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Spinodal decomposition in Fe–25Cr–12Co–1Si alloy under a 100 kOe magnetic field

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Abstract

Spinodal decomposition in Fe–25Cr–12Co–1Si alloy subjected to thermo-magnetic treatment under a 100 kOe magnetic field was investigated by transmission electron microscopy (TEM) and Mössbauer spectrometry. The high magnetic field was found to accelerate spinodal decomposition in the early stage, but restrain the coarsening process, which led to the formation of very fine modulated structures with small aspect ratio for the ferromagnetic α_1 phase. The abnormal deterioration of magnetic properties was mainly attributed to the decrease of shape anisotropy of ferromagnetic α_1 phase for the step-aged Fe–25Cr–12Co–1Si alloy.

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Keywords: Spinodal decomposition; Magnetic field; Fe–Cr–Co alloy; Thermo-magnetic treatment

1. Introduction

Thermo-magnetic treatment (TMT) is crucial in the determination of permanent magnetic properties for Fe–Cr–Co and Alnico alloys. These two kinds of alloys undergo spinodal decomposition to form two phases structure, one is ferromagnetic and the other is paramagnetic [1–5]. External magnetic field is usually employed during isothermal treatment to elongate the ferromagnetic α_1 phase, and thus impart magnetic anisotropy to these kinds of alloys [6–8]. Generally, increasing external magnetic field intensity is expected to improve the alignment of ferromagnetic α_1 phase and increase the aspect ratio of ferromagnetic α_1 phase, which are corresponding to better magnetic properties. Chin et al. [6] performed thermo-magnetic treatment with external magnetic field up to 5 kOe on Fe–28Cr–12Co alloy. They found that the magnetic properties reached saturation when the intensity of external magnetic field (H_{ext}) exceeded 3 kOe. However, in our previous report, we observed the abnormal decline of magnetic properties for Fe–25Cr–12Co–1Si alloy when the H_{ext} intensity exceeded 8 kOe [9].

In the present work, we employed a 100 kOe magnetic field in order to verify the abnormal trends previously reported. Modulated structures at as-TMT and step aged states were characterized with transmission electron microscopy (TEM). Spinodal decomposition under a magnetic field up to 100 kOe was studied by means of Mössbauer spectrometry.

2. Experimental

The low-cobalt-type Fe–25Cr–12Co–1Si alloy (wt%) in this study was melted in a vacuum induction furnace. The ingot was homogenized at 1200 °C and then hot forged to Ø60 mm bar. Flake-like samples of $18 \times 10 \times 2.8\ mm^3$ cut from the bar were solid solution treated at 1050 °C for 1 h, and then quenched into iced brine. The same optimal parameters of isothermal ageing at 647 °C for 1 h were

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adopted for the alloy with an external magnetic field of 100 kOe. A complex step ageing process was subsequently conducted following the isothermal treatment. The detail of step ageing process was described in our previous report [9].

TEM thin foils were jet-polished and then observed on a Philips Tecnai 20 transmission electron microscope at 200 kV. Mössbauer spectrums were obtained at room temperature in standard transmission geometry with a conventional constant acceleration spectrometer using a ^{57}Co source in a Pd matrix. Magnetic properties were measured with a DC automatic hysteresisgraph (Model NIM-200) at room temperature.

3. Results

3.1. Modulated structure

It is generally believed that increasing external magnetic field intensity can elongate the ferromagnetic α_1 phase during thermo-magnetic treatment, and thus introduce shape anisotropy for Fe–Cr–Co alloys that undergo spinodal decomposition within the miscibility gap. For example, a 2 kOe magnetic field produced ferromagnetic α_1 phase with aspect ratio of 3.6, and an 8 kOe magnetic field gave aspect ratio of 4.7 for as-TMT Fe–25Cr–12Co–1Si alloy, as shown in Fig. 1(a) [9]. However, in the present study, very fine two-phase microstructure was observed for the as-TMT alloy subjected to thermo-magnetic treatment with a 100 kOe magnetic field, as shown in Fig. 1(b). The average diameter of ferromagnetic α_1 phase is about 15 nm and the aspect ratio is about 2. The aspect ratio is even much smaller than that treated with low intensity of 2 kOe.

3.2. Magnetic properties

The magnetic properties of Fe–25Cr–12Co–1Si alloy as a function of external magnetic field intensity were shown in Fig. 2. As illustrated in our previous report [9], B_r, $_iH_c$ and $(BH)_{max}$ all increased with the increase of H_{ext} intensity,

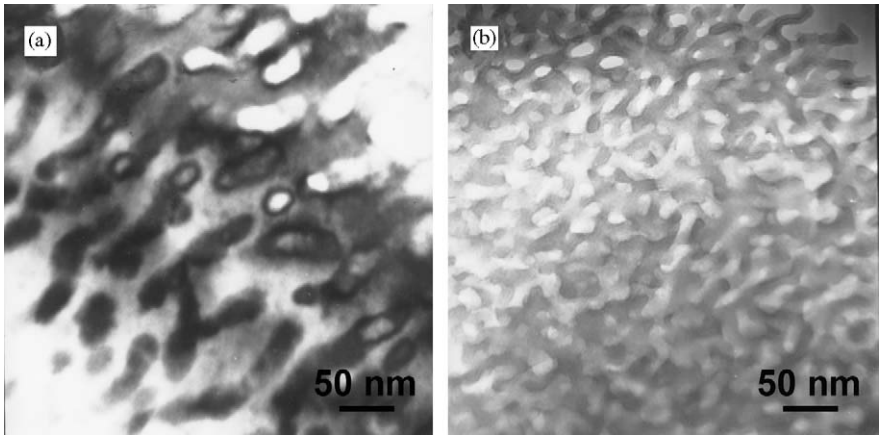

Fig. 1. TEM micrographs of the as-TMT Fe–25Cr–12Co–1Si alloy subjected to thermo-magnetic treatment with different H_{ext} intensities: (a) 8 kOe and (b) 100 kOe.

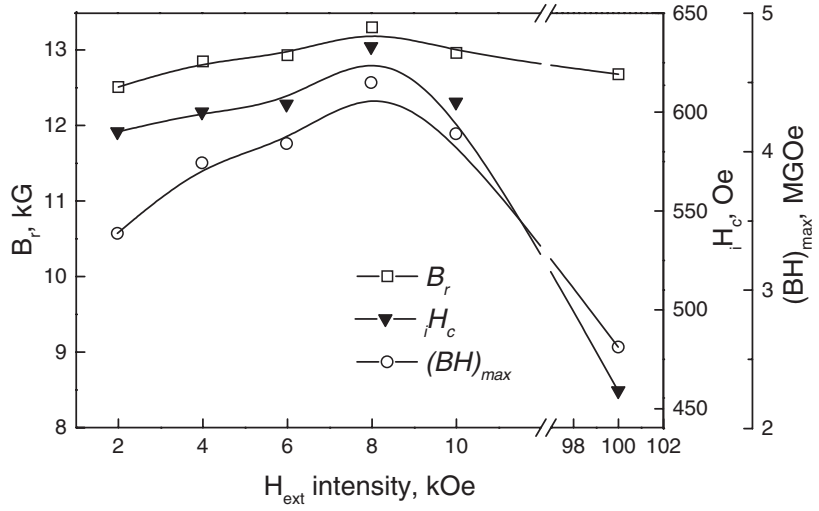

Fig. 2. Variation of magnetic properties with intensity of external magnetic field for the step-aged Fe–25Cr–12Co–1Si alloy.