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$\gamma \rightarrow \varepsilon$ martensite transformation and twinning deformation in fcc cobalt during surface mechanical attrition treatment

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Abstract

The deformation microstructure of face-centered cubic cobalt subjected to surface mechanical attrition treatment was studied as a function of strain levels. Strain-induced $\gamma \rightarrow \varepsilon$ transformation and twinning deformation were evidenced by transmission electron microscopy and were found to progress continuously in ultrafine and nanocrystalline grains as the strain increased.

Keywords: Martensite transformation; Twinning; Nanostructure; Surface mechanical attrition treatment; Cobalt

1. Introduction

Polycrystalline cobalt usually presents a combination of ε hexagonal close-packed (hcp) and γ face-centered cubic (fcc) phases at room temperature [1]. The γ phase is metastable at room temperature and will experience a strain-induced $\gamma \rightarrow \varepsilon$ martensite transformation on deformation [1,2]. X-ray diffraction analyses have demonstrated this phenomenon in ball-milled nanocrystalline (nc) cobalt [3,4]. In particular, the response of $\gamma \rightarrow \varepsilon$ transformation to deformation can lead to enhanced properties, e.g. greater work hardening and higher tensile ductility, as often observed in coarse-grained metastable alloys [5,6]. On the other hand, γ cobalt with low stacking fault energy facilitates twinning on deformation [3]. Twinning may play a crucial role in enhancing work hardening due to the fact that twin boundaries act as strong barriers to dislocation slipping [7–9]. Twinning has been demonstrated recently as being the deformation mechanism in nc metals [10–12]. Hence, the deformation microstructure of γ cobalt may be quite complex due to the deformation mechanism involving interplay between slip, the phase transformation potential and twinning induced by deformation. In the present study the detailed characteristics of deformation microstructure of the γ phase in cobalt subjected to surface mechanical attrition treatment (SMAT) [13] is investigated and correlated with the simultaneous occurrence of $\gamma \rightarrow \varepsilon$ transformation and twinning.

2. Experimental procedure

The material used in this study was an electrodeposited cobalt plate (purity: 99.98 wt%). The X-ray diffraction analysis indicated a duplex hcp and fcc (volume fraction ~18%) structure of the product. The average grain size was found to be ~30 μm.

The technique of SMAT was described in detail in our previous papers [13,14]. In brief, during the SMAT process, the hardened steel balls of 8 mm in diameter were placed at the bottom of a cylinder-shaped vacuum chamber attached to a vibration generator, with which

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the balls were resonated. Because of the high vibration frequency of the system, the sample surface was peened repetitively by a large number of balls within a short period of time. As a consequence the grains in the treated layer of the sample were effectively refined and revealed gradient distribution of grain sizes due to the gradient of strain varying from the surface (extremely large) towards the deep matrix (essentially zero) [13]. Hence, the deformation microstructure of various grain size regimes could be examined at different levels of strain. In the present work, the SMAT process was performed for 50 min at room temperature with a vibrating frequency of 50 Hz in a vacuum. The present study focused on the fcc phase in cobalt while a study of the hcp phase has been reported elsewhere [15].

After SMAT had been carried out, the microstructure was characterized using a transmission electron microscope (TEM, JEM200CX) operated at 200 kV. Both cross-sectional and plane foils were prepared [15].

3. Results

The deformation microstructure of the γ phase was first studied at a low strain level. Fig. 1(a) shows the intersecting planar arrays of dislocations due to slipping of dislocations on respective $\{111\}_\gamma$ plane at a depth of ~170 μm deep below the treated surface. Fig. 1(b) shows $\{111\}$ deformation twins (~160 μm deep). Such deformation modes are characteristic of fcc metals with low stacking fault energy.

Fig. 2(a) and (b) shows the presence of lamellae in the γ phase at higher strain (~150 μm deep). According to the electron diffraction pattern (EDP) as shown in Fig. 2(c), the composite diffractions of the fcc, the $\{111\}$ twin, and hcp are identified. Hence, the lamellae consist of the stacking of platelets of γ, twin, and martensite platelets. This indicates the onset of the $\gamma \rightarrow \varepsilon$ martensite transformation in the presence of strain. The $\gamma \rightarrow \varepsilon$ transformation results in largely coherent martensite platelets, having the (0001) habit plane and strictly complying with the following orientation relationship, namely $(0001)_\varepsilon // \{111\}_\gamma$ and $\langle 11\bar{2}0\rangle_\varepsilon // \langle 110\rangle_\gamma$.

The platelets labeled M_1–M_6 in Fig. 2(a) are ε-martensites according to the EDP as shown in Fig. 2(d). It is interesting to note the presence of the basal stacking faults (SFs) in the martensites. Between the martensite platelets lies the γ phase, as evidenced by the EDP shown in Fig. 2(e), but in this case it reveals a $\{111\}$ twin relationship. Deformation twins with two $\{111\}_\gamma$ orientations, indicated by solid and hollow triangles in Fig. 2(a) are visible in the γ phase. The inset in Fig.

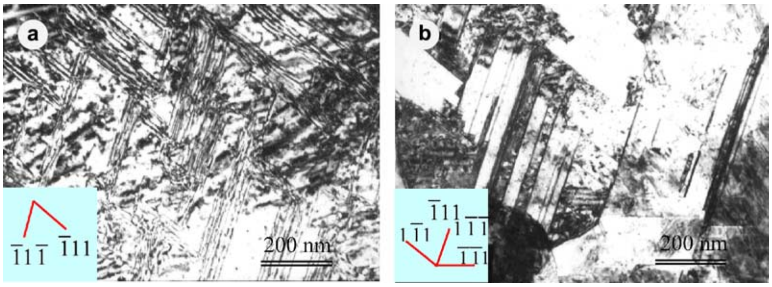

Fig. 1. (a) Planar arrays of dislocations (~170 μm deep) and (b) deformation twins (~160 μm deep).

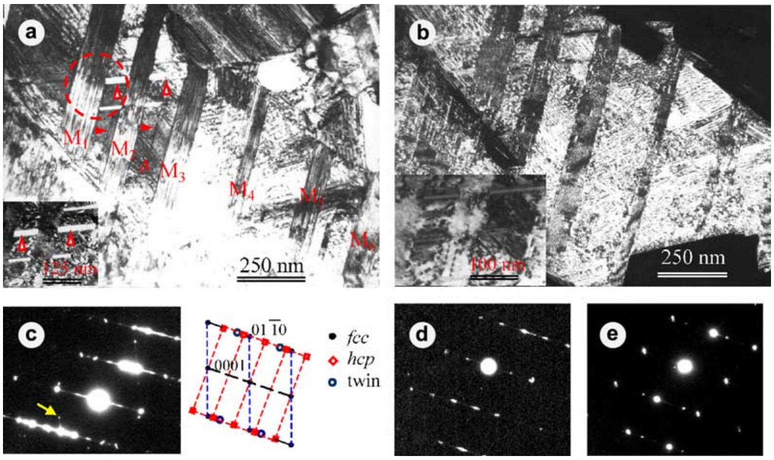

Fig. 2. (a) Lamellae in γ phase (~150 μm deep); (b) dark-field image of γ; (c) EDP from the encircled area in (a), with the zone axis $[\bar{1}10]_\gamma // [1\bar{1}0]_T // [01\bar{1}0]_\varepsilon$; (d) and (e) EDPs from M_1 and A in (a), with $[01\bar{1}0]$ and $[\bar{1}10]$ zone axis, respectively.