Materials Science & Engineering A 624 (2015) 71–78

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Efficiency of the refinement by deformation twinning in wire drawn single phase copper alloys

A. Kauffmann [a,c], J. Freudenberger [a,b,c,*], H. Klauß [a], W. Schillinger [d], V. Subramanya Sarma [e], L. Schultz [a,c]

[a] IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany
[b] TU Bergakademie Freiberg, Institute of Materials Science, 09596 Freiberg, Germany
[c] TU Dresden, Institute of Materials Science, 01062 Dresden, Germany
[d] Wieland-Werke AG, Graf-Arco-Straße 36, 89079 Ulm, Germany
[e] Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai 600036, India

ARTICLE INFO

Article history:
Received 18 July 2014
Received in revised form
2 October 2014
Accepted 17 November 2014
Available online 25 November 2014

Keywords:
Deformation twinning
Copper alloys
Cryogenic deformation
Stacking fault energy
Texture transition

ABSTRACT

The microstructure of single phase copper alloys is altered by cold deformation. Depending on the processing parameters like temperature and intrinsic material parameters as stacking fault energy, the dominant deformation mechanism is different and the refinement of the microstructure bears other rates with respect to the deformation strain. The formation of deformation twins is activated at low homologous temperature or at low stacking fault energy. Both also lead to smaller grain sizes achieved at a certain deformation strain. Lowering the temperature only yields to a high efficiency in strain hardening with respect to room temperature deformation for intermediate stacking fault energies. The maximum efficiency is found to occur in the vicinity of the onset of deformation twinning at room temperature which was found for a stacking fault energy of 30 mJ/m^2. The thermal stability of the microstructure is assessed by means of in situ resistivity measurements.

1. Introduction

There is significant industrial and commercial interest in increasing mechanical strength in balance with good ductility. Currently the most promising way of achieving a good combination of high mechanical strength and good ductility is by the formation of ultra-fine grained (UFG) microstructures. From economic point of view, advanced processing techniques for producing UFG materials rather than expensive alloying strategies are thus being developed or optimised. As an example, cryogenic deformation methods are investigated for their effectiveness to produce UFG microstructures [1–13].

The detailed progress of plastic deformation in single phase, face-centred cubic (FCC) metals is significantly altered by the temperature during deformation and their stacking fault energy (SFE). By either lowering temperature during deformation or SFE [11–16], suppression of dynamic recovery is achieved and deformation twinning besides dislocation slip can be activated due to the rising stress level. Especially, deformation at liquid nitrogen temperature enhances the possibility for activating deformation twinning in pure copper [12]. This leads to significantly different restructuring of the microstructure during deformation and a suitable strength increase when compared to conventional room temperature deformation [11,13].

By investigating the strength increase in the case of several copper- and aluminium-based materials due to deformation at room temperature (RT) vis-à-vis cryogenic temperature (CT), we obtained a maximum efficiency of strengthening due to cryo-deformation in dependence of SFE [11]. In the case of aluminium-based materials with high SFE of the order of 150–200 mJ/m^2, dislocation slip is dominant both at RT and CT. Thus, no significant difference in strengthening due to varying temperature is observed. At low SFE, e.g. in highly alloyed copper with poly-valent solute atoms (Zn, Al, Ga, Sn, Ge, etc.), plastic deformation is mediated by twinning over a wide temperature range and the material is restructured during the deformation process at RT as well as CT. An optimum of the strengthening efficiency of cryogenic deformation is observed in the vicinity of the onset of deformation twinning at RT.

In order to link the onset of deformation twinning which is a function of SFE and temperature during deformation to the change of mechanical properties, we performed a detailed analysis of

* Corresponding author at: IFW Dresden, P.O. Box 270116, 01171 Dresden, Germany.
E-mail address: j.freudenberger@ifw-dresden.de (J. Freudenberger).

http://dx.doi.org/10.1016/j.msea.2014.11.052
0921-5093/

global and local texture of single phase CuAl alloys subjected to wire-drawing. Due to the distinct orientation dependence of the occurrence of deformation twinning under mechanical load in combination with the state of stress and the texture evolution during wire-drawing [12], a relevant evaluation of deformation twinning can be done by means of texture analysis. These results are supported by the interpretation of the refinement potential provided by deformation twinning by means of electron backscatter diffraction and its resulting influence on the mechanical and electrical properties as well as the thermal stability of the investigated materials.

2. Experimental

Cu–Al alloys with varying Al content from 1 wt% to 7 wt% were melted in an induction furnace and cast into a graphite mould ($D=30$ mm, $l=300$ mm) in argon atmosphere from oxygen-free copper (Cu-OFE) and pure aluminium ($>99.99\%$). The nominal composition of the alloy is provided in the form of CuAlX where X represents the mass fraction of Al. Casting defects near surface were removed by machining the ingots to $D=28.5$ mm after homogenisation at 800 °C for 5 h in argon atmosphere. Rotary swaging down to $D=10.40$ mm was adopted in combination with a final annealing for 4 min above the recrystallisation temperature of the corresponding alloys in order to remove the as-cast microstructure. The preparation of pure copper and the details of the wire-drawing at RT and in liquid nitrogen (CT) are described elsewhere [13]. With a step reduction of about 0.4 true strain per step a final true strain of 2.4 was achieved.

Microstructural characterisation was carried out by scanning electron microscopy (SEM) using a FEI Helios 600i operating at 20 kV and 11 nA. The samples were prepared by a conventional metallographic procedure. Finally, vibratory polishing was applied using a VibroMet® 2 machine with Mastermet® 2 suspension (both provided by Buehler, Germany) for about 8 h. Electron backscatter diffraction (EBSD) was performed using an EDAX DigiView system. Global texture was analysed by means of X-ray diffraction using a Philips X'Pert MRD system operating with Cu-Kα radiation. After correction of defocusing (obtained from powder samples), orientation distribution function (ODF) of the sample (seven wire cross sections in parallel) was calculated utilising LaboTex 3.0 [17]. For plotting inverse pole figures of the wire axis, preparation induced tilt of the sample of a few degrees was corrected in order to get a centred ⟨111⟩–fibre texture component parallel to the wire axis. Tensile tests were performed at RT on as-drawn samples with a total length of 140 mm using an electro-mechanical Instron 8562 testing machine at a cross head displacement rate of 0.1 mm/min.

3. Results and discussion

In order to determine the onset of deformation twinning at RT as a function of SFE, we performed texture analysis on the cross sections of wires drawn up to true strain of 2.4. The results are depicted as inverse pole figures of the wire axis in Fig. 1. In pure copper and CuAl1, ⟨111⟩- and ⟨001⟩–fibre texture components are present only. These texture components are characteristic for wire-drawn FCC metals undergoing deformation by dislocation slip and the absence of additional texture components indicates homogeneous plastic deformation [18]. At alloying contents of 2 wt% Al and above, indications of deformation twinning in the form of a ⟨115⟩–fibre texture component are observed. This texture component corresponds to the ideal site of a $\{111\}\langle 11\bar{2}\rangle$–twin in a ⟨111⟩–fibre oriented crystal. The evolution of the ⟨115⟩–fibre orientation is similar to the evolution of the {552}⟨115⟩ rolling texture component resulting from twinning of the copper component {112}⟨111⟩ [19]. Matrix grains are aligned with ⟨111⟩ crystallographic axis parallel to the wire axis since these are favorable for deformation twinning under tensile load [12]. Predominately, twins with composition plane inclined to the wire axis appear since these lamellae provide a strain component in the direction of the wire axis. The twinning transform corresponds to a 60° rotation about the ⟨111⟩–axes which are inclined to the wire axis and results in the change towards the ⟨115⟩–fibre texture [20]. Table 1

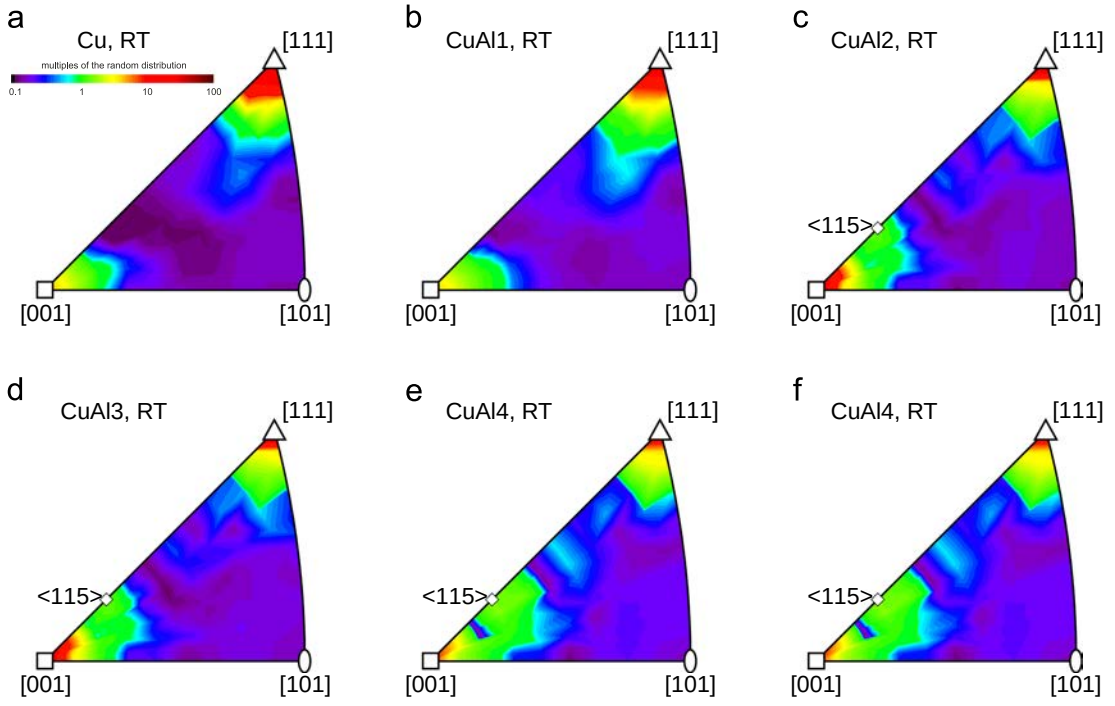

Fig. 1. Texture transition in CuAl-wires drawn at RT as a function of composition: (a) Cu, (b) CuAl1, (c) CuAl2, (d) CuAl3, (e) CuAl4 and (f) CuAl7.