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Deformation-induced grain refinement in body-centered cubic Co–Fe alloys upon room temperature compression

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ABSTRACT

Pronounced grain refinement to ultrafine or nanoscale size in initially coarse-grained Co–25Fe and Co–35Fe alloys has been achieved upon conventional compression at room temperature. Both Co–Fe alloys exhibit a large plasticity of more than 140% without fracture at room temperature, which is related to a multiscale-grained microstructure resulting from deformation-induced grain refinement. The grains refine with increasing deformation during compression. The microstructure features indicate that the possible mechanism for the strain-induced grain refinement under conventional compression is a consequence of the propagation and coalescence of dislocation cell structures with strain accumulation.

1. Introduction

Ultrafine-grained and nanocrystalline metals and alloys can exhibit a superior balance of mechanical properties (i.e. high strength and large plasticity) [1–5] as well as improved corrosion resistance [6] compared with their coarse-grained counterparts, which makes them superior to conventional polycrystalline materials for potential structural applications. Therefore, these fine-grained materials have attracted a great deal of attention in recent years, and many processing techniques have been employed to obtain such refined microstructures. Among them, severe plastic deformation techniques are well-known powerful techniques to produce fine-grained metallic materials [7–11]. Along with the improvement of the strength by refine microstructure, strategies have been developed to improve the plasticity of fine-grained materials by introducing heterogeneities of multiple length scale into the microstructure, or called bimodal microstructure [1,4,5], where a high strength nano-/ultrafine-grained eutectic matrix is toughened by micrometer-sized ductile dendrites (such as solid solution and cubic compound). The heterogeneity in the multiscale grain microstructure could significantly both enhance the plasticity without sacrificing high strength of the alloy [4,5,12,13]. For examples, the as-cast bulk titanium base alloys with multiple length-scale microstructure exhibit high strength of in excess of 2000 MPa and large plasticity up to 15% [4,5,12,13].

With recent technological advances for the next generation of high-speed aircrafts ("More Electric Aircraft"), there has been a resurgence of interest for Co–Fe alloys due to their excellent soft magnetic properties [14,15]. The primary obstacle of these alloys for potential applications is their poor mechanical properties. In general, the Co–Fe alloys are quite brittle at room temperature when ordered and less brittle when disordered, accompanied by a transition from largely intergranular fracture to transgranular cleavage [16]. Intensive research and development efforts over decades have resulted in a significant improvement of the ductility by microalloying (e.g. by V) and a better understanding of the mechanical behavior of Co–Fe alloys [17–20]. However, our previous results [17] showed that the as-prepared Co–25Fe alloy by suction casting exhibits a large tensile ductility of ∼20%, equal to that of the disordered alloys after secondary processing treatment [19]. The ductility comes from the formation of predominant wave slip behavior rather than planar slip in conventionally processed Co–Fe alloys [17]. This kind of complex stress and complicated straining pattern will improve ductility by deformation-induced grain refinement forming multiscale grained microstructure, as proved in the occurrence of deformation-assisted grain refinement in arc-melted Co–25Fe alloy during mechanical testing [21]. Accordingly, on one hand, it is expected according to the Hall–Petch relationship that the strength of Co–Fe alloys will be improved if the

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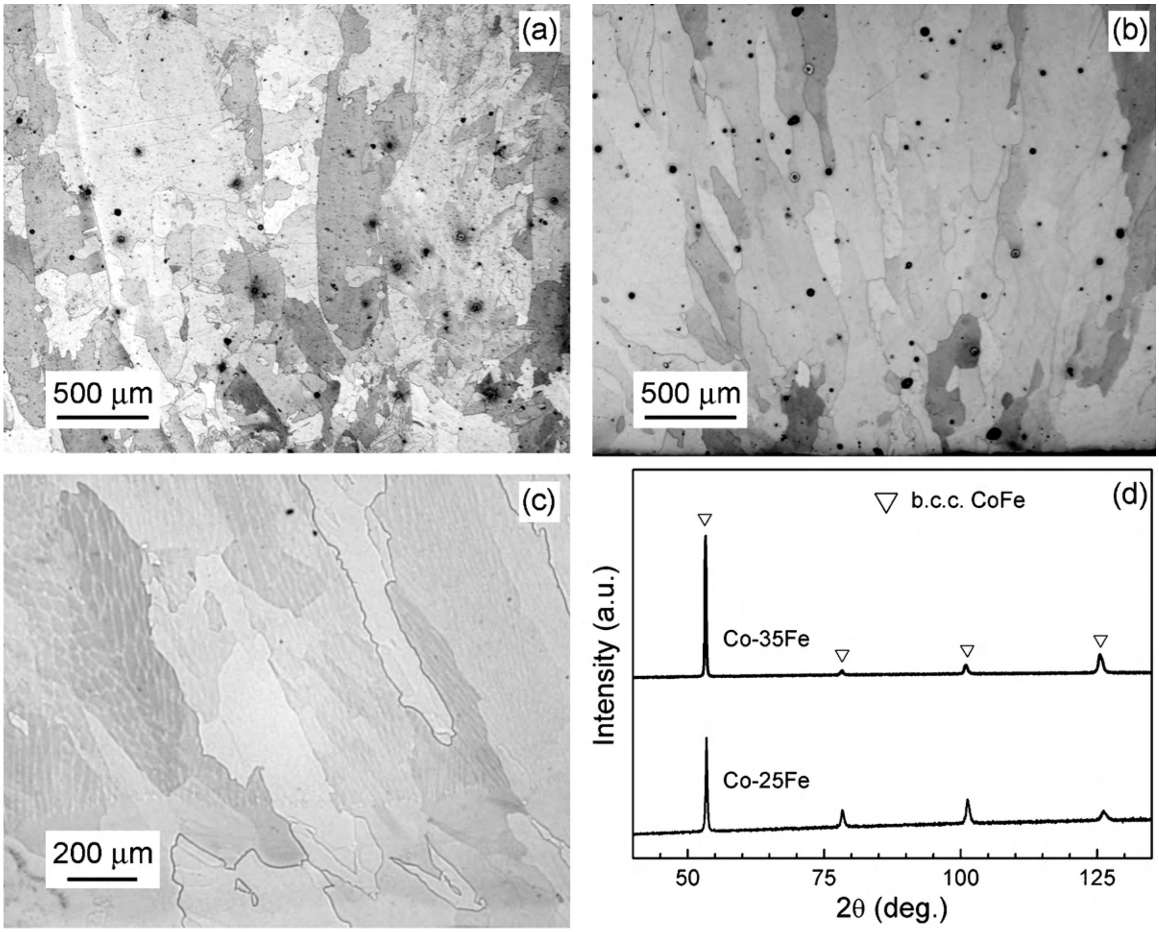

Fig. 1. Cross-sectional optical micrographs for the arc-melted (a) Co–25Fe, (b) Co–35Fe alloys, (c) an enlarged view of the Co–35Fe alloy showing subgrains, and (d) the XRD patterns for both alloys.

grain size of these alloys can be refined to ultrafine or nanometer scale; on the other hand, the formation of multiple length-scale microstructure in the Co–Fe alloys will further enhance their ductility. The easy grain refinement upon conventional room temperature compression is a very interesting phenomenon especially for a potential application to the processing of engineering materials to fine grain sizes, such as from the viewpoint to further improve the mechanical properties of Co–Fe alloys. However, the mechanism of easy grain refinement in Co–Fe under traditional mechanical testing has not revealed [21].

In this work, a detailed microstructure investigation was conducted on the pronounced grain refinement in body-centered cubic (bcc) Co–Fe alloys upon conventional compression testing at room temperature. The aim of this work is twofold: one goal is to gain more knowledge on the grain refinement of Co–Fe alloys; the other is to gain insight into the mechanism of the deformation-induced grain refinement upon conventional room temperature uniaxial compression testing.

2. Experimental procedure

The Co–25Fe and Co–35Fe alloys (weight percent, the same hereafter) were prepared by arc melting a mixture of the pure elements (99.9 wt%) under a Ti-gettered argon atmosphere [17,21]. The cooling rate was estimated to be in the order of 1–10 K/s. The mechanical properties were evaluated under uniaxial compression testing at room temperature. For this purpose, cylindrical specimens with 6 mm diameter and 9–12 mm length were cut from the arc-melted alloys and tested with an Instron 8562 testing machine at a strain rate of $1.2 \times 10^{-4}\,s^{-1}$. Both loading surfaces were carefully polished to be parallel to an accuracy of less than 10 μm. The structural features before and after compression were examined by X-ray diffraction (XRD) using a Philips PW 1050 diffractometer

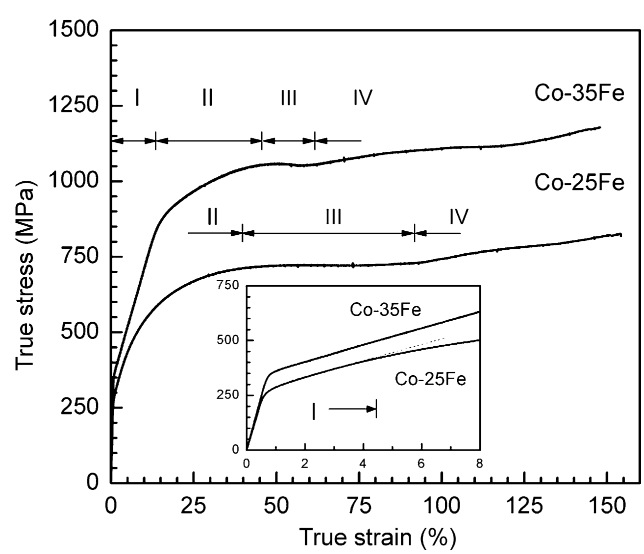

Fig. 2. Typical true stress–strain curves for the Co–Fe alloys under uniaxial compression testing at room temperature. Four different deformation regimes are obvious: I—nonlinear elastic deformation, II—strain hardening, III—stable plastic deformation, and (IV) apparent stress increase.