ELSEVIER

Journal of Magnetism and Magnetic Materials 226–230 (2001) 1108–1110

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

The influence of deformation bands on the texture and on the B_r/B_s ratio of Fe–20Mo–5Ni-C semi-hard magnetic alloys

H.F.G. Abreu[a,*], J.R. Teodósio[b], C.S.C. Viana[c]

[a]Mechanical Department, Federal University of Ceará, Brazil
[b]Metallurgical and Materials Department, COPPE, Federal University of Rio de Janeiro, Brazil
[c]Metallurgical and Materials Department, Engineering Military Institute (IME), Rio de Janeiro, Brazil

Abstract

Fe–Mo–Ni alloys show high mechanical plasticity and magnetic properties similar to Vicalloy-II with the advantage of the absence of cobalt in their composition. The addition of carbon has improved the magnetic property H_c (coercive force) without significant reduction in B_r (remanence). After heat treatment, a coercive force and maximum energetic product as high as 420 Oe and 1.8 MGOe were obtained, respectively. Severe cold rolling deformation prior to magnetic aging improves the magnetic properties B_r and H_c and increases the ratio B_r/B_s. This work investigates changes in the texture and in the B_r/B_s ratio with the development of inhomogeneities during deformation.

Keywords: Magnetic materials; Texture; Deformation bands; Cobalt free magnets

1. Introduction

Fe–Mo–Ni alloys without carbon show high mechanical plasticity and magnetic properties similar to Vicalloy-II. Their advantages include the absence of the expensive element cobalt and high mechanical ductility [1]. The addition of carbon increases the magnetic property H_c (coercive force) without significant reduction in B_r (remanence). Magat et al. [2] showed that severe cold deformation prior to magnetic aging improved the magnetic properties B_r and H_c in Fe–20Mo–5Ni (wt%) alloys probably due to the development of texture and magnetic anisotropy.

In a previous work, Abreu et al. [3] have considered cold rolled Fe–20Mo–5Ni with carbon contents varying from 0.020 to 0.092 wt% until 99% of reduction and they have shown that cold rolling in excess of 80% followed by heat treatment developed a $\{100\}\langle 110\rangle$ texture component, increasing the ratio B_r/B_s in these alloys; until 90% cold rolling reduction, texture development was similar to cold rolled low carbon steel and, after 90% cold rolling reduction, a decrease in the component $\{100\}\langle 110\rangle$ occurred and texture became weaker. Marthur and Backofen [4] also noted a change in the rolling texture of iron after heavy reductions. The change was attributed to the appearance of intense deformation bands.

2. Materials and methods

An Fe–Mo–Ni–C ingot was prepared by induction melting under vacuum. Composition of the ingot in weight percent was 0.02 C, 5 Ni, 20.3 Mo, 0.16 Mn, Co < 0.01 and iron. It was soaked at 1250°C for 30 min, and then hot rolled with 60% of reduction in one step to minimize the temperature reduction in order to avoid Laves phase formation (Fe_2Mo). Strips were reheated to 1250°C and then were quenched in water. Hot-rolled strips were cold worked to get samples 80%, 90%, 97% and 99% reduced. Magnetic aging was performed at 610°C for 1 h.

*Correspondence address: Federal University of Rio de Janeiro, DEMP/UFC, CP 12144, Campus do Pici, CEP 60455-760, Fortaleza–Ceará, Brazil. Fax: + 55-85-288-9636.

E-mail address: hamilton@dem.ufc.br (H.F.G. Abreu).

0304-8853/01/$ - see front matter
PII: S0304-8853(00)01320-2

Crystallographic textures were determined by calculating the orientation distribution function (ODF) applying Roe's method [5]. ODFs were computed from the measured {1 1 0}, {2 0 0} and {2 1 1} pole figures by series expansion method ($l_{max} = 22$) with eight interactions for the missing parts. Plots of ODFs are according to Bunge φ_2 sections [6]. A Siemens D-500 X-ray diffractometer equipped with texture goniometer with k_α Co radiation was used for measurements.

Magnetic properties (hysteresis loops) were measured in a vibrating sample magnetometer EGG-PAR (Princeton Applied Research Corporation), model 4500, software 458A. The demagnetizing factor was calculated as a function of the ratio of the diameter to the thickness of samples. The shearing correction of magnetization curves was made according to Ref. [7].

3. Results

Fig. 1 shows $\varphi_2 = 45°$ ODF sections for samples cold rolled 80%, 90%, 97% and 99%. The evolution of texture with cold rolling in these alloys can be observed. Samples 80% and 90% cold rolled show an increase of the intensity of components {1 0 0}⟨1 1 0⟩, {1 1 1}⟨1 1 0⟩ and {1 1 2}⟨1 1 0⟩. This behavior is similar to that of other BCC alloys [6]. Continuing cold rolling to 97% and 99% texture components {1 0 0}⟨1 1 0⟩ decreases intensity. For example, the component {1 0 0}⟨1 1 0⟩ for a sample 90% cold rolled, has an intensity of 13, and for another sample 99% cold rolled the intensity is less than 3. The component {1 1 2}⟨1 1 0⟩ reduces from 11 to 2 in samples 90% and 99% cold rolled. The component {1 1 1}⟨1 1 0⟩ for a sample cold rolled 90% has an intensity of 5. For the sample cold rolled 99% this component disappears and the main texture component in this sample is {1 1 1} ⟨u v w⟩.

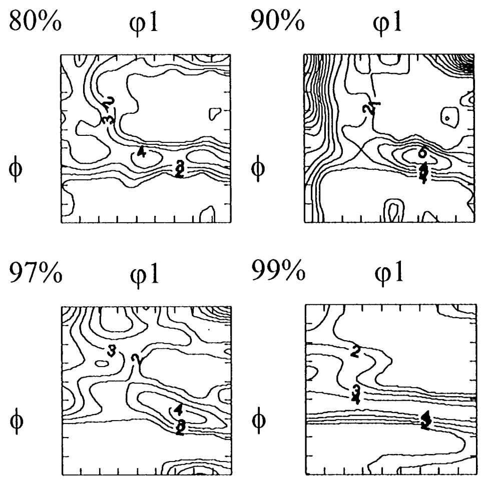

Fig. 1. Cold rolling texture of alloy for different reductions ($\varphi_2 = 45°$ ODF sections).

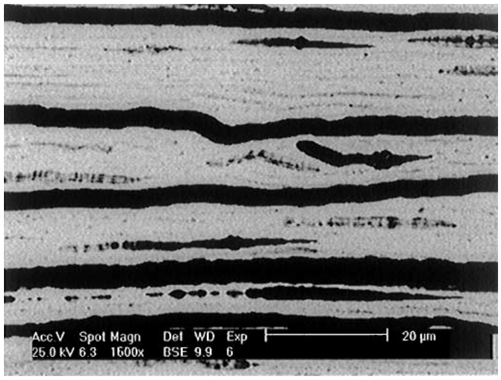

Fig. 2. SEM images of deformation bands on a 99% cold rolled Fe–20M0–5Ni–0.020C.

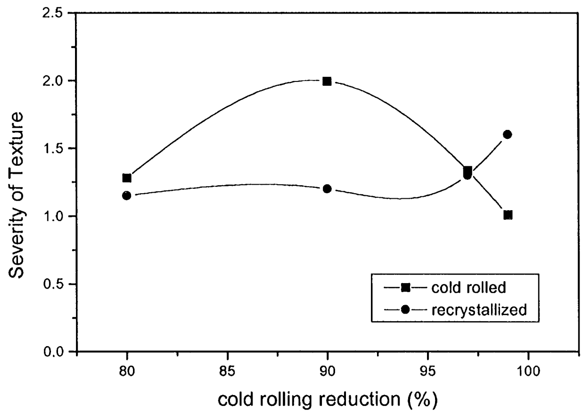

Fig. 3. The variation of the severity of texture with cold rolling reduction for samples deformed and heat treated after deformation.

Deformation bands are regions of distortion where part of a grain rotates to another orientation in order to accommodate to an applied stress. Optical micrographs of longitudinal sections for 80% and 90% cold rolled samples did not show evidence of deformation bands. Marthur and Backofen reported that deformation bands were not found in aluminum-killed steel deformed 90% and less. The work of Dillamore [8] suggests that the presence of component {1 1 2}⟨1 1 0⟩ should inhibit the propagation of deformation bands during cold rolling.

The presence of deformation bands in the longitudinal sections of 97% and 99% cold rolled samples is intense. Fig. 2 presents SEM images of longitudinal sections of 99% cold rolled samples. This is similar to a figure obtained by Marthur and Backofen [4] for an aluminum-killed steel 99% cold rolled.

Fig. 3 shows the variation of the severity of texture parameter with cold rolling reduction for samples cold

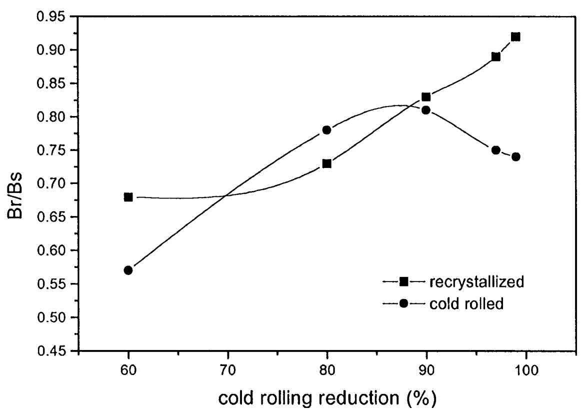

Fig. 4. The variation of the ratio B_r/B_s with cold rolling reduction for samples deformed and heat treated after deformation.

rolled and not heat treated and samples heat treated after deformation. The severity of texture parameter measures the departure of texture from random and is equal to unity for the uniform distribution. The severity of texture was calculated according to Ref. [9].

Fig. 4 shows the variation of the ratio B_r/B_s with the amount of deformation in samples cold rolled and not heat treated and in samples heat treated and consequently, recrystallized. It seems that inhomogeneities influence the ratio B_r/B_s in the same way that they influence texture.

To increase values of H_c, B_r and BH_{max}, samples were heat treated at 610°C for 1 h. This heat treatment recrystallizes the alloy. The recrystallized texture is similar to the deformed one [10]. Samples deformed 80% and 90% show a decrease in the main components of the deformed texture but a different phenomena happens with samples cold rolled 97% and 99%. Texture presents the same components as the sample cold rolled 90%, but more intense. One hypothesis for this phenomenon is recrystallization destroys existing inhomogeneities.

4. Conclusion

Deformation bands were observed in samples of Fe–Mo–Ni–C cold rolled 97% and 99%. They have strong effects on deformation texture of these samples. Deformation texture in these alloys are similar to other BCC deformation textures for samples cold rolled 90% and less. For 97% and 99% there is a decrease in the intensity of components $\{100) < 110\}$, $\{112\}\langle 110\rangle$. This change in texture due to inhomogeneities also changes the ratio B_r/B_s. After heat treating at 610°C for one hour this alloy recrystallizes, inhomogeneities are destroyed and the recrystallization texture is similar to the recrystallization texture of a carbon steel.

References

[1] S. Jim, T.H. Tiefel, J. Appl. Phys. 52 (3) (1981) 2503.
[2] E.M. Magat, G.M. Makarov, L.P. Lapina, E. Beloterov, Fis. Metal. Metaloved 55 (1988) 1075.
[3] H.F.G. Abreu, J.R. Teodosio, J.M. Neto, M.R. Silva, Scr. Metall. 39 (9) (1998) 1163.
[4] P.S. Marthur, W.A. Backofen, Metall. Trans. 4 (1973) 643.
[5] R.J. Roe, J. Appl. Phys. 36 (1965) 2024.
[6] H.J. Bunge, Texture Analysis in Material Science, Mathematical Methods, Cuvillier, Göttingen, 1993.
[7] S. Chikazumi, Physics of Magnetism, Wiley, New York, 1964.
[8] J.L. Dillamore, J.G. Roberts, A.C. Bush, Met. Sci. (Feb. 1979) 73.
[9] G.J. Davies, J.S. Kallend, P.R. Morris, Acta Metallurgica 24 (1976) 159.
[10] H.F.G. Abreu, J.R. Teodósio, C.S. Viana, Texture Microstruct. 31 (1998) 97.