acta phys. slov. 35 (1985), No. 4—5

SOME MAGNETIC PROPERTIES AND MAGNETIC AFTER-EFFECT IN AMORPHOUS $Fe_{80}T_3B_{17}$ ALLOYS[1])

L. POTOCKÝ[2]), P. VOJTANÍK[2]), Košice
É. KISDI-KOSZÓ[3]), A. LOVAS[3]), Budapest

In the paper presented the coercive force, the initial susceptibility, the critical field of the perminvar effect and the magnetic after-effect in the quasi-binary $Fe_{80}T_3B_{17}$ (T = Fe, V, Cr, Mn, Co, W. Pt) alloys have been investigated. The obtained results are explained in relation to the mechanism of the coercive force and to the mobility of the domain walls in the amorphous soft magnetic materials. The magnetic after-effect in the given alloys is discussed in relation to the free volume.

НЕКОТОРЫЕ МАГНИТНЫЕ СВОЙСТВА И МАГНИТНОЕ ПОСЛЕДЕЙСТВИЕ В АМОРФНЫХ СПЛАВАХ $Fe_{80}T_3B_{17}$

В работе приводятся результаты исследований коэрцитивной силы, начальной магнитной восприимчивости, критического поля перминварного эффекта и магнитного последействия в квазибинарных аморфных сплавах типа $Fe_{80}T_3B_{17}$ (T = Ee, V, Cr, Mn, Co, W, Pt). Полученные результаты объяснены на основе механизма коэрцитивной силы и подвижности границ домена в аморфных мягких магнито материалах. Обсуждается магнитное последействие в данных сплавах на основе свободного объема.

I. INTRODUCTION

The practical applications of the amorphous ferromagnets are determined by the stability of their magnetic properties. Therefore it is topical to investigate how to obtain the time and temperature stability of the magnetic parameters of these materials. It was shown in [1—4] that many magnetic properties of the Fe-B amorphous alloys vary by the substitution of iron by a relatively small amount of the transition metal. With regard to this we studied the initial magnetic susceptibility, the coercive force, the critical field of the perminvar effect and the temperature — time dependence of the magnetic reluctance of the quasi-binary iron — transition metal — boron amorphous alloys.

[1]) Contribution presented at the 7th Converence on Magnetism, KOŠICE, June 5—8, 1984.
[2]) Faculty of Science, P. J. Šafárik University, Februárového víťazstva 9, 041 54 KOŠICE, Czechoslovakia.
[3]) Central Research Institute for Physics, Hung. Acad. Sci., 1525 — BUDAPEST, Hungary.

II. SAMPLES AND EXPERIMENTAL METHOD

Experiments were made on amorphous $Fe_{80}T_3B_{17}$ (T = Fe, V, Cr, Mn, Co, W, Pt) samples prepared in the form of thin ribbons by rapid quenching from the melt. The measurements were carried out on as-cast samples and after their annealing at a temperature of $T=0.8\ T_C$ (T_C = Curie temperature) for 12 hours. This treatment removed to a great extent the strain-magnetostriction anisotropy in the samples, introduced during their preparation [3].

Magnetic susceptibility was measured at 0.1 A/m and 970 Hz using a mutual inductance bridge with a photoelectric temperature controller (for the temperature range 300—450 K) and with a system for automatic demagnetization [5, 6]. The magnetic after-effect was quantitatively estimated by a relative quantity $\Delta r/r\ (T)=[r(t=1800\ \mathrm{s})\ -\ r(t=30\ \mathrm{s})]/r(t=30\ \mathrm{s})$, where r is the magnetic reluctance ($r=\chi^{-1}$, χ = magnetic susceptibility); the reluctance was measured at 30 s ($r_{(t=30\ s)}=\chi_{30}^{-1}$), resp. 1800 s ($r_{(t=1800\ s)}=\chi_{1800}^{-1}$) after demagnetization at a constant temperature (T = absolute temperature). The temperature dependence of this quantity (relaxation spectrum) gives some information on the distribution of the activation parameters of the magnetic after-effect. The coercive force was measured by an electronic fluxmeter.

III. RESULTS AND THEIR DISCUSSION

Table 1 shows the obtained results. It follows from them, above all, that the substitution of iron in the Fe-B alloy by a transition metal has a significant influence on the investigated magnetic parameters and on the magnetic after-effect. In all as-cast alloys (except for the alloy with Pt) a decrease of the coercive force (H_c) in comparison with that of the binary Fe-B alloy may be observed. The initial susceptibility (χ_{30}) is in all cases larger and the critical field of the perminvar effect (H_{cr}) is in all cases lower than the corresponding values for the binary Fe-B. The undercritical annealing produces various changes of the coercive force and of the initial susceptibility. While in alloys with Fe and V a decrease of the coercive force and in alloys with Fe, V and Co an increase of the initial susceptibility may be observed, alloying by Cr, Mn, Co, W and Pt leads to an increase of the coercive force and in alloys with Mn, W to a decrease of the initial susceptibility; in alloys with Cr and Pt such an annealing has no apparent influence on the initial susceptibility. Such complicated dependences of the magnetic properties of iron-boron alloys on the additional transitional metal and on the undercritical annealing result from the influence of various microphysical parameters. If we suppose that for the coercive force in the amorphous soft ferromagnets the irreversible displacements of the domain walls are responsible [7], then the explanation of the coercive force may be found in the influence of the added

transition metals and/or of the heat treatment on the ferromagnetic exchange, the total anisotropy (including the strain-magnetostrictive anisotropy introduced into the alloy during its preparation), the magnetic moment resp. saturation magnetic polarization, the sample geometry (mainly for correlation between thickness and the used parameters of preparation); of course, other factors may also play an important role, including the state of sample surface (surface roughness), the

Table 1

Influence of annealing $T_a=0.8\ T_c$, $t_a=12$ h, on coercive force H_c, critical field H_{cr}, measure of magnetic relaxations $\Delta r/r_{30}$ and initial susceptibility χ_{30} for amorphous $Fe_{80}T_3B_{17}$ alloys (T = Fe, V, Cr, Mn, Co, W, Pt)

$Fe_{80}T_3B_{17}$	As-cast				Annealed			
	H_c [Am^{-1}]	H_{cr} [Am^{-1}]	$\Delta r/r_{30}$ [%]	χ_{30} [m^3kg^{-1}]	H_c [Am^{-1}]	H_{cr} [Am^{-1}]	$\Delta r/r_{30}$ [%]	χ_{30} [m^3kg^{-1}]
T = Fe	23.7	7.7	19	0.07	13.5	0.7	11.7	0.163
V	10	1.05	14	0.125	5.7	0.4	12.3	0.195
Cr	3.7	1.15	10.6	0.255	9.5	0.6	8.1	0.254
Mn	7.5	1.7	12.4	0.196	13.1	1.1	14.7	0.120
Co	12.5	5.5	16.9	0.105	25	1.2	6.4	0.214
W	2.2	1.7	14.1	0.229	8.5	0.6	10.1	0.157
Pt	49	6.3	10.5	0.088	78	2.8	2.8	0.089

microstructural state of the alloy including the structural and chemical inhomogeneities, the micromagnetic properties including the anisotropy fluctuations and others. These factors influence -in a specific way- the magnetic quantities. We expect that the decrease of the coercive force could be connected with the increase of the initial susceptibility and vice versa. However, such a behaviour is observed only in as-cast samples (the alloy with Pt is an exception); in samples subjected to undercritical annealing the connection between the measured initial susceptibility and the coercive force is complicated in some cases (alloys with Cr, Co, Pt). This may be connected with the complex influence of the microphysical parameters on the domain structure of the alloys and its dynamics. The corresponding differences are given by energetic disturbance connected with the formation of domain walls and by the character of obstacles hindering the displacement of domain walls during the sample magnetization. All this evidently depends on the type of the added transition metal and/or on the heat treatment. It should also be noted that the value of χ_{30} was measured 30 s after the demagnetization of the sample and so it reflects also the corresponding magnetic after-effect. The influence of the total anisotropy, of the ferromagnetic exchange and of the saturation magnetic polarization on the coercive force is evident in some investigated alloys. It is known, for example, that the presence of Co and Pt in the given alloys apparantly increases the Curie temperature and thus also the exchange constant [4] in comparison with the binary $Fe_{83}B_{17}$; also the anisotropy in both as-cast and after annealing states is higher [3]. Addition of Pt causes only a little increase of the saturation magnetic polarization, but the addition of Co has an about ten-times larger effect on this increase. This is manifested by substantially larger values of the coercive force for

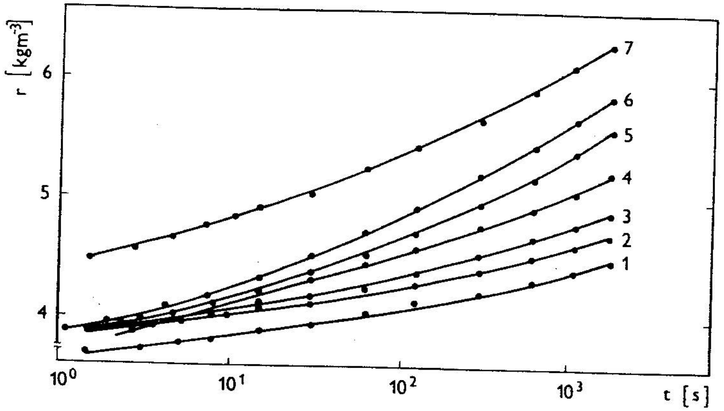

Fig. 1. Time increase of magnetic reluctance in annealed $Fe_{80}Cr_3B_{17}$ amorphous alloy. Curve 1 — $T=360$ K; 2 — 375 K; 3 — 390 K; 4 — 405 K; 5 — 420 K; 6 — 435; 7 — 450 K.

the $Fe_{80}Pt_3B_{17}$ alloy in the as-cast state as well as after annealing and for the $Fe_{80}Co_3B_{17}$ alloy in the annealed state in comparison with the binary $Fe_{83}B_{17}$. In the $Fe_{80}W_3B_{17}$ as-cast alloy the presence of tungsten causes the decrease of the coercive force and the increase of the initial susceptibility; the decrease of the coercive force in the annealed state is not accompanied by the increase of the initial susceptibility. According to [4] such a content of tungsten decreases the exchange constant but increases anisotropy [3] and significantly lowers the saturation magnetic polarization (by more than 50 %). The observed significant decrease of the coercive force, resp. increase of permeability, may be therefore regarded as unexpected. It should be noted that in all alloys the strain-magnetostriction anisotropy is present, which may be significantly lowered by an undercritical annealing. On the other hand, however, such an annealing leads to changes in the character of both material inhomogeneities and the free volume and eventually to the formation of clusters. These changes depend on the physical and chemical properties of the added transition metal.

It follows from the given results that in iron-boron alloys the influence of iron substitution by a transitional metal on the mobility of domain walls may be

expected and this is manifest in the magnetic after-effect. On all the annealed samples the time dependence of the reluctance at various constant temperatures was investigated as well. It was found that in the temperature range from 300—450 K the logarithmic time dependence of reluctivity $r=r_1+\dot{r}\ln t$ [5] is not always valid ($\dot{r}$ is the change of r between the times t_1 and t_2, for which $\ln t_2/t_1=1$). Fig. 1 shows the dependences obtained on the $Fe_{80}Cr_3B_{17}$ samples. Fig. 2 shows the

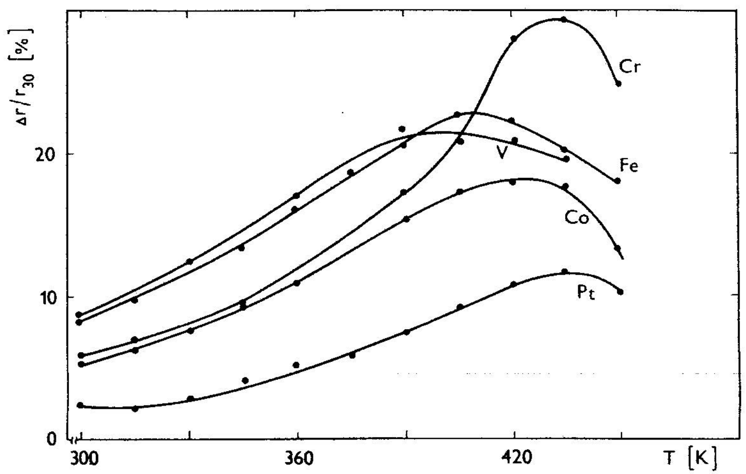

Fig. 2. Relaxation spectra $\Delta r/r_{30}(T)=\dfrac{r(t_2=1800\ \text{s})-r(t_1=30\ \text{s})}{r(t_1=30\ \text{s})}$ for selected amorphous $Fe_{80}T_3B_{17}$ alloys (T = Fe, V, Cr, Co. Pt).

relaxation spectra for alloys with V, Cr, Co, Pt in comparison with the spectrum for the binary $Fe_{83}B_{17}$ alloy. As it is seen, by the addition of the transition metal the value of the maximum in the relaxation spectrum is changed. In almost all cases this maximum is lower than that for the binary Fe-B. This may be connected with the supposed decrease of the free volume in the alloy; the alloy with Cr is an exception, showing an increase of the maximum of the relaxation spectrum. It should be also noted that the density of the binary Fe-B alloy is not changed when the iron is substituted by chromium [8]. It may also be supposed that depending on the added metal the free volume will play a greater or a smaller role in the magnetic after-effect and it should be also accepted that this after-effect is controlled also by other mechanisms. In some cases the free volume may play a decisive role. In all the investigated alloys (except for the alloy with Mn) the undercritical annealing is manifested by an apparent decrease of the rate of the magnetic after-effect. This supports the conception of the connection of the magnetic after-effect with the free volume, which also decreases due to the structural relaxation. It is also evident from Fig. 2 that the temperature corresponding to the maximum of the relaxation spectrum depends on the type of the added transition element. An increase of this temperature gives evidence of the broadening of the continuous activation energies spectra towards the higher values and is typical for alloys except for the alloy containing V. In this alloy the average value of the activation energies is decreased. All this gives evidence of the complex influence of the added transition metal on the magnetic properties of the Fe-B amorphous alloys.

REFERENCES

[1] Lovas, A., Potocký, L., Novák, L., Kisdi-oszó, É., zámbó-Balla, K.: *Proc. Conf. on Metallic Glasses: Science and Technology*, Vol. 2, Budapest 1980.
[2] Kisdi-oszó, É., Lovas, A., Vojtaník, P., Boškovičová, M., Potocký, L.: J. Magn. Magn. Mater. *26* (1982), 121.
[3] Novák, L., Potocký, L., Uličiansky, S., Kisdi-oszó, É., Lovas, A., Takács, J.: J. Magn. Magn. Mater. *26* (1981), 118.
[4] Potocký, L., Daniel-Szabó, J., Kováč, J., Kisdi-oszó, É., Lovas, A., Zámbó-Balla, K.: J. Magn. Magn. Mater. *41* (1984), 125.
[5] Vojtaník, P., Kekalo, I. B.: Phys. Stat. Sol. (a) *60* (1980), K 45.
[6] Vojtaník, P., Kekalo, I. B.: Acta Phys. Slov. *31* (1981), 113.
[7] Luborsky, F. E.: *Amorphous Ferromagntes*, in *Ferromagnetic Materials*, Vol. *1*, Ed. by E. P. Wohlfarth, North-Holland Publ. Comp. 1980.
[8] Konczos, G., Kisdi-oszó, É., Lovas, A., Kajcsos, Zs., Potocký, L., Daniel-Szabó, J., Kováč, J., Novák, L.: J. Magn. Magn. Mater. *41* (1984), 122.

Received November 22nd, 1984
Revised version received March 15th, 1985