form of the 10 mm wide and 20 μm thick ribbons [4, 5]. The 150 mm long samples were isothermally annealed within the temperature range of 100-310°C in the argon protective atmosphere for 1 hour at the 5 deg/min cooling rate. The magnetic quantities and the Barkhausen noise parameters were measured at room temperature.

The measured magnetic quantities were: the whole quasi-static hysteresis and anhysteresis curves from which the coercivity, H_c, the total and stress induced anisotropy energy, K_i and K_σ, respectively, the total demagnetization factor, D, as a sum of the internal and geometrical demagnetization factors, D_i and D_g, respectively, were evaluated [6]-[8]. The parameters K_i and K_σ were determined from an area over the virgin and demagnetization curves, respectively. The parameter K_σ indirectly represents the value and the distribution of internal stresses [9]. The geometrical demagnetization factor, $D_g = 8.5\times10^{-5}$, was calculated from the sample geometry [9].

The measured Barkhausen noise parameters were: the intensity of the power spectrum, $S(f)$, the number and the total number of the Barkhausen pulses per a volume unit, n and N, respectively. The external magnetic field intensity for the Barkhausen noise measurement varied in the ±1000 Am^{-1} range. During the magnetization process along one branch of the hysteresis loop within the interval $\langle 0, +1000\rangle$ [Am^{-1}], the parameter n increased within the interval $\langle 0, N\rangle$, and then the parameter N represents the n value reached at 1000 Am^{-1} (Figs.1, 3) [6]-[8].

3. RESULTS AND DISCUSSION

The annealing process of amorphous alloys is usually connected with a relaxation process characterized by the internal stress decrease, and a crystallization process, which could be generally attributed to low and high annealing temperature, respectively [10, 11].

The internal stresses in the amorphous alloy, so-called the ‘frozen’ melt, are a consequence of the different density of atoms along the sample thickness. The different density results from the temperature gradient along the sample thickness during a casting process. The crystallization process in the amorphous alloy is preceded by a formation of regions of such chemical composition to be suitable for the crystallization of individual phases [10, 11]. Due to the $Fe_{85}B_{15}$ amorphous alloy composition corresponding to the eutectic point composition of the Fe-B binary diagram [Barabas], the regularly distributed regions enriched with the Fe and B-atoms are formed for the crystallization of the α-Fe and Fe_2B phases, respectively [12].

It may be then assumed that the low- and high-temperature annealing processes lead to the atom density homogenization, and consequently to the chemical heterogenization of the primary chemical-homogeneous ‘frozen’ melt, respectively. On the other hand, the chemical heterogenization of the amorphous alloys, originating during the high-temperature annealing process, causes the internal stress increase [10, 11].

The expressive influence of the relaxation process, observed within the temperature range of 100-240°C (Figs.1, 2), was a reason of the internal stress reduction, causing the concave decrease of the H_c, K_i, K_σ. The change of the concave course of H_c, K_i, K_σ to the convex one at about 240°C could indicate the presence of the regions of different chemical composition, suitable for the crystallization of the α-Fe and Fe_2B phases. As published in [13], the creation of the crystalline grains within the regions is reflected by the H_c, K_i rapid increase; as observed, in the case of the $Fe_{85}B_{15}$ amorphous alloy, at the temperature 310°C.

The difference K_i-K_σ within the temperature range of 100-300°C was constant and small, so it can be concluded that K_i originates K_σ. The increase of K_i at 310°C was a consequence of the magnetocrystalline anisotropy. On the other hand, the increase of K_σ at 310°C may be assumed to be caused by the presence of crystalline lattice defects, increasing the internal stresses. The values of H_c, K_i, K_σ at 310°C are 226 Am^{-1}, 486 Jm^{-3}, 208 Jm^{-3}, respectively [6]-[7].

Modifying the $Fe_{85}B_{15}$ amorphous microstructure by the annealing, D_g was unchanged so possible change of D would be only due to the D_i change. The factor D_i is represented by the demagnetising field due to magnetic inhomogeneities, e.g. nonmagnetic inclusions or clusters. The almost constant course of D within the temperature range of 100-300°C (Fig.2) may indicate the homogeneous distribution of the regions in the Fe-B amorphous alloy unlike the results in [7]. The increase of D at 310°C may be attributed to the magnetocrystalline anisotropy [6]-[7].

Fig.3 shows the course of n during the magnetization process for the as-cast and annealed states. It is evident that n was almost constant above 60 Am^{-1} of the external magnetic field intensity, H, so the contribution of domain walls irreversible motion to the total magnetization was then expressive in the range up to 60 Am^{-1}. The external magnetic field intensity was a linear function of time, so n was also time-dependent and then $\partial n / \partial t \propto dn / dH$ [6]-[7].

The intensity of the Barkhausen noise power spectrum, $S(f) \propto \partial n / \partial t$ (Fig.4), was always registered at the external field intensity equal to the sample coercivity. The inexpressive changes of the gradient of n at $H=H_c$ (Fig.3) were then responsible for the inexpressive changes of $S(f)$. The small shift of $S(f)$ towards lower frequencies by the annealing process corresponded to the shift of maximum and inflexion points of the courses of $S(f)$, ω_m and ω_i (Tab.1), respectively. The Barkhausen pulses of the annealed states are then characterized by longer duration [6]-[9]. The maximum and inflexion points from curves to fit the courses of $S(f)$ were in a good agreement with the relation $\omega_i = \omega_m \left(3 + \sqrt{5}\right) / 2$ [8].

The increase of N (Fig.1) was given by the decrease of the $\partial U / \partial x$ function barriers, which influence the domain wall motion, and are not influenced by the external magnetic field but by the internal stresses; where $U(x)$ is the energy depending on the microstructure, not on external magnetic field, and x indicates a domain wall position [9].

4. CONCLUSIONS

The results obtained from the investigation of the influence of the isothermal annealing process on the magnetic quantities and the Barkhausen noise parameters of the $Fe_{85}B_{15}$ amorphous alloy are as follows:

- the concave-convex decrease of H_c, K_i, K_σ during the isothermal annealing process within the temperature range of 100-300°C was a consequence of the amorphous microstructure relaxation of the expressive intensity within the temperature range of 100-240°C, causing the atom density homogenisation;
- along with the microstructural relaxation within the temperature range of 240-300°C, the convex decrease of H_c, K_i, K_σ was caused by the chemical heterogenization, represented by the formation of the regions of such chemical composition to be suitable for the crystallization of individual phases [6]-[8];
- the rapid increase of H_c, K_i, K_σ at the temperature 310°C was connected with the crystallization process, creating crystalline grains within the regions [6]-[8];
- regarding the sample states within the temperature range of 240-300°C, the small shift towards lower frequencies and the smaller slope of $S(f)$ were reflected by the shorter duration of the Barkhausen pulses and by the higher slope of their increasing part [6]-[8].

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BIOGRAPHY

Ladislav Ceniga was born on 1965. In 1988 and 1993 he graduated (MSc.) from the Faculty of Mechanical Engineering at Technical University in Košice, and the Faculty of Sciences (the Department of Physics of Solids) at the P.J.Šafarik University, respectively, both with distinction. He defended his PhD. in 1999 in the field of Physics of Solids at the Institute of Experimental Physics in Košice. Since 2000 he has been working at the Institute of Materials Research in Košice in magnetism of amorphous and crystalline alloys, and the continuum mechanics applied on composite materials.

Anna Stančáková was born on 1958. In 1981 he graduated (MSc.) from the Faculty of Sciences (the Department of Physics of Solids) at the P.J.Šafarik University. Since 1982 she has been working at the Department of Physics at the Technical University in Košice in magnetism of amorphous and crystalline alloys.

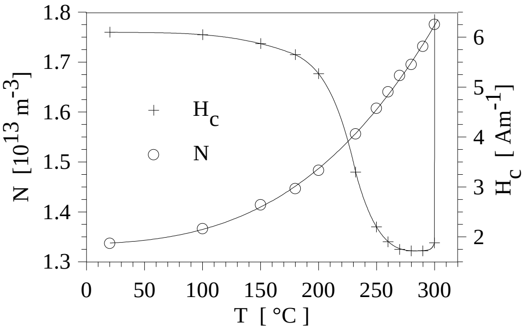

Fig.1 The coercivity, H_c, and the total number of the Barkhausen pulses per a volume unit, N, vs. the isothermal annealing temperature.

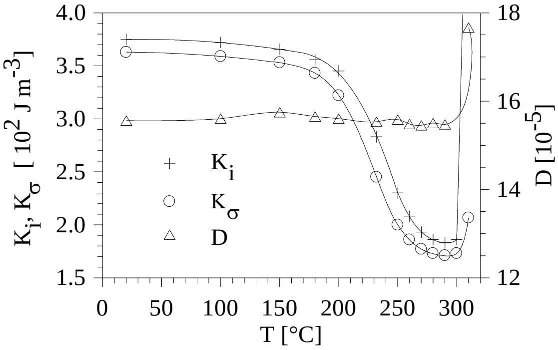

Fig.2 The total and stress induced anisotropy energy, K_i and K_σ, respectively, and the total demagnetizing factor, D, vs. the isothermal annealing temperature.

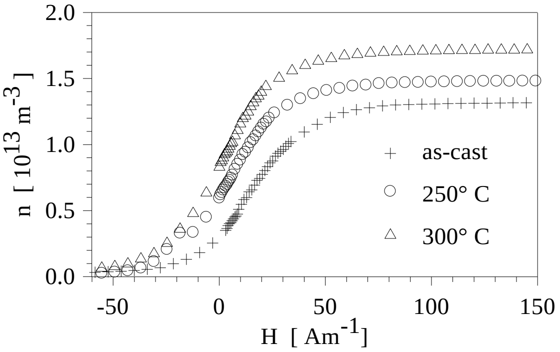

Fig.3 The number of Barkhausen pulses per a volume unit, n, for different annealing temperature vs. the external magnetic field intensity, H.

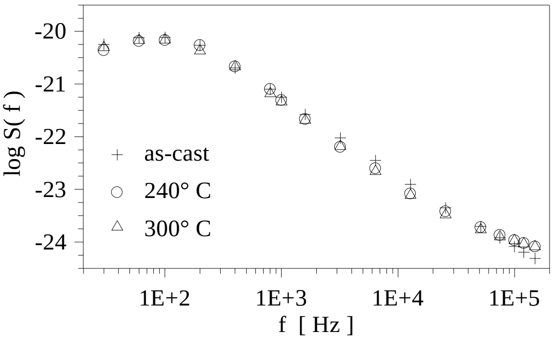

Fig.4 The Barkhausen noise power spectrum intensity, *S(f)*, for the as-cast and annealed samples.

$Fe_{85}B_{15}$	As-cast	240°C	300°C
ω_m [2πHz]	496	424	396
ω_i [2πHz]	1320	1132	1025

Tab.1 The maximum and inflexion points of the intensity of the Barkhausen noise power spectrum, ω_m and ω_i, respectively, for the as-cast and annealed samples.