Materials Characterization 128 (2017) 37–42

Contents lists available at ScienceDirect

Materials Characterization

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

Microstructure and microtexture evolution of shear bands in Al–Cu single crystal during asymmetric rolling

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ARTICLE INFO

Article history:
Received 21 September 2016
Accepted 12 March 2017
Available online 22 March 2017

Keywords:
Asymmetric rolling
Single crystal
EBSD
Shear bands
Texture

ABSTRACT

Asymmetric rolling process (ASR) introduces extra shear deformation compared with conventional symmetric rolling (SR), and induces shear bands in microstructures. ASR technique has been applied to manufacture thick aluminum plate with improved mechanical properties due to the fine grains or even ultrafine-grains obtained in shear bands. Single crystal specimens of Al–Cu alloys were prepared in this work to study the microstructure and texture evolution in asymmetric rolled sheet. Microstructures of deformation bands were observed and the microtexture was analyzed through electron backscatter diffraction (EBSD). Compared with the SR process, ASR induced more homogeneous deformation and shear bands were observed in deformation area. Microstructure of shear bands depends on the initial orientations of single crystals. After single crystal with $(3, -1, 9)$ plane orientation is processed in ASR, shear bands consist of S-type grains were formed, which have uniform size and almost the same twisting degree. But for single crystal with $(-3, 0, 7)$ plane orientation, shear bands have various twisting degrees and grains distributed inhomogeneously. Texture of the shear bands in ASR processed specimens always rotated towards Copper component for single crystals with different orientations.

1. Introduction

Asymmetric rolling process (ASR), which was applied to obtain fine grains or even ultrafine-grained materials, can feasibly be adapted in industry scale [1–2]. As previous investigations reported [3–5], asymmetric rolling is a process in which the upper and lower rolls with different peripheral velocities or feeding the sheet into the rotating rolls with a specified angle. A rolling technique combined the rolls with different peripheral velocities and horizontally-displaced rolls to get the specified feeding angle has been presented as snake rolling [6]. Compared with conventional symmetric rolling (SR) process, ASR introduces severe plastic deformation and extra shear bands appear in microstructures. The snake rolling technique has been applied to manufacture thick aluminum plate with improved mechanical properties due to the extra shear deformation introduced compared with conventional symmetric process [7–8].

Textures formed by ASR process are different from those formed by SR process [9–10]. In metals with face-centered cubic (f.c.c.) crystal structure, such as aluminum, for SR process, the brass-type component, $\{110\}\langle 112\rangle$ increases with rolling reduction, but copper-type, $\{112\}\langle 111\rangle$ and S-type, $\{123\}\langle 634\rangle$ reach the maximum at reduction greater than 80% [11]. The development of texture component is equal to the β fiber change in the Euler space, which runs from brass through *S* to copper [11]. However, the additional shear deformation in ASR process produces a strong $\{111\}\parallel$ND fiber texture [9]. While aluminum alloys with $\{111\}$ fiber texture component have lower planar anisotropy [12], Al sheets manufactured by ASR can present high formability [7].

Single crystals have been used in analyzing texture because the deformation texture developed by rolling depends on the initial crystal orientation [13–16]. As the single crystallographic orientation of single crystal, the slight difference of microstructure and texture components is more easily to observe, when single crystals were used in studying the various rolling process. Kikuchi et al. [14] studied the rotation of rolling textures in copper single crystals, and they found that $\{112\}\langle 111\rangle$, $\{110\}\langle 112\rangle$, $\{110\}\langle 001\rangle$ and $\{123\}\langle 412\rangle$ orientations are maintained after heavy deformation. However, crystal rotation occurs easily in the case of single crystals with the initial $\{123\}\langle 412\rangle$ and $\{001\}\langle 100\rangle$ orientations. All the above texture results were based on texture measurements without reference to microstructure observations or on qualitative estimates of the lattice rotations leading to the textures. Rolling textures change of specimens is easy to test and analyze quantitatively combined with the microstructure observation by the electron backscatter diffraction (EBSD) method. In this study, single crystal specimens of Al-Cu alloys were processed by ASR

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http://dx.doi.org/10.1016/j.matchar.2017.03.022
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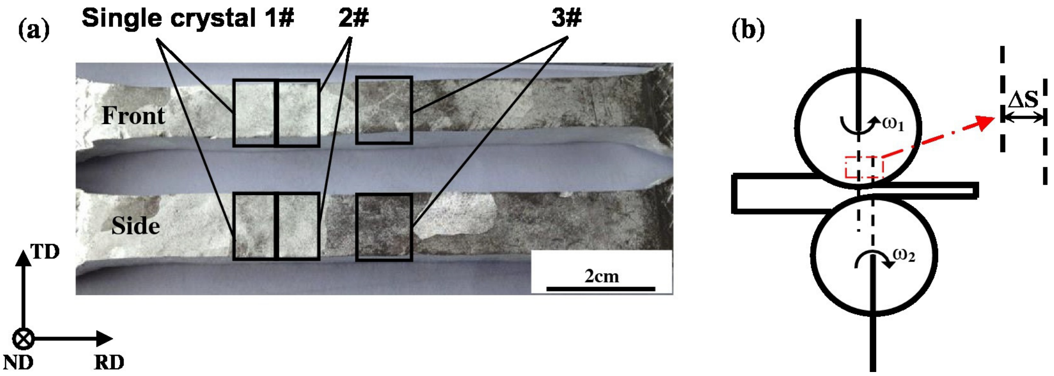

Fig. 1. (a) Large grains bar with single crystal specimens 1#, 2# and 3#; (b) Schematic illustration of the rolling system designed for ASR process.

and SR. Microstructures of deformation bands were observed and the microtexture evolution was analyzed through EBSD.

2. Materials and Methods

The raw material of the single crystal specimens used in this study was Al–1.45Cu (wt%) alloy. Single crystal specimens with grain up to 10 mm diameter were grown by pulling bars cut from the alloy plate to 0.5–1.0% strain, followed by annealing in a forced-air furnace at 525 °C for 24 h, then repeating the cycle 8–10 times. Single crystals 1#, 2# and 3# were cut from the macro-grains bars showed in Fig. 1. The three dimensions of all three rectangular specimens are the same with 15 mm × 10 mm × 10 mm. The orientations of three single crystals were determined by EBSD in the FEI Helios NanoLab™ 600i DualBeam Scanning Electron Microscopy. Crystallographic orientations of raw single crystals 1# and 2# are the same with $(3, -1, 9)$ $[-8, 3, 3]$, while 3# has a different orientation $(-3, 0, 7)$ $[7, -5, 3]$. Single-pass cold-rolling experiments were carried out on a special rolling system, which is showed as schematic in Fig. 1. The rolling mill has a roll diameter of 100 mm for both rolls, at room temperature and without lubricants applied, and the rotational speed of the lower roll was fixed at 15 rpm. The speed ratio (ω_1/ω_2) of two rollers could be adjusted through change the rotational speed of upper roll, while an offset distance (ΔS) also could be set. For ASR process in this study, the rotational ratio between the upper and lower rolls (ω_1/ω_2) is 1.3 and the offset distance (ΔS) is 4 mm. For comparison, conventional SR process (i.e. $\omega_1/\omega_2 = 1$ and $\Delta S = 0$) experiments is conducted. Single crystals 2# and 3# were under ASR process, while 1# was SR. All three single crystals were cold-rolled by 50% reduction. Texture and microstructure of rolled sheets were measured by EBSD, and all the microstructures were recorded on the normal plane (ND) of the rolled sheet. Prior to EBSD, the normal rolling surface (RD-TD) of the samples were mechanically ground and polished to 3000 grit using SiC paper, then electro-polishing in a mixture of 10% perchloric acid and 90% ethanol at 22 V for 10 s at room temperature. The raw data were analyzed using the TSL OIM Analysis 6.5 software [17]. Microtextures were determined according to only the originally

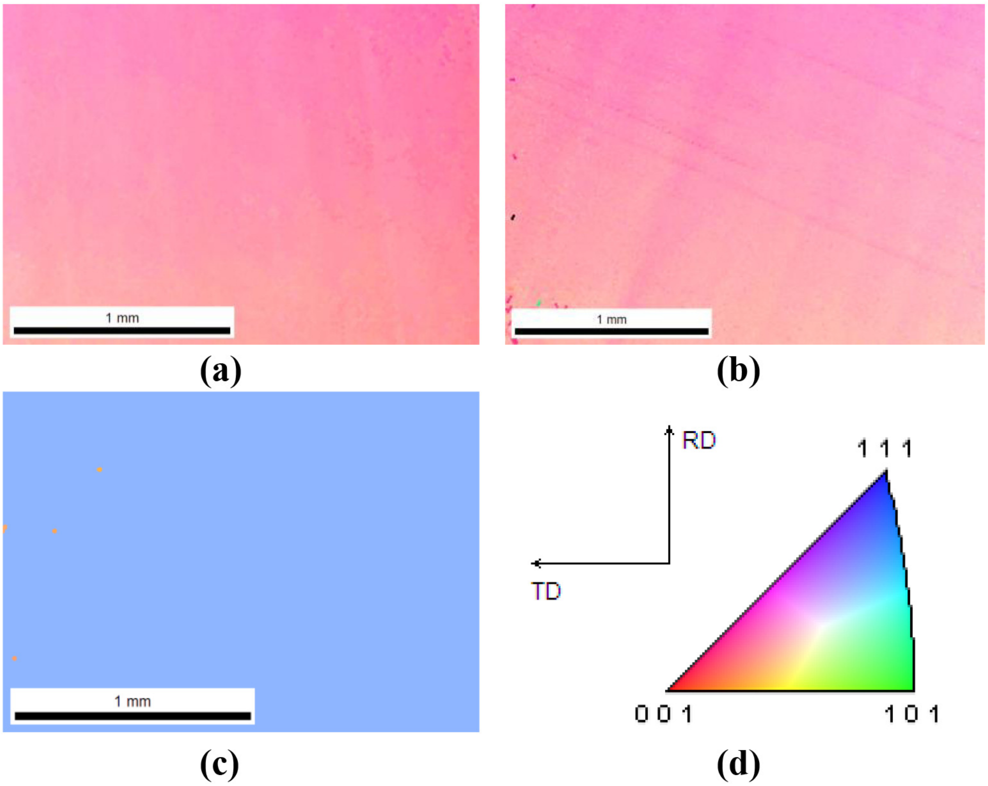

Fig. 2. The orientations of the Al–2Cu alloys single crystal specimens were determined by EBSD, (a) of 1# specimen and (b) of 2# specimen with (hkl) [uvw] orientation of $(3, -1, 9)$ $[-8, 3, 3]$; (c) of 3# specimen with (hkl) [uvw] orientation of $(-3, 0, 7)$ $[7, -5, 3]$; (d) Color coded map type of the [001] IPF in aluminum.