Journal of Magnetism and Magnetic Materials 321 (2009) 3778–3781

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Antiferromagnetic $Mn_{50}Fe_{50}$ wire with large magnetostriction

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ARTICLE INFO

Article history:
Received 22 April 2009
Received in revised form
12 July 2009
Available online 23 July 2009

PACS:
75.80.+q
76.50.+g
75.50.Ee

Keywords:
Magnetostriction
Mn–Fe wire
Fiber texture
Plastic deformation

ABSTRACT

This work presents a study on the relation between the fiber texture and the magnetostrictive performance in an antiferromagnetic $Mn_{50}Fe_{50}$ alloy wire, which was prepared through the combining process of hot rolling and cold drawing. The face-centered cubic (fcc) crystal structure can be retained during the plastic deformation process. Mixed fiber textures consisting of both $\langle 110 \rangle$ and $\langle 100 \rangle$ components were formed along the drawing direction (DD) in the wire. A large magnetostriction of 750 ppm was obtained along DD under 1.2 T, which can be ascribed to the single γ phase and the formation of preferred crystal orientation.

1. Introduction

Magnetostrictive wires, such as Ni, Fe–Ni and Fe–Ga alloy wires are of great interest for transducer and sensor applications [1,2]. The early magnetostrictive wires, such as Ni and Fe–Ni alloy wires have been stepped into applications due to their good mechanical properties, but they can only possess a relatively low magnetostriction of about 20 ppm [3,4]. It has been reported recently that a $Fe_{85}Ga_{15}$ alloy wire developed by combining plastic deformation processes can exhibit a room temperature magnetostriction of 66 ppm under a relatively low magnetic field of 80 Oe [2]. However, the high cost of Ga element should be a limitation for further applications. Although the terfenol alloys have also attracted much attention due to their giant magnetostriction over 2000 ppm, it is difficult to fabricate wire materials because of their brittleness [5,6]. In 2006, Peng and Zhang have reported that the magnetostriction of an antiferromagnetic γ-$Mn_{42}Fe_{58}$ polycrystalline sample can reach 169 ppm under 1 T [7]. This value is comparable to that of ferromagnetic Fe–Ga alloys [8,9], although it requires a much higher magnetic field. Moreover, Mn–Fe alloys possess a high mechanical strength and good ductility, in addition to the low material cost [10,11]. It is of interest to develop γ-Mn–Fe wires as potential candidates in magnetostrictive applications in transducers and sensors. Due to the good ductility, a textured γ-Mn–Fe alloy has been prepared through cold rolling, exhibiting improved magnetostriction performance [12]. In this work, a $Mn_{50}Fe_{50}$ magnetostrictive wire was prepared through a combining plastic deformation process. The formation of the crystallographic texture along the wire axis and its relation to the magnetostrictive performance were also discussed.

2. Experimental

Polycrystalline $Mn_{50}Fe_{50}$ alloy sample was fabricated by vacuum induction melting under an argon atmosphere using high purity iron and high purity electrolytic manganese. The ingot was remelted for three times to ensure homogeneity. Sample with the size of $8 \times 10 \times 100\,mm^3$ was cut from the ingots. The combined processing of hot rolling and cold drawing was schematically shown in Fig. 1. The ingot was homogenized for 24 h at 900 °C, and then was rolled down to a thickness of 5 mm at 850 °C. The specimen was cut to $5 \times 5 \times 180\,mm^3$. After thermal annealing at 700 °C for 4 h, cold drawing was undertaken to obtain a wire with a diameter of 3.6 mm.

Phase identification and texture determination of the as-cast and the deformed $Mn_{50}Fe_{50}$ specimens were conducted by a D/max 2550 pc X-ray diffractometer with Cu K_α radiation, respectively. The wire specimens with a length of 1.5 mm were cut from the Φ 3.6 mm wire and put together into a ring with a diameter of 10 mm. The cross section of the wire specimens was mechanically ground and polished for pole figure measurement. The (2 0 0) and (2 2 0) pole figures were used to describe the fiber texture. The specimens were ground and subsequently etched in a

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doi:10.1016/j.jmmm.2009.07.038

reagent with 5 g ferric chloride, 2 ml hydrochloric acid and 100 ml alcohol. Microstructures of the etched samples were observed under an optical microscopy (LEICA MPS60). Magnetostriction measurements were performed on specimens with the size of $3 \times 10 \times 2\,mm^3$ by standard strain gauge method. The external magnetic field was up to 1.2 T, which was applied along DD.

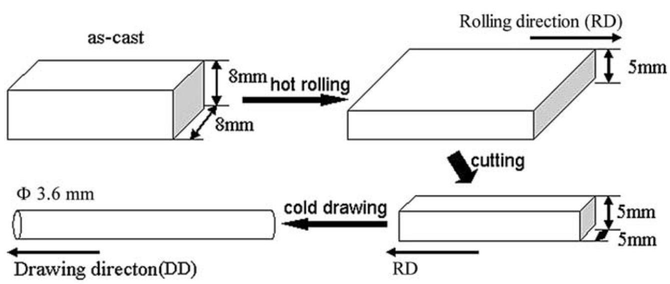

Fig. 1. Schematic diagrams of the combined processes of hot rolling and cold drawing.

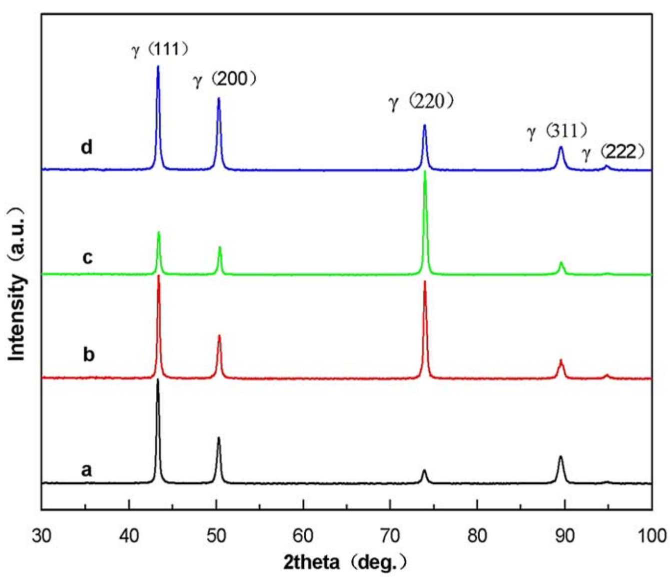

Fig. 2. XRD patterns of $Mn_{50}Fe_{50}$ alloys: (a) the as-cast sample, (b) the as-rolled sheet, (c) the annealed sheet and (d) the as-drawn wire, respectively. (b) and (c) were taken from the sample surface parallel to the rolling plane; (d) was taken from the sample surface which lies parallel to the wire surface.

3. Results

Fig. 2 shows the XRD patterns of $Mn_{50}Fe_{50}$ alloys for the as-cast sample, the as-rolled sheet, the annealed sheet, and the as-drawn wire, respectively. It can be seen that all the samples exhibit single austenite (γ) phase with a fcc structure, indicating that no stress-induced-structural-transformation occurred during the deformation processes of hot rolling and cold drawing.

Fig. 3 shows optical micrographs of the longitudinal section of the as-cast and the as-drawn $Mn_{50}Fe_{50}$ samples. The as-cast $Mn_{50}Fe_{50}$ alloy had a regular equiaxed polycrystalline structure with an average grain size of about 65 μm and a random distribution of crystallographic orientations of the γ phase, as shown in Fig. 3a. After hot rolling and cold drawing, a significantly deformed microstructure consisting of elongated grains was found and most of the elongated grains were arranged along DD, as shown in Fig. 3b. It can also be seen that the plastic deformation was inhomogenous with an average elongated grain size of about 150 μm long and 30 μm wide.

Fig. 4 shows X-ray diffraction pole figures measured on the as-drawn $Mn_{50}Fe_{50}$ alloy wires. Textures measured using X-ray diffraction measurements are global textures. The pole figure presents, in a stereographic projection, using two dimension color contour maps, the distribution of a special crystal direction with respect to the sample reference axis, e.g., DD. The uniform distribution of poles represents random crystal orientation, while dense clusters of poles indicate strong textures. The $\{h\,k\,l\}$ $\langle u\,v\,w\rangle$ designates the plane $\{h\,k\,l\}$ which lies parallel to the wire surface and the direction $\langle u\,v\,w\rangle$ is parallel to DD. The fiber texture of the as-drawn $Mn_{50}Fe_{50}$ alloy wire, as shown in Fig. 4, from (2 0 0) and (2 2 0) pole figures, can be described as {0 1 1} ⟨1 0 0⟩ and {0 1 1} ⟨1 1 0⟩, which were indicated by different symbols of the filled circles and delta-stars, respectively. Additionally, there was a texture component with a {0 0 1} ⟨1 1 0⟩, which indicated by the filled squares. Therefore, ⟨1 0 0⟩ and ⟨1 1 0⟩ duplex fiber texture paralleled to DD was formed after cold drawing.

Fig. 5 shows the magnetostriction as a function of magnetic field for the as-cast and the as-drawn samples at room temperature. The external magnetic field was applied along DD. It can be seen that the magnetostriction values of the samples increased steadily as the applied field increased, which were not saturated even under an applied field of 1.2 T. Magnetostriction value under 1.2 T for the as-cast $Mn_{50}Fe_{50}$ sample was just 303 ppm. After hot rolling and cold drawing, which induced a fiber texture along DD, magnetostriction under 1.2 T of the as-drawn sample reached 750 ppm, which was twice as high as that of the as-cast one.

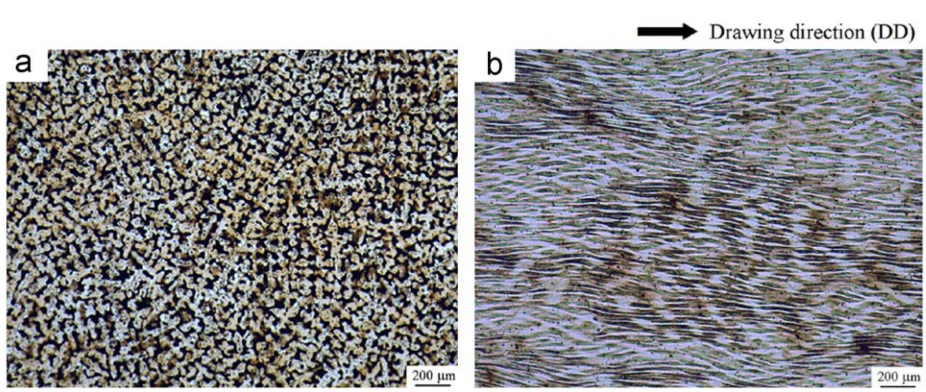

Fig. 3. Optical micrographs of the longitudinal section of the (a) as-cast and (b) as-drawn $Mn_{50}Fe_{50}$ samples.