Journal of Alloys and Compounds 749 (2018) 399–405

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Development of Goss texture in Al–0.3%Cu annealed after heavy rolling

L.F. Shuai [a], T.L. Huang [a, *], G.L. Wu [a, **], X. Huang [a, b], O.V. Mishin [b]

[a] College of Materials Science and Engineering, Chongqing University, Chongqing 400045, China
[b] Department of Mechanical Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark

ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form
9 March 2018
Accepted 14 March 2018
Available online 15 March 2018

Keywords:
Aluminum alloys
Cold rolling
Annealing
Recrystallization
Goss texture

ABSTRACT

The evolution of the microstructure and texture during annealing has been studied in the center layer of 95% cold rolled Al–0.3%Cu with a large initial grain size. The cold-rolled condition is characterized by a strong Brass texture component and a deformed microstructure comprising lamellar structures intersected by a large number of shear bands. Recrystallization and precipitation take place during annealing at 200 °C, and a strong Goss texture develops. In the beginning of recrystallization, Goss oriented grains nucleate preferentially at the shear bands. At a later stage of recrystallization, new Goss nuclei can appear in regions where lamellae of the dominant Brass component are interspersed with Goss-oriented subgrains. When recrystallization is almost complete, recrystallized Goss-oriented grains grow into grains of other orientations, which results in a rapid increase in the average grain size of Goss-oriented grains and strengthening of the Goss texture. As a result, new low angle boundaries are formed between Goss-oriented grains in this strongly textured material.

1. Introduction

Depending on the chemical composition, homogenization and subsequent thermomechanical processing, different annealing textures can develop in rolled Al-alloys. The most commonly reported recrystallization texture component after heavy rolling in aluminum with a low concentration of impurities is the cube texture {001}⟨100⟩ [1–4]. However, in Al-alloys containing coarse particles the texture can be dominated by the P component, defined as either {011}⟨111⟩, {011}⟨566⟩ or {011}⟨122⟩ [4–9], which is typically attributed to particle stimulated nucleation. A so-called retained deformation texture can be produced during annealing when recrystallized grains have orientations of the rolling texture [1,4,10]. The Goss {110}⟨001⟩ texture along with a weaker Q {013}⟨231⟩ component has also been reported after annealing of heavily rolled Al-alloys [11–13]. Compared to the other "standard" rolling texture components, such as Copper (Cu) {112}⟨111⟩, S {123}⟨634⟩ and Brass (Bs) {110}⟨112⟩, the Goss orientation is a minor rolling texture component. Whenever this component is produced during recrystallization, it alters the rolling texture so much that the final texture can no longer be described as a retained deformation texture.

In previous studies of Al–1.8%Cu, it has been suggested that grains of the Goss and Q orientations nucleate at shear bands [4,11,12]. Furthermore, local orientation measurements in Al–1%Mg provided experimental evidence that grains of these orientations can indeed nucleate at shear bands [13]. However, quantitative microstructural analysis of such grains and their evolution during annealing has not been conducted in these early publications. It should also be noted that since nucleation at shear bands results in grains of different orientations, and since there can also be other types of nucleation sites, the Goss component in the recrystallization texture is combined with other texture components. Therefore, reported volume fractions of the Goss component in the annealing texture are usually moderate [13,14].

A rather strong Goss component was found in our preliminary study [15] of a heavily rolled and subsequently annealed Al–0.3%Cu alloy. After recrystallization at 200 °C, the fraction of the Goss texture in this alloy was approximately 40%. The very limited microstructural analysis presented in Ref. [15] was insufficient to clearly understand how the deformed material evolved to produce such a strong Goss texture during annealing. Therefore, the purpose of the present work is to characterize in detail the development of this strong texture during isothermal annealing covering both

* Corresponding author.
** Corresponding author.
E-mail addresses: huangtl@cqu.edu.cn (T.L. Huang), wugl@cqu.edu.cn (G.L. Wu).

https://doi.org/10.1016/j.jallcom.2018.03.187
0925-8388/

nucleation and growth of Goss-oriented grains. Electron backscatter diffraction (EBSD) is used in this work to monitor the evolution of microstructure and texture starting from the as-rolled sample to a completely recrystallized material.

2. Experimental

The material used in this experiment was produced from 99.999% pure Al and oxygen-free high conductivity copper. The as-cast ingot contained 1.5–2 mm large grains and was forged at 200 °C to obtain a 50 mm thick plate suitable for cold rolling. X-ray texture measurements revealed different dominant orientations in specimens taken from several different regions of the forged material, thus reflecting the presence of very large grains of varying orientations. The only consistent result obtained from the different regions was an increased concentration of orientations near the Goss component [15]. The microstructural examination of the forged sample demonstrated that the initial grains could still be clearly identified in the microstructure and that they were subdivided by dislocation boundaries. The forged sample was cold-rolled by multiple passes to a final thickness of 2.5 mm, which corresponded to a reduction of 95% (von Mises strain $\varepsilon_{vM} = 3.46$). The rolled material was inhomogeneous through the sample thickness, and could roughly be divided into 3 distinct layers, each with a thickness of approximately 1/3 of the sample thickness. All examinations in the present work were conducted for the center layer with a thickness of ~0.8 mm. The cold-rolled sample was annealed at 200 °C for different periods of time.

The microstructure was investigated using a Zeiss Supra 35 field emission gun scanning electron microscope equipped with a Channel 5 EBSD system and in a Zeiss AURIGA dual-beam SEM equipped with an AZtecHKL EBSD package. The longitudinal section containing the rolling direction (RD) and the normal direction (ND) was prepared using mechanical polishing followed by electrolytic polishing. A step size of either 25 nm or 30 nm was used for the EBSD analysis of the deformed microstructure, while larger step sizes were used for microstructural examinations of the annealed samples. Low angle boundaries (LABs) and high angle boundaries (HABs) in the EBSD data were defined as boundaries with misorientations $\theta = 2–15°$ and $\theta \geq 15°$, respectively.

The energy stored in the deformed and recovered microstructure was calculated from the EBSD data as described by Godfrey et al. [16,17]. The specific boundary energy of the LABs was calculated from the Read–Shockley equation [18,19], whereas the specific boundary energy of HABs was assumed to be 0.324 J/m^2 [20]. Recrystallized grains were identified based on the method described in Ref. [21]. In the present work, such grains were defined as regions greater than 5 μm with internal misorientations less than 1° surrounded by boundaries with $\theta \geq 2°$. An additional criterion was that there should be at least one HAB segment among the boundaries between each recrystallized grain and its surrounding matrix.

Texture measurements of the rolled sample and each annealed sample were conducted using EBSD with a step size of 10 μm and covering several millimeters along the RD and the entire thickness of the center layer. Fractions of texture components were calculated applying a 15° deviation from the closest exact {*hkl*}⟨uvw⟩ orientation.

Electrical conductivity was measured using a portable eddy-current conductivity meter D60K. The measurements were

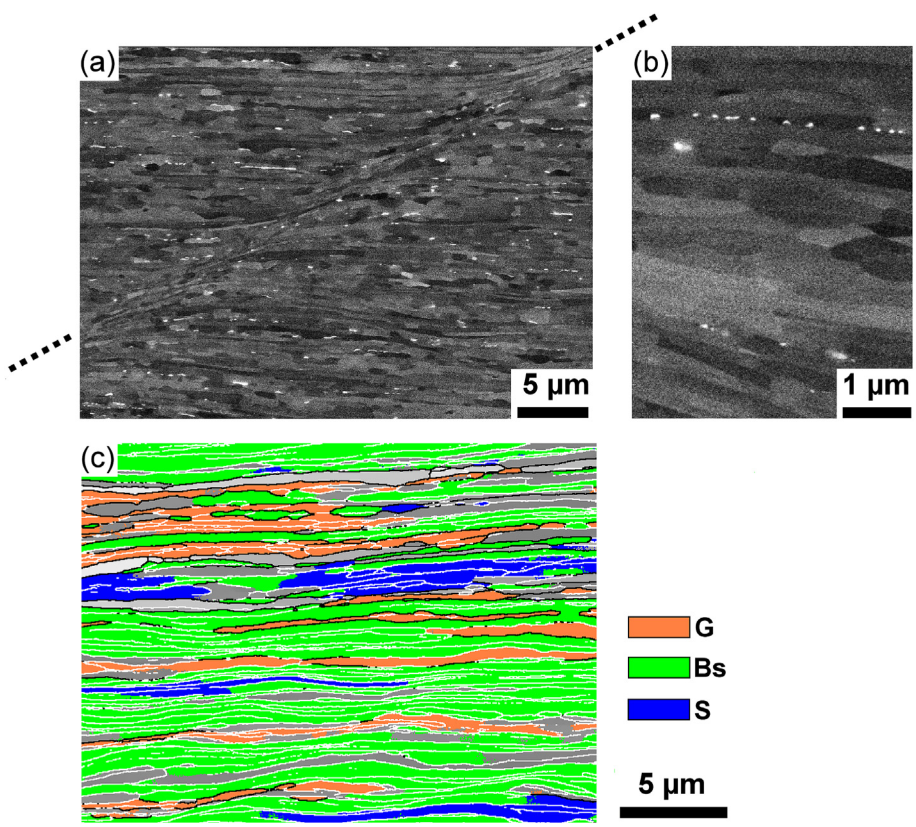

Fig. 1. Microstructure of 95% rolled Al–0.3%Cu: (a) BSE image showing lamellar structures and a shear band (marked by a dashed line). (b) a high magnification BSE image showing particles (bright features); (c) orientation map obtained using EBSD, where random orientations are shown in gray and where LABs and HABs are shown as white and black lines, respectively. The RD is parallel to the scale bar. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)