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Letter

Effects of cold work, prior to aging, on the magnetic properties of Fe–20Mo–5Ni alloys with different amounts of carbon

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Abstract

Magnetic properties of the Fe–20Mo–5Ni–*x*C (wt.%, *x* from 0.016 to 0.14) alloys were studied after hot rolling, solution treatment, cold rolling and magnetic aging at two different temperatures. It was concluded that coercive force decreases and the relation B_r/B_s increases with cold rolling reduction.

Keywords: Magnetic materials; Magnets; Cobalt free magnets

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1. Introduction

Searching for cobalt free magnetic alloys, motivated by the cobalt crisis on the 70s, Jin and Tiefel [1] studied the Fe–20Mo–5Ni alloy. They obtained magnetic properties for these alloys similar to the ones of Vicalloy I. The coercive force was found to be $H_c = 210$ Oe and maximum energy product $BH_{max} = 1.1$ MGOe.

Magat et al. [2] and Lujinskaia et al. [3] also studied this alloy under severe cold deformation, prior to magnetic aging. They showed that this procedure increases significantly the magnetic properties H_c and B_r of the alloy.

Braid et al. [4] studied the magnetic properties of hot rolled and quenched Fe–20Mo–5Ni with different amounts of carbon. These alloys, without any cold work or magnetic aging, presented magnetic properties similar to the ones found by Jin and Teifel [1] with 30% of cold deformation in area and magnetic aging at 610 °C for 4 h.

More recently, Braid et al. [5] have studied the effects of magnetic aging on the magnetic properties of the Fe–20Mo–5Ni with different amounts of carbon. It was shown that the addition of carbon to the alloy increases their magnetic properties significantly.

The present work studies the effects of cold work prior to aging on the magnetic properties of Fe–20Mo–5Ni alloys with different amounts of carbon.

2. Experimental

Two different groups of ingots of Fe–20Mo–5Ni with different amounts of carbon were prepared in a vacuum induction-melting furnace. In the first group, samples designed by A, B, C, D, G, H, I, J, K and L, we used pure iron, nickel and molybdenum and graphite, and the samples E and F were prepared from scraps of low carbon steel. The chemical composition of the samples is shown on Table 1. The ingots were soaked at 1250 °C, hot rolled (60% reduction in area), water quenched, cold rolled and magnetically aged at two different temperatures, 610 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

Alloys from 0.016% C to 0.14% C (wt.%) were studied at two different temperatures, 610 and 650 °C. Alloys with carbon contents above 0.085% C (wt.%) showed to be brittle

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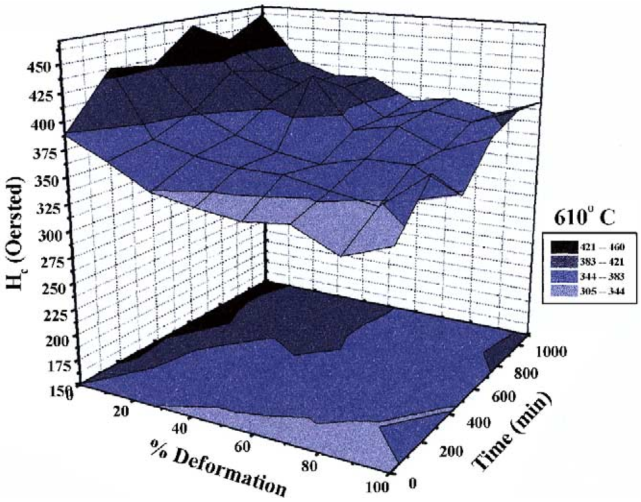

Fig. 1. Variation of the coercive force with cold work and aging time.

Table 1
Chemical composition of the samples (wt.%)

Sample	C (%)	S (%)	Mo (%)	Ni (%)	Fe (%)
A	0.016	0.006	19.0	5.1	Balance
B	0.026	0.003	20.2	5.2	Balance
C	0.038	0.002	19.2	5.1	Balance
D	0.046	0.011	19.3	5.0	Balance
E	0.051	0.02	19.8	5.0	Balance
F	0.057	0.013	20.1	5.0	Balance
G	0.075	0.005	21.2	5.0	Balance
H	0.085	0.004	20.1	5.2	Balance
I	0.090	0.01	20.2	5.0	Balance
J	0.10	0.004	20.5	5.0	Balance
K	0.12	0.005	20.0	5.2	Balance
L	0.14	0.017	19.3	5.0	Balance

Ingots A–D and G–J were prepared from electrolytic materials and graphite, and ingots E and F were prepared from scraps of low carbon steel.

during cold work deformation. Even though the 0.085% C alloys could not be cold rolled easily, some parts that were not completely compromised during cold work could be laminated close to 90% (reduction in area). The alloys with carbon contents above 0.085% C could not be cold-worked. According to Abreu et al. [6] rich precipitate is formed during the thermal–mechanical work of these alloys, and it is responsible for the embrittlement of the alloy.

Alloys produced from electrolytic iron and graphite and the ones produced from low carbon steel were studied and showed very similar characteristics. The complete set of results of all studied alloys can be found at Braid [7].

Fig. 1 shows the variation of the coercive force with cold work and aging time. As one can see, for any aging time the coercive force decreases with the increasing of cold work deformation. Nevertheless, a tendency of increasing coercive force can be seen for cold work deformation above 95% (reduction in area). This increase must have been caused by the presence of deformation bands. Abreu et al. [8] studied the occurrence of deformation bands on this kind of alloys close to 93% reduction in area and related the formation of these bands to the increasing of the coercive force.

The shape of the curve of BH_{max} with aging time in Fig. 2 is very similar to the ones without cold work studied by Braid et al. [5]. For the alloys produced from scraps of low carbon steel (ingots E and F), BH_{max} decreases with the increase of cold work deformation prior to magnetic aging. One can also observe in Fig. 2 a tendency of BH_{max} to increase for deformations above 90% of reduction in area.

The behavior of B_r and B_s in the alloys with cold work prior to the magnetic aging is also very similar to the alloys without this cold work. Nevertheless, for cold deformations above 80% (in area) we observed an increase in the magnetic property B_r. These results are in complete agreement with Abreu et al. [8]. They observed that the cold work in these

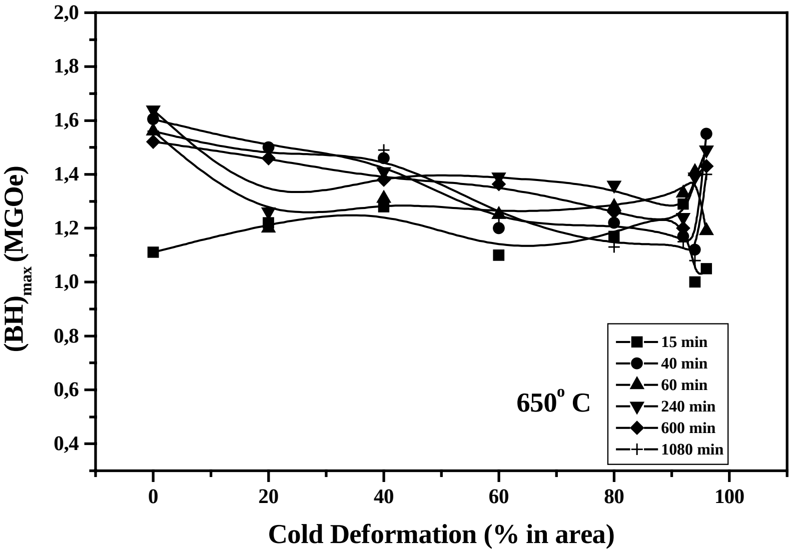

Fig. 2. Variation of BH_{max} with cold deformation for different aging periods.

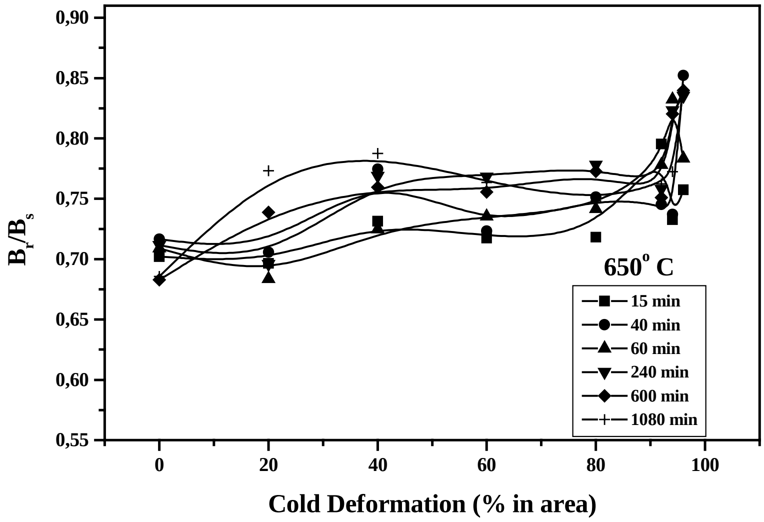

Fig. 3. Variation of B_r/B_s with cold deformation for different aging times.

alloys introduces a significant crystallography texture in the material. It was not observed a considerable change in B_s between the two conditions (with and without cold work prior to aging), showing that this magnetic property depends basically on the chemical composition of the material, as stated by Becker et al. [9].

Finally, as expected B_r/B_s increases with the increase in material deformation, Fig. 3.

4. Conclusions

1. The magnetic aging of the alloys with carbon, at 610 °C for 4 h or 650 °C for 1 h, increase the coercive force to 450 Oe, and maximum energy product to 1.8 MGOe.
2. The alloys produced from low carbon steel, with or without any magnetic aging, show the same values of magnetic properties as the ones produced from electrolytic iron and graphite. The use of low carbon steel has the advantage of reducing the production cost of the alloy.
3. The cold deformation, prior to the magnetic aging, upto 99% reduction, in area in alloys with carbon content between 0.016 and 0.14% (in weight), decreases the coercive force and the maximum energetic product. However, these values of magnetic properties are higher than the ones obtained for the alloys without carbon, with the same thermomechanic work history. Furthermore, for cold deformations, above 95% in area reduction, there is an increase in the coercive force.
4. BH_{max} decreases with the increase of cold work deformation prior to magnetic aging. One can also observe in Fig. 2 a tendency of BH_{max} to increase for deformations above 90% of reduction in area.
5. Cold deformations above 80% (in area) build up a significant crystallographic texture that raises the value of the magnetic remanence ratio (B_r/B_s) of the alloy.

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