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Influence of Na_2SO_4 on magnetic properties of $(Fe_{1-X}Co_X)_{73.5}Cu_1Nb_3Si_{13.5}B_9$ (X=10, 40) alloys

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Materials

ABSTRACT

Purpose: In this paper magnetic properties of new $(Fe_{1-X}Co_X)_{73.5}Cu_1Nb_3Si_{13.5}B_9$ (X=10, 40) alloys have been presented. Moreover comparison of the changes of their magnetic properties due to influence of corrosion medium Na_2SO_4 has been done.
Design/methodology/approach: The material was obtained by the method of rapid cooling from liquid phase. The measurements of magnetic properties were made on the Maxwell-Wien bridge, the fluxometr and the VSM – Vibrating Sample Magnetometer.
Findings: The results allowed defining that are significant dependence between the magnetic properties and the corrosion.
Research limitations/implications: Due to the high influence the corrosion on the magnetic properties of the material further research should be undertaken.
Practical implications: The measurements allow giving information to the industry how decrease the magnetic properties of alloy after influence the corrosion medium.
Originality/value: The Finemet is very attractive due to his excellent soft magnetic properties. The problem of the corrosion has been presented and her influence on the magnetic properties.
Keywords: Amorphous materials; Finemet type alloys; Soft magnetic properties; Corrosion

1. Introduction

Factors which could decrease the efficiency of machines are certainly numerous, from wrong exploitation, to low conservation but the most of them is not sufficient protection against external agents – corrosion which strongly makes worse use of machines due to influence of environment.

The corrosion affects about 30 percent of all products made of metals and alloys [1]. Process of corrosion in many cases causes failure of surface and formation of products of corrosion is observed [2]. Prolonged influence of corrosion medium on material cause gradual decrease of magnetic properties of the alloys [3-7].

The excellent soft magnetic properties of nanocrystalline FeSiBCuNb alloys obtained by annealing first were reported by Yoshizawa. Magnetic properties are changed with change the chemical composition. This could be obtained by partial substitution of Fe by Co in nanocrystalline Finemet-type alloys and it is a way to extend their outstanding soft magnetic properties to elevated temperatures. Their magnetic properties depend on chemical composition and they are also capable to be optimised by applying of a annealing in temperature ranges close to the crystallisation temperature. This material has slightly worse magnetic properties at room temperature than typical Finemet, but is more stable at elevated temperatures. Magnetic properties of studied alloys specially depend of chemical constitution [8-15].

2. Experimental

Researches of influence of corrosion medium on magnetic properties were made on following amorphous alloys – $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$, $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ obtained in the form of strips (thickness of about 25 μm) by the method of rapid cooling from liquid phase. Samples were exposured in one molar Na_2SO_4 solution by 14 days. The range of researches covers amorphous alloy and strips after isothermally heat treatment (denoted as annealing temperature T_a) within the temperature range 300-973 K for 1 h in Ar protective atmosphere with the step of 50 or 25 K in a temperatures 773-873 K when was expected the best magnetic permeability μ. Alloys have been influence of one molar Na_2SO_4 solution were treated in this same range of temperatures. The following magnetic properties were measured at room temperature were as follows: (initial magnetic permeability μ_p, relative magnetic permeability μ_w, coercive force H_C, remanence B_r, saturation magnetisation B_s). These properties were measured by making use of the Maxwell – Wien bridge – working within a weak magnetic field (about 0.5 A/m) of frequency about 1 kHz and the VSM – Vibrating Sample Magnetometer. Research of roughness was also made before and after influence of corrosion medium on alloy at temperature 798 K – denoted as optimal temperature T_{op} due to the best initial magnetic permeability μ_p.

3. Results and discussion

Magnetic permeability doesn't depend only on chemical composition and annealing but also is sensitive on small changes in microstructure of the magnetic material and specially on changes by partial replacement of iron by cobalt in Finemet [8].

The samples obtained by method melt-spinning techniques in both cases ($Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$, $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$) have amorphous structure. Figure 1 shows initial magnetic permeability μ_p for alloy $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$.

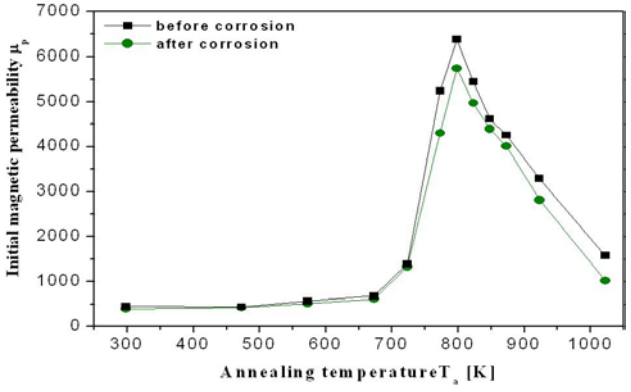

Fig. 1. Initial magnetic permeability μ_p for $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy as function of temperature in field 0.5 A/m, after exposure in one molar solution Na_2SO_4 and without it

For both examined alloys the magnetic permeability passes by similar maximum. This fact indicates that application suitable one – hour annealing can optimalize magnetic permeability of these alloys. The best initial magnetic permeability μ_p is for 798 K temperature named as optimal temperature T_{op}. Obviously the most interesting is the strong increase of the magnetic permeability observed in the second stage [15]. Influence of Na_2SO_4 solution on magnetic permeability is very high for all temperatures.

Similar influence on magnetic properties is noticed for relative magnetic permeability, fig. 2. Also in cases relative magnetic permeability μ_w value of permeability decrease after influence of corrosion medium for samples „as quenched" and after annealing in temperature 798 K – due to the best initial magnetic permeability μ_p in this temperature.

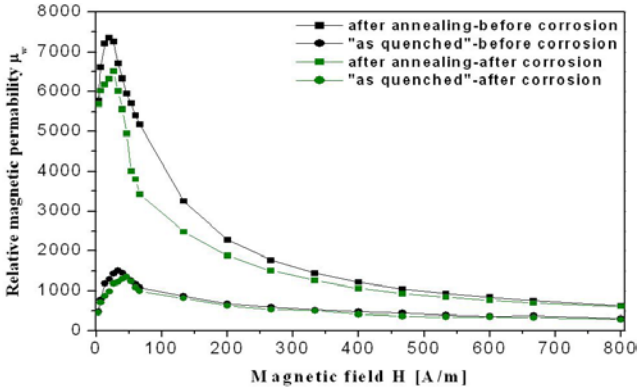

Fig. 2. Relative magnetic permeability μ_w $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy as function of magnetic field for samples after annealing, before and after exposure in one molar solution Na_2SO_4

The relative magnetic permeability μ_w for material in state „as quenched" decreases of about 170 units but a decrease for material after annealing T_{op} 798 K was stronger about 836, what indicates on unfavourable influence of corrosion medium Na_2SO_4 an magnetic properties of alloy. In all range the permeability in function of magnetic field decreases due to influence of corrosion.

Figure 3 presents initial magnetic permeability μ_p for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy, after exposure in one molar Na_2SO_4 solution and without it

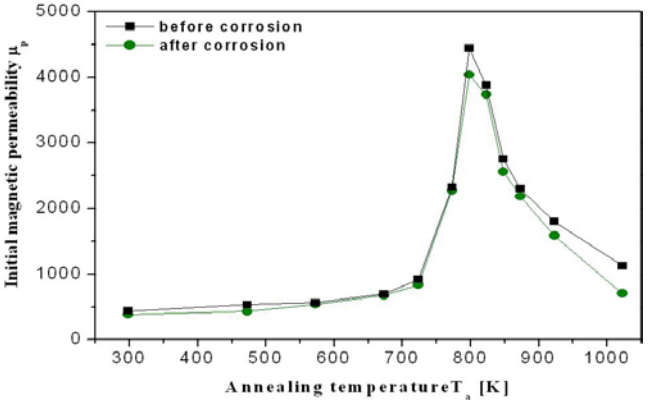

Fig. 3. Initial magnetic permeability μ_p for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy as function of temperature in field 0.5 A/m, after exposure in one molar solution Na_2SO_4 and without it

Similar situation is for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy for which is also observed decrease of initial magnetic permeability after exposure in one molar Na_2SO_4 solution.

Shape of curves obtained after exposure in one molar Na_2SO_4 solution is similar to curves for $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy but values are lower of about 30 units for material in state „as quenched" and of about 1696 for material after annealing T_{op}.

The fact that permeability for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy less decrease than for $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy could be caused by partial replacement of iron by cobalt. Iron is element which has bigger flexibility on influence of corrosion medium than cobalt. The same effect is observed in research for relative magnetic permeability for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$, fig. 4.

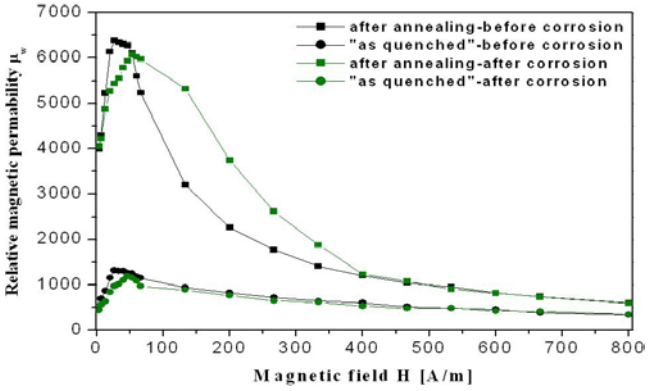

Fig. 4. Relative magnetic permeability μ_w for alloy $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ in function magnetic field for samples after annealing, before and after exposure in one molar solution Na_2SO_4

The relative magnetic permeability shaded about 124 for samples „as quenched" and about 308 to value 6237 for material after annealing T_{op}. This confirmed supposition about bigger corrosion resistance of $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy on influence corrosion medium comparison with $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy.

Next research works on Vibrating Sample Magnetometer cover determination magnetic properties: coercive force, remanence, saturation magnetisation, table 1.

Table 1
Magnetic properties of $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy, without influence corrosion medium

State of material $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$		Magnetic properties without influence corrosion medium		
		Coercive field H_C, A/m	Remanence B_r, T	Saturation magnetisation B_s, T
„as quenched"		23.221	0.111	0.987
After annealing	673 K	8.644	0.123	1.187
	773 K	2.497	0.015	1.200
	T_{op}-798 K	2.462	0.037	1.210
	973 K	33.009	0.238	1.296

Increase of temperature of annealing of researched $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy caused improvement of coercive force up to optimal temperature T_{op} corresponding to the best initial magnetic permeability. Value of remanence for optima temperature T_{op} 798 K is very low, what is negative effect in industry. The best remanence is getting for temperature 973 K about 0,238. The annealing also improves value of saturation magnetization which grows with increase of temperature of heat treatment grows.

In table 2 is observed a significant influence the corrosion medium on the magnetic properties $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy. The material exposed on corrosion medium Na_2SO_4 has worse magnetic properties: coercive force is bigger and remanence and saturation magnetization is lower.

Increase of the coercive force and decrease of the remanence and the saturation magnetization in the same moment caused getting worse very important properties of researched $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ material.

Table 2
Magnetic properties of $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ alloy, after exposure in one molar Na_2SO_4 solution

State of material $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$		Magnetic properties after exposure in one molar Na_2SO_4 solution		
		Coercive field H_C, A/m	Remanence B_r, T	Saturation magnetisation B_s, T
„as quenched"		24.378	0.102	0.876
After annealing	673 K	12.775	0.113	1.083
	773 K	4.213	0.012	1.098
	T_{op}-798 K	4.182	0.031	1.107
	973 K	35.089	0.229	1.192

Researches of magnetic properties for next $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy after influence of corrosion medium Na_2SO_4 allowed finding negative influence of corrosion on magnetic properties, tables 3 and 4.

Table 3
Magnetic properties of $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy, without influence corrosion medium

State of material $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$		Magnetic properties without influence of corrosion		
		Coercive field H_C, A/m	Remanence B_r, T	Saturation magnetisation B_s, T
„as quenched"		27.157	0.093	0.962
After annealing	673 K	12.925	0.069	1.136
	773 K	4.852	0.011	1.142
	T_{op}-798 K	5.230	0.029	1.157
	973 K	40.018	0.183	1.193

Influence of corrosion medium Na_2SO_4 on $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy is observed for each of temperatures. The medium affects are very negative and causes deterioration: coercive force increases his value, remanence decreases and saturation magnetization increases.

Table 4
Magnetic properties of $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ alloy, after exposure in one molar solution Na_2SO_4

State of material $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$		Magnetic properties after exposure in one molar Na_2SO_4 solution		
		Coercive field H_C, A/m	Remanence B_r, T	Saturation magnetisation B_s, T
„as quenched"		28.597	0.086	0.905
After annealing	673 K	14.114	0.059	1.103
	773 K	5.265	0.004	1.105
	T_{op}-798 K	5.782	0.057	1.125
	973 K	43.145	0.169	1.143

Decrease of initial and relative magnetic properties and coercive force, remanence and saturation magnetisation take place for both alloys. During the material is exposured in chemical medium occurs changes in the structure of surface material also is observed increase roughness of alloy on both sides glossy and mat (from side of drum during cast) what made worse homogeneity of material surface. It is caused by corrosion on material surface. To determine the corrosion products it is necessary to use scanning microscope, only colour of corrosion products can suggest about kind of corrosion on material surface.

4. Conclusions

The main reason of such research is define how corrosion medium Na_2SO_4 has influence on magnetic properties two alloys $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ and $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$. This present paper also presents in which way partial replacement of iron by cobalt in alloy reduces influence of corrosion.

The optimal magnetic properties for Finemet are obtained after annealing: $Fe_{63.5}Co_{10}Cu_1Nb_3Si_{13.5}B_9$ 798 K, and for $Fe_{33.5}Co_{40}Cu_1Nb_3Si_{13.5}B_9$ 823 K.

The main conclusions of the present study can be summarised as follows:

- Influence of corrosion medium Na_2SO_4 on magnetic properties: initial magnetic permeability, relative magnetic permeability, coercive force, magnetic, remanence and saturation magnetization is negative
- It is observed changes in roughness – increases it and formations of products of corrosion on surface of alloy,
- Partial replacement of iron by cobalt makes decrease of magnetic properties but improves resistance on corrosion.

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