Available online at www.sciencedirect.com
ScienceDirect
Trans. Nonferrous Met. Soc. China 25(2015) 3953−3958
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Microstructure evolution of alumina dispersion strengthened copper alloy deformed under different conditions

Ling LI[1], Zhou LI[1,2], Qian LEI[2], Zhu XIAO[3], Bin LIU[1], Na LIU[1]

1. School of Materials Science and Engineering, Central South University, Changsha 410083, China;
2. State Key Laboratory of Powder Metallurgy, Changsha 410083, China;
3. Key Laboratory of Nonferrous Metal Materials Science and Engineering, Ministry of Education, Central South University, Changsha 410083, China

Received 26 November 2014; accepted 5 May 2015

Abstract: Microstructure and texture evolution of Cu−0.23%Al_2O_3 dispersion strengthened copper alloy, deformed at room temperature or cryogenic temperature, were investigated. The main textures in hot-extruded specimen were Brass {011} ⟨211⟩ and Cube {100} ⟨100⟩. Textures of Brass {011} ⟨211⟩ and Goss {011} ⟨100⟩ were observed in specimen after deformation at room temperature; while textures of Brass {011} ⟨211⟩, Goss {011} ⟨100⟩ and S {123} ⟨634⟩ were detected after deformation at cryogenic temperature. It is believed that the additional Al_2O_3 nanoparticles can result in dislocation pinning effect, which can further lead to the suppression of dislocations cross-slip. While in the specimen deformed at cryogenic temperature, both pinning effect and cryogenic temperature are responsible for the formation of Brass, Goss and S textures.

Key words: cryogenic deformation; microstructure; texture; dispersion strengthened copper alloy

1 Introduction

Copper alloys have been widely applied in electro-technique, electronic information technique, automotive industry, due to their superior electrical and thermal conductivities as well as excellent ductility and machinability [1,2]. Oxide dispersion strengthened copper alloys, such as Cu−Al_2O_3, Cu−TiB_2, Cu−ThO_2, Cu−Y_2O_3 and Cu−CaO [3,4], are newly innovated copper alloys, which boast high strength and electrical conductivity. In recent years, Cu−Al_2O_3 alloys have attracted a great deal of interest [5,6]. Most previous researches have been concentrated on the deformation behavior of Cu−Al_2O_3 alloys during deformation at room temperature. According to the results of their researches, Al_2O_3 nanoparticles show great influence on the deformation characteristics of Cu−Al_2O_3 dispersion strengthened copper alloy [7,8]. On one hand, Al_2O_3 nanoparticles act as dislocation source, and a large amount of dislocations multiply during deformation. On the other hand, the pinning effect of Al_2O_3 nanoparticles on long range motion of dislocations inhibits the creation of dislocation cells in Cu−Al_2O_3 dispersion strengthened copper alloys.

The advantages of cryogenic deformation are readily discernible, such as grain refinement, which enhances both the strength and hardness [9]; its inducement of deformation twinning or/and shear zone, which improves the strength without sacrificing conductivity [10]; and its promotion on the formation of deformation textures, which adjusts the anisotropic properties [11,12]. However, the microstructure evolution of Cu−Al_2O_3 dispersion strengthened copper alloys during cryogenic deformation has not yet been reported. This work focuses on the microstructure evolution of Cu−0.23%$A1_2O_3$ (volume fraction) alloy deformed at cryogenic temperature or room temperature, in order to fulfill the realization of optimum comprehensive properties.

2 Experimental

A Cu−0.23%$A1_2O_3$ alloy was produced using an

Foundation item: Project (51271203) supported by the National Natural Science Foundation of China; Project (YSZN2013CLD6) supported by the Nonferrous Metals Science Foundation of HNG-CSU, China; Project supported by the Program Between the CSC (China Scholarship Council) and the DAAD (German Academic Exchange Service)
Corresponding author: Zhou LI; Tel: +86-731-88830264; E-mail: lizhou6931@csu.edu.cn
DOI: 10.1016/S1003-6326(15)64044-4

internal oxidation process [13]. The process included: 1) induction melting of Cu−0.05%Al (mass fraction) alloy in mid-frequency induction furnace, 2) nitrogen atomization, 3) mixing of the atomized Cu−Al alloy with an oxidant, 4) oxidation at 1000 °C for 1 h, 5) hydrogen reduction at 900 °C for 1 h under a pressure of 27 MPa and a vacuum of 1.33×10^{-2} MPa, and 6) hot extrusion at 930 °C with a ratio of 20:1 to form the final cylinder with a diameter of 53 mm. Samples with dimensions of 30 mm (length) × 30 mm (width) × 20 mm (height) were cut from the hot-extruded rod. Multiple forging processes were carried out until the heights of samples were reduced from 20 to 4 mm (reduced by 80% in height) during deformation at both room and cryogenic temperatures. Specimens had been given cryogenic treatment in a liquid−nitrogen solution (−196 °C) for 30 min before each cryogenic temperature forging process.

Specimens for optical microscope observation were ground, polished and finally etched by a solution containing ferric chloride (5 g), hydrochloric acid (25 mL) and alcohol (100 mL). The microstructure of metallographic specimens was observed using a Leica optical microscope. Electron back-scattered diffraction (EBSD) analysis was carried on a Siron 200 scanning electron microscope equipped with EBSD detector, with a scanning area of 10 μm×10 μm and a scanning step size of 45 nm. The X-ray diffraction texture analysis was conducted on a D8 Discover X-ray diffractometer. The orientation distribution function (ODF) maps were calculated using the harmonic series expansion method (series rank 22, Gaussian smoothing 5°, orthorhombic sample symmetry). Fractions of texture components were calculated using a texture calculation software [14]. Specimens for EBSD and XRD texture analysis were surface treated by electro-polishing. Transmission electron microscopy (TEM) observation was performed using a JEOL−2100F transmission electron microscope. Specimens for TEM observation were reduced by jet-polishing in a solution containing 25% nitric acid and 75% methanol. The central sections of the samples were selected to observe the microstructure and texture evolution.

3 Results and discussion

3.1 Microstructure of materials

Figure 1 shows the metallographic microstructure evolution of $Cu-Al_2O_3$ alloy during deformation process. Equiaxed grains appeared in the hot-extruded specimens, with an average size of 50 μm, before deformation (Fig. 1(a)). Fiber-shape morphology occurred in the specimen after forging deformation at cryogenic temperature (CT) and room temperature (RT) with a reduction of 80% (Figs. 1(b) and (c)). Compared with the non-forging specimen, the grain boundaries of specimens forged at CT and RT became discontinuous, which suggested that initial grains were refined during forging deformation process. Furthermore, the average width of fibers in specimens forged at CT was less than that of specimens forged at RT.

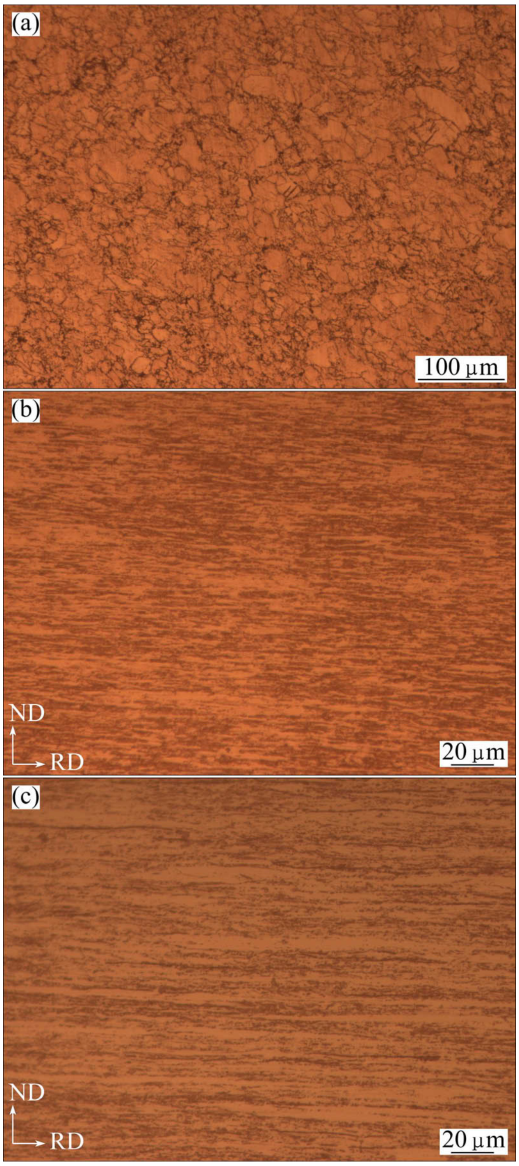

Fig. 1 Optical micrographs of hot-extruded $Cu-0.23\%Al_2O_3$ alloy (a) and specimens forged at different temperatures with a reduction of 80%: (b) Cryogenic temperature; (c) Room temperature

Figure 2 shows the EBSD maps of the specimens after forging at CT and RT. Grains were compressed in transverse direction (TD), and many sub-boundaries were observed after forging deformation. Compared with grains deformed at RT (Fig. 2(b)), the sizes of grains deformed at CT were smaller (Fig. 2(a)). As shown in Fig. 3, the percentage of grains with the diameter less than 0.2 μm in specimens forged at CT was 87%