JOURNAL OF MATERIALS SCIENCE 27 (1992) 5801–5804

The effect of lattice disorders on domain wall–dislocation interaction in Ni–5wt% Mn alloy

A. R. ALI, Z. M. FARID, E. TAKLA
Physics Department, Faculty of Science, Cairo University, Giza, Egypt

The behaviour of domain wall–dislocation interaction in Ni–5 wt% Mn alloy has been investigated in pre-annealed, quenched and γ-irradiated samples using some magnetic structure-sensitive properties. In all three samples it was found that the initial magnetic susceptibility, χ_a, and the maximum magnetic susceptibility, χ_{max}, were increased with the degree of plastic strain, and attributed to the formation of loops of domain wall around dislocations during the early stage of deformation. Further increase in dislocation density in the matrix during the later stage of deformation, affects the average value of the strength of interaction between the domain wall and dislocation, thus contributes to the decrease in χ_a and χ_{max}. The observed changes in the magnetic anisotropy, *K*, with plastic strain deformation is explained in terms of the magnetic hardening of the material by dislocations. Excess quenched vacancies and their clusters had an observable effect on domain wall–dislocation interaction, which is assumed to be due to the expected interaction and their pinning action that appear in the field of the nickel matrix.

1. Introduction

It is now almost universally accepted that in ferromagnetic material the displacement of magnetic domain walls under the influence of a magnetic field are hindered by lattice imperfections [1, 2]. Several theories have been proposed in order to study the effect of domain wall–defect interaction on the behaviour of domain-wall motion in the material. The potential theory [3] assumes the domain wall to be finite and rigid, whereas the domain-wall bowing theory [4] considers the domain wall to be flexible in one dimension only. However, it was reported by others [5, 6] that the behaviour of nickel and nickel alloys can be excellently described by the rigid domain-wall pinning model. Hilzinger and Kronmüller [7] came to the conclusion that domain-wall bowing out under the action of a magnetic field is expected to be predominant in materials in which strong defect interaction or more extended domain walls exist. Moreover, in the case of a large number of defects, randomly distributed on both sides of the domain wall, the average force acting on the sides of the domain wall cancels out. Only spatial fluctuations of the defect concentration act as effective pinning centres for domain-wall displacement [7].

From these considerations, the aim of the present work was to throw more light on the behaviour of domain wall–dislocation interaction in pre-annealed, quenched and γ-irradiated Ni–5 wt % Mn alloy. The study was also extended to examine the role of lattice defects produced by quenching and γ-irradiation on domain wall–dislocation interaction in cold-worked samples. Associated changes in maximum magnetic susceptibility, χ_{max}, energy loss, $\tan\delta$, and magnetic anisotropy, *K*, with the plastic strain of Ni–5 wt % Mn alloy were taken as a tool of study in the present work.

2. Experimental procedure

The test material, Ni–5 wt % Mn alloy in the form of sheets of thickness 0.7 mm, width 2.0 mm and length 6 cm, was given an initial pre-anneal for 2 h at 800 °C (pre-annealed sample). The sample was introduced as the core of a magnetization coil and the cathode ray technique was employed to obtain room-temperature *B–H* curves at different magnetizing fields. The maximum magnetic susceptibility was obtained from the relation $\chi_{max} = (B/H)_{max}$, which characterizes the magnetization of both reversible and irreversible domain-wall motion. Plastic strain deformation was induced on the samples by using a conventional strain machine. The pre-annealed sample was quenched from 850 °C in cold water at a quenching rate of 3×10^3 °C s^{-1}. A second pre-annealed sample was irradiated at room temperature by γ-irradiation with a maximum dose of 2 Mrad.

3. Results

3.1. Effect of plastic strain on χ_{max}, H_{cr} and $\tan\delta$

The magnetic susceptibility, χ, measured at room temperature as a function of the magnetic field, *H*, for

0022-2461

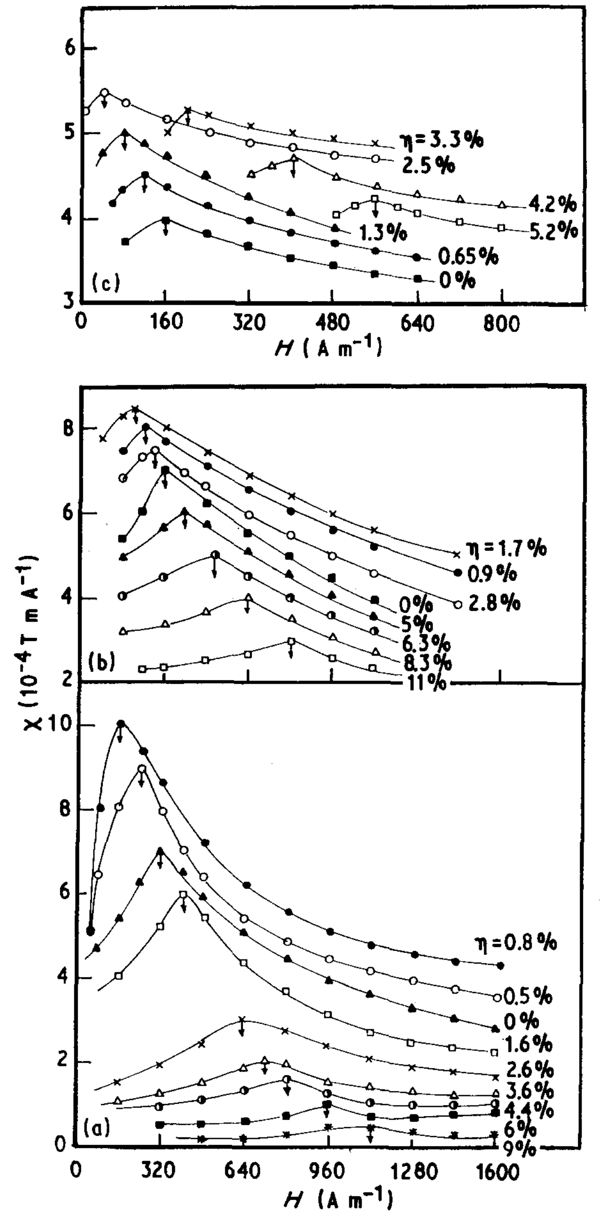

Figure 1 The dependence of magnetic susceptibility on the magnetic field of Ni–5 wt % manganese alloy (a) pre-annealed, T_a = 800 °C, for 2 h, (b) γ-irradiated of maximum dose 2 Mrad, and (c) quenched sample, T_q = 850 °C, with different degrees of strain deformation, η(%).

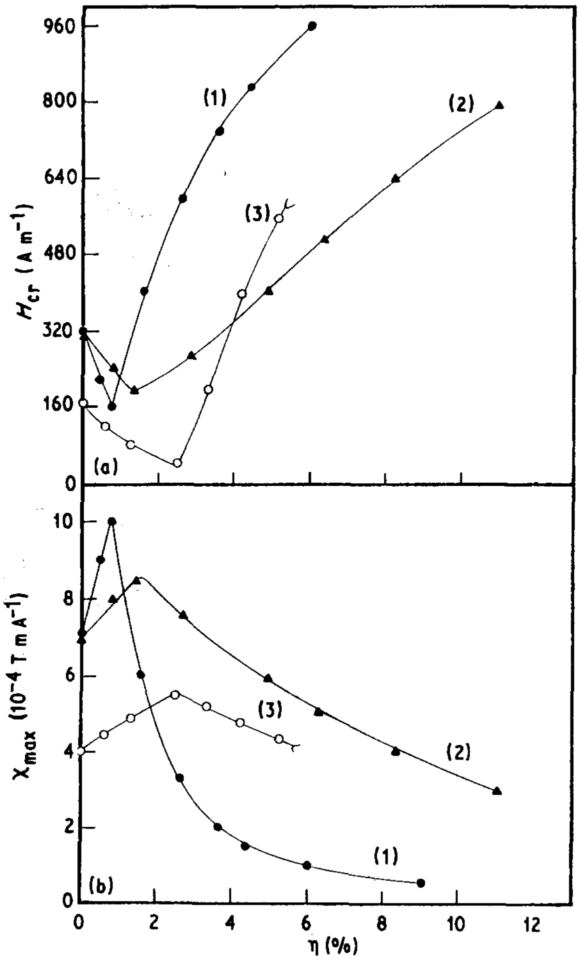

Figure 2 The dependence of (a) H_{cr} and (b) χ_{max} on the degree of strain deformation, η(%), of (1) pre-annealed, (2) γ-irradiated, and (3) quenched sample of Ni–5 wt % Mn alloy.

pre-annealed, quenched and γ-irradiated samples of different degrees of plastic strain is presented in Fig. 1 for Ni–5 wt % Mn alloy. The curves are characterized by a pronounced peak value in magnetic susceptibility, χ_{max}, which is found to shift position with magnetic field, H_{cr}, when increasing the degree of plastic strain. The dependence of both the maximum susceptibility, χ_{max}, and the magnetic coercivity, H_{cr}, on the degree of plastic strain is illustrated in Fig. 2a and b. It is clear that for the three samples, the maximum susceptibility, χ_{max}, initially increased followed by a pronounced decrease with the degree of plastic strain. Meanwhile, the magnetic coercivity, H_{cr}, initially decreased followed by a pronounced increase with the degree of plastic strain, η(%). The change in χ_{max} and H_{cr} noticed in the present work was nearly the same for the three samples; however, the observed maxima in χ_{max} and minima in H_{cr} with η(%) shifted to a higher degree of deformation for quenched sample (see Fig. 2a and b). The dependence of energy loss, tan δ, on the degree of plastic strain is shown in Fig. 3. It is clear that for pre-annealed, quenched and irradiated samples of Ni–5 wt % Mn alloy, the energy loss showed a continuous decrease in magnitude with η(%).

3.2. Effect of plastic strain on *K* and χ_a

The magnetic anisotropy, *K*, and the initial magnetic susceptibility, χ_a, were determined using a method previously adopted by Chikazumi [8]. In connection with the magnetization, *B*, in ferromagnetic material under a moderately strong magnetic field, *H*, the magnetic anisotropy, *K* could be determined using the equation

$$dB/dH = M_s[(a/H^2) + (2b/H^3) + \ldots] + \chi_a \quad (1)$$

where χ_a is the initial magnetic susceptibility, M_s is the saturation magnetization and *a* is constant depending on the internal stress and non-magnetic inclusions in the matrix. This constant is valid only within a finite range of strength of the magnetic field [9], and *b* is a constant which can be determined using the equation

$$b = 0.0762\,(K^2/M_s^2) \quad (2)$$

where *K* is the magnetic anisotropy.

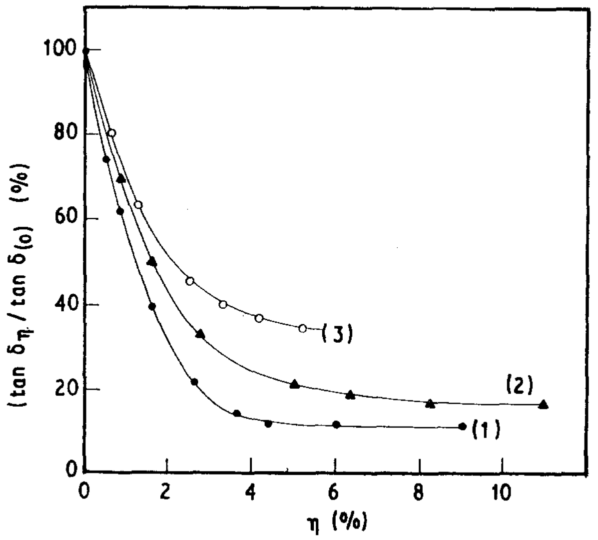

Figure 3 The dependence of the relative change in energy loss on the degree of strain deformation, η(%), of (1) pre-annealed, (2) γ-irradiated, and (3) quenched sample of Ni–5 wt % Mn alloy.

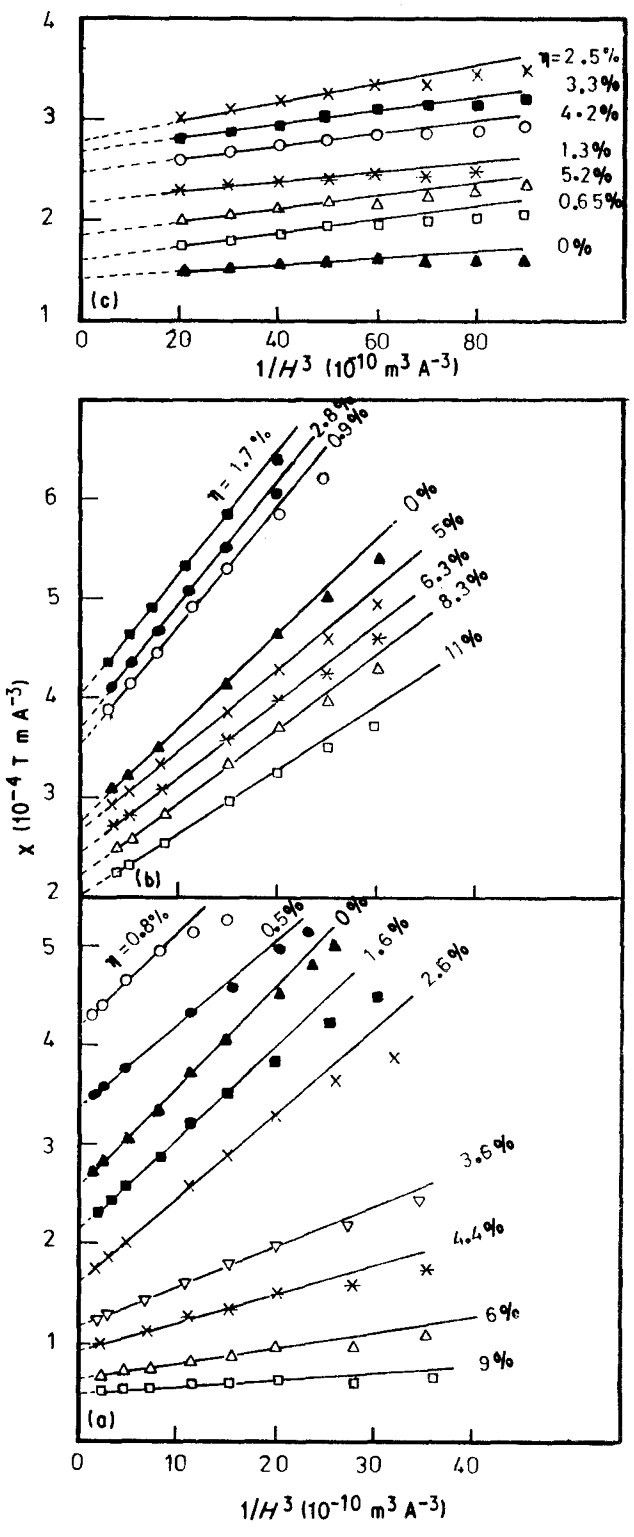

Figure 4 Effect of strain deformation, η(%), on the room-temperature (dB/dH)–($1/H^3$) curves of (a) pre-annealed, (b) γ-irradiated, and (c) quenched sample of Ni–5 wt % Mn alloy.

On these grounds, under a moderately strong magnetic field where the constant $a = 0$ [9], the values of dB/dH should give a straight line when plotted against $1/H^3$. From the gradient of this line we could determine the value of the constant b (see Equation 1). Therefore, the value of the magnetic anisotropy, K, could be obtained (see Equation 2). The actual value of the initial magnetic susceptibility, χ_a, can also be obtained from the extrapolated points of this straight line to the ordinate.

In the present work, the effect of pre-cold work by plastic strain of pre-annealed, γ-irradiated, and quenched samples on the corresponding room-temperature (dB/dH)–($1/H^3$) curves is shown in Fig. 4. The values of the magnetic anisotropy were calculated from the slope of the linear part of the curves (see Fig. 5a), which characterized the magnetization by rotation domain-wall motion for the different samples, where $M_s = 0.0463$ T. The initial magnetic susceptibility, χ_a, was evaluated from the extrapolated point on the curve to the ordinate, which characterizes the magnetization by reversible domain-wall motion is given in Fig. 5b. From these results, the general trend is apparent that the initial magnetic susceptibility, χ_a, initially increased followed by a pronounced decrease with the degree of plastic strain, η(%). Meanwhile, the magnetic anisotropy, K, decreases with the degree of plastic strain in three stages (see Fig. 5a).

4. Discussion

The effect of strain deformation on the structure-sensitive magnetic properties of ferromagnetic material might be interpreted in terms of an existing network of structure defects, particularly dislocations. This seems to affect the magnetic properties by controlling the location of magnetic domain [10]. Near the core of a dislocation, the regular arrangement of atoms becomes highly distorted. A weak interaction between the atomic magnets is thus expected and the magnetic domain might wrap around any obstacle or dislocation that crosses its path. The formation of wall-wrapping dislocations is presumably a compromise between the tendency of the dislocations to impose a certain orientation on the wall in its vicinity, and the tendency of the wall to adopt a different orientation related to the crystal structure [11]. The formation of such pinched-off loops of boundaries was previously found in pure nickel [11, 12].

In the present work, for pre-annealed, γ-irradiated and quenched samples, magnetic domain walls are more likely, by extending over large areas between

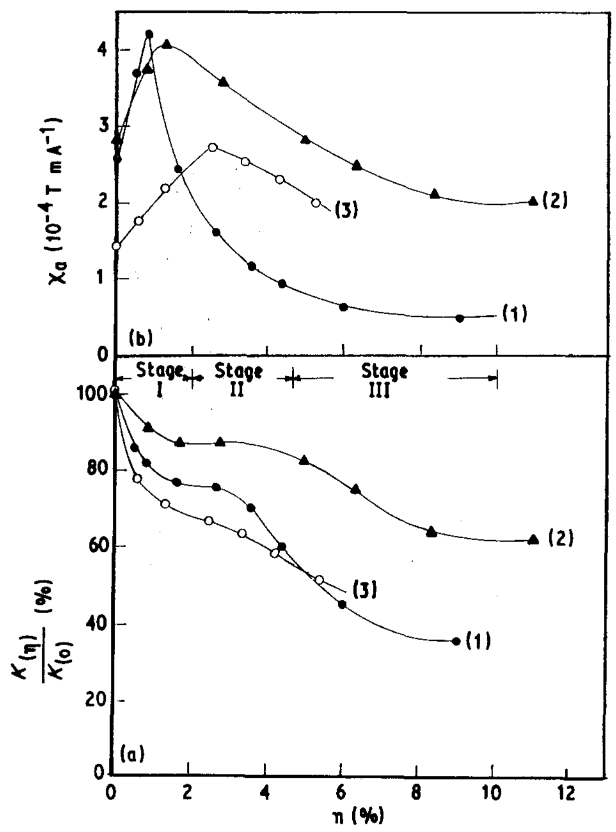

Figure 5 The dependence of (a) the magnetic anisotropy, K, and (b) the initial susceptibility, χ_a, on the degree of strain deformation, η(%), in (1) pre-annealed, (2) γ-irradiated, and (3) quenched sample of Ni–5 wt % Mn alloy.

dislocation pinning points [10], so that the maximum susceptibility, χ_{max}, energy loss, tan δ, magnetic anisotropy, K, and the initial susceptibility, χ_a, are large. On increasing the dislocation density in the matrix, loops of domains around dislocations are formed, thus increasing χ_a and χ_{max} in Ni–5 wt % Mn alloy to some extent. Further increase in dislocation density produced by plastic strain, presumably affects the average value of the strength of interaction between the domain wall and the dislocation [7] and thus contributes to the decrease in the values of χ_{max} and χ_a. In addition, the observed shift in the maxima of χ_a and χ_{max} for the quenched sample, could be attributed to the expected interaction of vacancy–manganese pairs and their clusters formed during quenching [13] with dislocations and their pinning action appearing in the field of the nickel matrix. The situation is different for the effect of plastic-strain deformation on the magnetic anisotropy, K, which reflects the strength of the torque exerted by magnetic pressure on the rotational motion of domain walls. Therefore, in the range of a moderately strong magnetic field, the pinning action of magnetic domain walls by dislocations was inferred to leak out the magnetic pressure exerted by the magnetic field on domain walls [14] and, as expected, the torque exerted by the magnetic pressure on the domain walls decreased with increasing plastic strain in the matrix. Hence it is reasonable to assume that the observed decrease in the magnetic anisotropy, K, with plastic strain might be related to the leak out of the torque exerted by the magnetic field on domain walls which originated during plastic-strain deformation in the matrix. On the other hand, the observed decrease in magnetic anisotropy, K, with the plastic-strain deformation in three stages could correspond, respectively, to the following phenomena [2]: creation of an isolated dislocation (stage I), clustering of dislocations into tangles (stage II), and onset of cellular structures composed of dislocation walls (stage III). The relative small changes observed in the magnetic anisotropy during stages I and II (see Fig. 5a) leads to the conclusion that the rotation magnetization of domain walls depends only on the magnitude of crystal anisotropy, which is fairly insensitive to weak internal stress in the matrix [8], whereas the magnetic susceptibility due to the reversible and irreversible displacement of domain walls is very sensitive to the irregularity of the substance [8]. Hence it is not surprising that the energy loss, tan δ, continuously decreases with the plastic strain (see Fig. 3), because it reflects the total energy loss during the irreversible magnetization processes.

References

1. D. C. JILES, *Phys. Status Solidi* (*a*) **108** (1988) 417.
2. J. DEGAUQUE, B. ASTE, J. L. PORTESEIL and R. VERGNE, *J. Magn. Magn. Mater.* **26** (1982) 261.
3. H. TRAUBLE, in "Modern Problem der Metall Physik", edited by A. Seeger (Springer-Verlag, Berlin, 1966) p. 24.
4. H. D. DIETZE, *Phys. Kondens. Mater.* **2** (1964) 117.
5. H. KRONMÜLLER, *Z. Angew. Phys.* **30** (1970) 9.
6. A. R. ALI, Z. M. MANSY, F. MOHSEN and R. KAMEL, *Physica* **112B** (1982) 245.
7. H. R. HILZINGER and H. KRONMÜLLER, *ibid.* **86–88B** (1977) 1365.
8. S. CHIKAZUMI, "Physics of Magnetism" (Wiley, London, 1964) pp. 277, 263.
9. E. CZERLINSKY, *Ann. Physik* **13** (1932) 80.
10. A. R. ALI and G. SAID, *Physica* **112B** (1982) 241.
11. G. REMONT, P. DELAVIGNETTE, A. LAGASSE and S. AMELINCKX, *Phys. Status Solidi* **11** (1965) 329.
12. A. R. ALI, S. A. MAHMOUD and G. SAID, *Phys. Status Solidi* (*a*) **84** (1984) K67.
13. J. E. EPPERSON, K. W. GERSTENBERG, D. BERNER, G. KOSTORZ and C. ORTIZ, *Phil. Mag. A* **38** (1978) 529.
14. A. R. ALI and M. A. FAHIM, *J. Mater. Sci.* **25** (1990) 1468.

Received 31 July 1991
and accepted 16 January 1992