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Temperature dependence of microstructure and texture in cold drawn aluminum wire

Xiao-guang MA[1], Jian CHEN[2], Yang YANG[2], Lei LI[2], Zheng CHEN[1], Wen YAN[2]

1. State Key Laboratory of Solidification Processing, School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China;
2. School of Materials Science and Chemical Engineering, Xi'an Technological University, Xi'an 710021, China

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Abstract: The effect of strain and drawing temperature on the evolution of microstructure and fiber textures of aluminum wires drawn at room temperature and cryogenic temperature was investigated by TEM and EBSD observations. The results show that low angle boundaries frequency increases and high angle boundaries frequency decreases with strain increasing when the strain is low. At high strain, most of grain and dislocation boundaries are parallel to the drawn direction and low angle boundaries frequency decreases and high angle boundaries frequency increases with strain increasing. The decrease of deformation temperature leads to microstructure finer and low angle boundaries frequency increasing. Texture analysis indicates that volume fraction of complex texture component decreases with strain increasing and a mixture of ⟨111⟩ and ⟨100⟩ fiber texture forms at high strain. ⟨111⟩ is stable at low strains but ⟨100⟩ becomes stable at high strain. The decrease of temperature can enhance the stability of ⟨111⟩ orientation at high strain.

Key words: aluminum wire; cryogenic drawn deformation; dislocation boundary; fiber texture; misorientation angle distribution

1 Introduction

Because of excellent mechanical behavior of ultra-fine crystal materials, preparations have been extensively studied in the past decades [1−3]. Cold drawn deformation can be used to prepare ultra-fine crystal materials [1] and super-fine bonding wires [3]. In order to understand their properties, microstructure and texture of cold-drawn metal wires have received wide attention [3−5].

During deformation process, the evolution of microstructure and texture is closely relative to stacking fault energy (SFE) [6,7]. For example, PIERCE et al [7] researched on equal channel angular pressing (ECAP) and showed that with the SFE decreasing, grain refinement mechanism transforms from dislocation slip to twin splitting and the minimum critical grain size of ultrafine crystal materials decreases. The investigations on the cold rolling of FCC metals indicated that deformation texture of FCC metals with medium to high SFE is copper-type texture, whereas for FCC metals with low SFE, it is brass-type texture [8−10].

Up to now, for cold drawn deformation, the investigations [10−12] mainly focus on the Ag wires with low SFE (16 mJ/m^2 [13]) and copper wires with medium SFE (45 mJ/m^2 [13]). The study on cold drawn Ag wires shows that abundant of deformation twins form at low strains [10]. The volume fraction of complex texture component decreases, and ⟨111⟩ and ⟨100⟩ texture components paralleled to the axis direction of wires increase with strain increasing. However, when the strain is higher than 0.58, the variation in the volume fraction of each texture component is not evident with strain increasing and the volume fractions of complex, ⟨111⟩ and ⟨100⟩ texture components are about 40%, 35% and 25%, respectively. For drawn copper wires with medium SFE, the predominant deformation mechanism is dislocation slip [11,12]. ⟨100⟩ and ⟨111⟩ are stable orientations during cold drawn process, at high strains, the volume fractions of ⟨100⟩ and ⟨111⟩ are close to 60% and 40%, respectively.

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Corresponding author: Jian CHEN; Tel: +86-29-86173324; E-mail: chenjian@xatu.edu.cn
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In the present work, the microstructure and texture of pure Al wires drawn at room temperature (RT) and cryogenic temperature (CT) are characterized based on the following reasons. Firstly, although the microstructure and texture of drawn FCC metals with low and medium SFE have been widely investigated, little works [14−16] on microstructure evolution of pure FCC metals with high SFE can be found, especially on cold dawn deformation [15]. Al is a typical FCC metal with high SFE (166 mJ/m^2 [13]). Therefore, the microstructure and texture of drawn Al wires can reveal the effect of SFE on microstructure and texture of drawn FCC metals with high SFE. Secondly, the decrease in deformation temperature can lead to the decrease in the SFE [17,18]. Thus, the microstructural analysis of CT-drawn Al wires can further reveal temperature dependence of deformation behavior.

2 Experimental

The experiments were conducted on pure aluminum (99.98%) polycrystalline wires produced by forging, with a diameter of 8 mm. For microstructure homogenization, the Al wires were annealed for 60 min at 300 °C followed by immediate water quenching. Cold drawn process was conducted at RT and CT (the specimens were soaked in liquid nitrogen), respectively. The Al samples were drawn up to a large strain of 4.12. The strains are defined by ε=2ln(d_0/d), where d_0 and d denote the diameter of original (8 mm) and drawn Al wires, respectively.

The samples for electron backscattering diffraction (EBSD) analysis were polished mechanically and then electro-polished in a solution of ethanol and perchloric acid (11:1) at 30 V and −25 °C for 2 min. EBSD analysis was performed on a FEI field emission gun scanning electron microscope at 20 kV with a working distance of 18 mm and 70° tilt angle using an Oxford Instruments HKL Nordlys F+ camera with HKL fast acquisition software. For textural measurements, a large area from the center to the surface of samples was investigated using step sizes between 0.3 and 2 μm. The fraction of successfully indexed orientation was higher than 65% and, in most cases, higher than 75%. For the microstructure determination, step sizes between 0.04 and 0.1 μm were used. For all maps used for microstructural imaging, the fraction of successfully indexed orientation was higher than 75% and, in most cases, higher than 85%. Non-indexed data points were repaired by HKL Channel 5 software. The samples for TEM were electro-polished using the same solution as EBSD, and TEM analysis was carried out on a JEM 2010 with an acceleration voltage of 200 kV.

3 Results and discussion

3.1 Grain macroscopic subdivision

Figure 1 shows the EBSD orientation maps of RT-drawn Al samples. It can be seen that the grains are equiaxed in the annealed Al sample and the average grain size is about 100 μm. The results in Figs. 1(b)−(d) show that grains are elongated along the drawn direction with strain increasing. Meanwhile, the grain subdivision appears in some grains. When strain is higher than 1.96, almost all original grain boundaries are parallel to cold drawn direction and fiber microstructure forms (Figs. 1(e)−(h)).

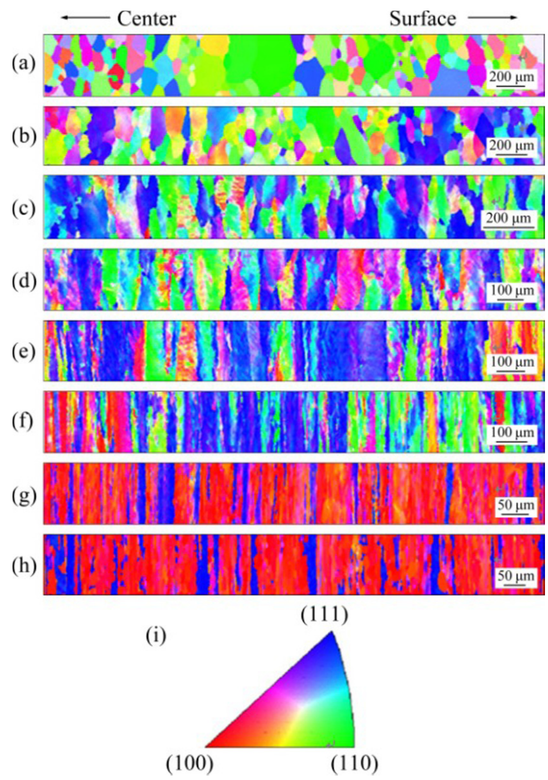

Fig. 1 Drawn direction EBSD orientation maps of RT-drawn Al at strains of 0 (a), 0.28 (b), 0.58 (c), 0.94 (d), 1.39 (e), 1.96 (f), 2.77 (g) and 4.12 (h)

Figure 2 shows the EBSD orientation maps of CT-drawn Al samples with strains higher than 1.39. Because the decrease of ductility leads to the fracture of wires during CT deformation, the EBSD orientation map of CT-drawn Al samples at strain of 4.12 is not given in Fig. 2. The results in Figs. 1 and 2 show that the microstructure evolution in the CT-drawn wires is analogous to the RT-drawn samples. However, the decrease of deformation temperature can accelerate macro-subdivision. Compared to the RT-drawn wires, CT-drawn Al samples have a smaller space of deformation bands and less critical strain of the formation of fiber microstructure.