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Studies on magnetically aged Fe–Mo–Ni–C alloys with different carbon additions

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Abstract

Magnetic properties of the Fe–20Mo–5Ni–xC (wt%, x varying from 0.016 to 0.14) alloys were studied after hot rolling, solution treatment, water quenching and magnetic aging at two different temperatures. Coercive force and maximum energetic product as high as 450 Oe and 1.8 MGOe, respectively, were obtained. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

Since the 1980s it has been known that Fe–Mo–Ni alloys show high mechanical plasticity when cold deformed as well as magnetic properties similar to Vicalloy I.

Tiefel et al. [1] obtained a Fe–20Mo–5Ni (wt%) alloy with coercive force $H_c = 210$ Oe and maximum energetic product $(BH)_{max} = 1.1$ MGOe, after hot rolling, solution treatment at 1200°C and magnetic aging at 610°C for 4 h. With aging temperature of 650°C, the results were similar [1].

Recently, Teodósio et al. [2] studied the influence of small contents of carbon, from 0.016% to 0.14% (wt%), on the magnetic properties of the Fe–20Mo–5Ni alloy. The alloys containing carbon achieved $H_c = 262$–267 Oe and $(BH)_{max} = 0.83$–0.97 MGOe after hot rolling, solution treatment at 1250°C and water quenching, without the necessity of any aging heat treatments or cold deformation.

The aim of this work is to determine the influence of aging treatment on the magnetic properties of Fe–20Mo–5Ni alloys with carbon additions ranging from 0.016% to 0.14% (wt%) and aging time varying from 0 to 1080 min.

2. Materials and methods

The ingots were prepared in a vacuum induction-melting furnace using high-purity materials. The chemical composition of the alloys is given in Table 1. The ingots were soaked at 1250°C, hot rolled (60% reduction), water quenched and magnetically aged at two different temperatures, 610°C and 650°C. The magnetic properties were determined in a vibrating sample magnetometer. A maximum field of 10 000 Oe was applied during measurement.

3. Results and discussion

Figs. 1 and 2 present the variation of coercive force with the aging time for the temperatures of 610°C and 650°C, respectively. It can be seen that there is a very similar behavior for all the alloys with different carbon content. The coercive force starts from about 260 Oe

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Table 1
Chemical composition of the alloys (wt%)

Alloy	C%	S%	Mo%	Ni%	Fe%
A	0.016	0.006	19.0	5.1	Bal.
B	0.026	0.003	20.2	5.2	Bal.
C	0.038	0.002	19.2	5.1	Bal.
D	0.046	0.011	19.3	5.0	Bal.
G	0.075	0.005	21.2	5.0	Bal.
H	0.085	0.004	20.1	5.2	Bal.
I	0.12	0.01	20.2	5.0	Bal.
J	0.14	0.01	20.0	5.0	Bal.

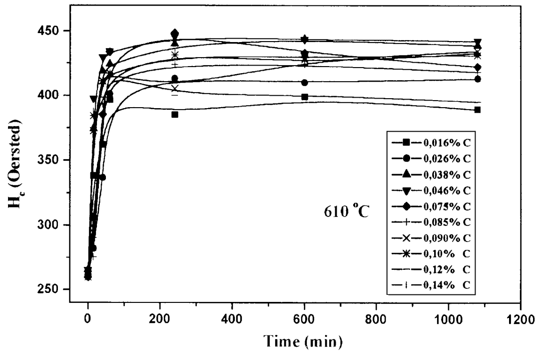

Fig. 1. Coercive force, H_c against aging time, after aging at 610°C.

(with no aging treatment), and then it increases rapidly until 4 h of aging time for 610°C, and 1 h for 650°C, and stabilizes in a plateau around 450 Oe for both temperatures. The alloys that present the highest coercive force are in the region of 0.046% and 0.075% (wt%) of carbon content. There is a great similarity between the behavior of H_c for 610°C and 650°C of aging temperature. The only difference between the two plots is that at 650°C the increase of H_c is even faster than the increase observed at 610°C, because of the kinetic effect of the temperature.

Fig. 3 shows B_s, saturation induction, against aging time for the alloys with different carbon content, for an aging temperature of 610°C. From this figure one can see a great symmetry with the equivalent H_c plot (Fig. 1). For all alloys, B_s starts around 17 500 G (with no aging treatment), drops very fast until 4 h of aging time and stabilizes at a plateau around 14 000 G. The B_s behavior was also investigated at 650°C; the values obtained were similar to those obtained at 610°C. The only difference between the two temperatures is that the drop of B_s at 650°C is faster than the drop observed at 610°C because of the kinetic effect of the temperature.

According to Becker et al. [3], the microstructure of the material has no influence on B_s. On the other hand,

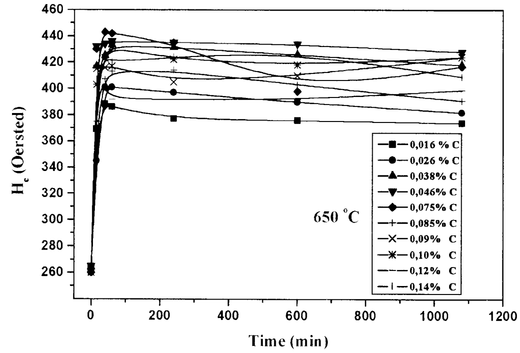

Fig. 2. Coercive force, H_c against aging time, after aging at 650°C.

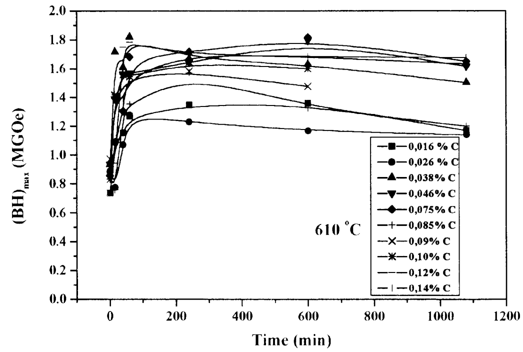

Fig. 3. Maximum energetic product, $(BH)_{max}$ against aging time, after aging at 610°C.

this property is strongly influenced by the chemical composition of the alloy. The precipitation of carbides changes the α-matrix composition. But the microstructure of the material has a strong influence on the coercive force.

Tiefel et al. [1] and Magat et al. [4] proposed that Fe_2Mo precipitates are responsible for the high H_c values. More recently, Teodósio et al. [5] showed the presence of M_6C carbide precipitates in the alloys containing carbon where M can be Fe or Mo. These carbides are ferromagnetic and hinder domain wall motion enhancing H_c values. The precipitation of carbides during magnetic aging decreases the quantity of Mo dissolved in the α-matrix and, consequently, the saturation B_s decreases.

Fig. 4 shows the maximum energetic product of the alloys after magnetic aging at 610°C. This value of maximum energetic product is higher than that obtained for the alloy without carbon (1.1 MGOe) [1]. The time of heat treatment (4 h) for the highest value of the maximum energetic product is the same that gives the highest value of H_c. The temperature of 650°C was also investigated

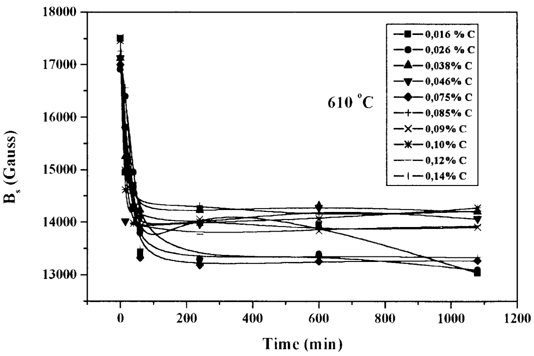

Fig. 4. Saturation, B_s against aging time, after aging at 610°C.

and the maximum energetic product was achieved after 1 h of aging time. The values obtained for $(BH)_{max}$ were similar to those obtained at 610°C.

4. Conclusions

Fe–20Mo–5Ni–xC(wt%) magnetic alloys, x varying from 0.016 to 0.14, were hot rolled, solution treated at 1250°C and magnetic aged at 610°C and 650°C. The following conclusions can be made:

1. After 4 h of aging, at 610°C, and 1 h at 650°C, the coercive forces of the alloys reached the maximum values from 400 to 450 Oe, and maximum energetic product reached the maximum values from 1.3 to 1.8 MGOe. These values of H_c and $(BH)_{max}$ are about twice as high as those of the same alloy without carbon and aged at the same temperatures.
2. The highest magnetic properties were obtained for the alloys with carbon contents between 0.046 and 0.075% (wt%).
3. The perfect symmetry between H_c and B_s, together with the presence of precipitates observed in previous works, shows a strong indication that the mechanism of magnetic hardening is developed by the formation of precipitates in the α-matrix during low-temperature aging.

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