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Effects of original orientation combination on substructure characteristics during continuous dynamic recrystallization in an extruded Al-Cu-Li alloy

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ABSTRACT

The deformation behavior of a material is closely related to its preferred orientations. Usually, material contains more than one preferred orientation, and the combination of different preferred orientations makes the deformation behavior more complicated. In this study, the effects of orientation combination on the deformation substructure characteristics of an extruded Al-Cu-Li alloy were investigated. Isothermal compression tests of Al-Cu-Li samples with different orientation combinations were conducted to study the flow stress behavior. The microstructure of the deformed samples was examined and analyzed by electron backscatter diffraction. A novel deformation restriction factor γ' has been proposed to compare the deformation restriction of different orientation combinations. It was found that compared with the sample which contains $\langle 001 \rangle$ & $\langle 101 \rangle$ orientation combination, the sample containing $\langle 001 \rangle$ & $\langle 111 \rangle$ orientation combination possesses higher subgrain misorientation and finer grain size because of the larger deformation restriction between $\langle 001 \rangle$ & $\langle 101 \rangle$ orientated grains. The present work shows that it is feasible to control the continuous dynamic recrystallization microstructure of the Al-Cu-Li alloy by adjusting the original orientation combination.

1. Introduction

Compared with conventional commercial aluminum alloys, aluminum-lithium alloys have a higher stiffness to density ratio. For each 1 wt% Li added to Al, the density of Al alloy reduces by 3% and the elastic modulus increases 6% [1]. Furthermore, the addition of lithium induces the formation of precipitates at grain boundaries, which increases the fracture toughness and fatigue crack growth resistance [2]. These outstanding performances improvements have led to a wide range of applications of Aluminum-lithium alloys in the aerospace industry [3–7], such as manufacturing fuselage, wings and empennage [8]. As plastic forming is one of the most widely used manufacturing technologies for the production of aluminum-lithium alloy parts, it is necessary to investigate the microstructure evolution during plastic formation in order to control the properties.

In our previous study, we observed grain refinement by continuous dynamic recrystallization (CDRX) in an Al-Cu-Li alloy [9]. As an important process during microstructure evolution, CDRX can effectively refine the grain and has been studied extensively over the past two decades [10–14]. It has been widely reported that the CDRX grains form through the continuous transformation of the deformation substructures, such as subgrains and microbands [15]. Thus, studying the factors affecting the deformation substructures and related mechanisms is the foundation of utilizing microstructure control by CDRX. Many researches show that the deformation substructure characteristics strongly depend on the grain orientation [16–19]. Some studies suggest that the effect of orientation on deformation substructures is mainly due to the orientation's own characteristics. For instance, X. Huang et al. indicated equiaxed subgrains trend to form in $\langle 001 \rangle$ orientated grains, since $\langle 001 \rangle$ orientation has multiple slip systems which are easy to active, and microbands with parallel dislocation boundaries tend to form in $\langle 111 \rangle$ orientation grains since $\langle 111 \rangle$ orientation's slip systems are more difficult to activate [20,21].

However, some other studies suggest that the neighbor orientation of the deformation grain also affects deformation substructure, although the impact is rather limited. The neighbor orientation affects the deformation substructures through the grain boundary. The change of the neighbor orientation leads to the change of grain boundary property which affects the dislocation and stress distribution near the grain boundary. Benjamin Britton and Guo et al. indicated that if the grain boundary is not suitable for slip transfer, it will lead to dislocation pile-up and stress concentration near the boundary [22,23]. Dislocation pile-up and stress concentration can promote the formation of substructures near the grain boundary. In general, for materials with

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Table 1
The chemical composition of Al-Cu-Li alloy (wt%).

Cu	Li	Mn	Zr	Zn	Al
2.8	1.4	0.3	0.12	0.1	Other

random orientation distribution, there is no preferred distribution of any kind of grain boundaries. So, the influence of the grain boundary on the macroscopic distribution of substructure can be ignored. However, for material with multiple preferred orientations, the combination of different preferred orientations, named as orientation combination in this study would cause preferred distributions of the grain boundaries. Therefore, the influence of the orientation combination on the CDRX substructure should be take into consideration.

In the current work, Al-Cu-Li samples with different orientation combination have been successfully prepared and their compressive behavior has been studied. After compression, the microstructures of different samples under several strains were examined and analyzed. The effects of the orientation combination on CDRX substructure characteristics have also been investigated.

2. Material and Methods

2.1. Material and Compression Test

The material used was an extruded 2397 Al-Cu-Li alloy, whose chemical composition (wt%) is given in Table 1. Its original crystallographic texture was measured along the axial direction and radial direction by Electron Back-Scattered Diffraction (EBSD). In the axial direction, there are mainly 〈001〉 and 〈111〉 orientation grains. While, in the radial direction, 〈001〉 and 〈011〉 orientation grains are the majority. Two kinds of cylindrical specimens with 8 mm in diameter and 12 mm in length were prepared by the method illustrated in Fig. 1(a). Fig. 1(b) shows typical orientations in compression sample 1 and 2.

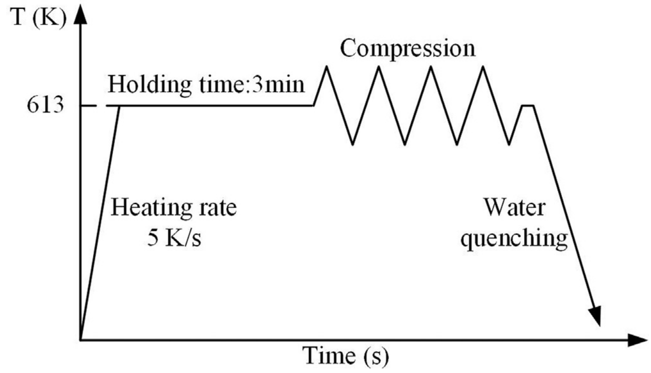

Fig. 2. Compression test procedure.

Compression tests were performed on a thermo-mechanical testing equipment (Gleeble 3500). Specimens were heated to 613 K at a rate of 5 K/s under a high purity nitrogen atmosphere, and held for 3 min to ensure a uniform temperature. Then, the heated specimens were compressed with a height reduction of 50% at a strain rate of 10^{-3}/s, followed by water quenching to retain the microstructure. The compression procedure is shown in Fig. 2.

2.2. EBSD Mapping Procedure

After compression, the specimens were barrel-shaped. In order to get strain distribution in barrel-shaped specimens, the stress-strain curves obtained by compression tests were imported into DEFORM-3D to simulate the compression process. Fig. 3(a) and (b) show the strain distribution on the middle cross-section and the central axis. Based on the strain distribution, three areas with different strains of 0.3, 0.6, 0.9 were chosen to run EBSD scanning to investigate the microstructure evolution during compression.

For EBSD observation, specimens were sectioned along axial

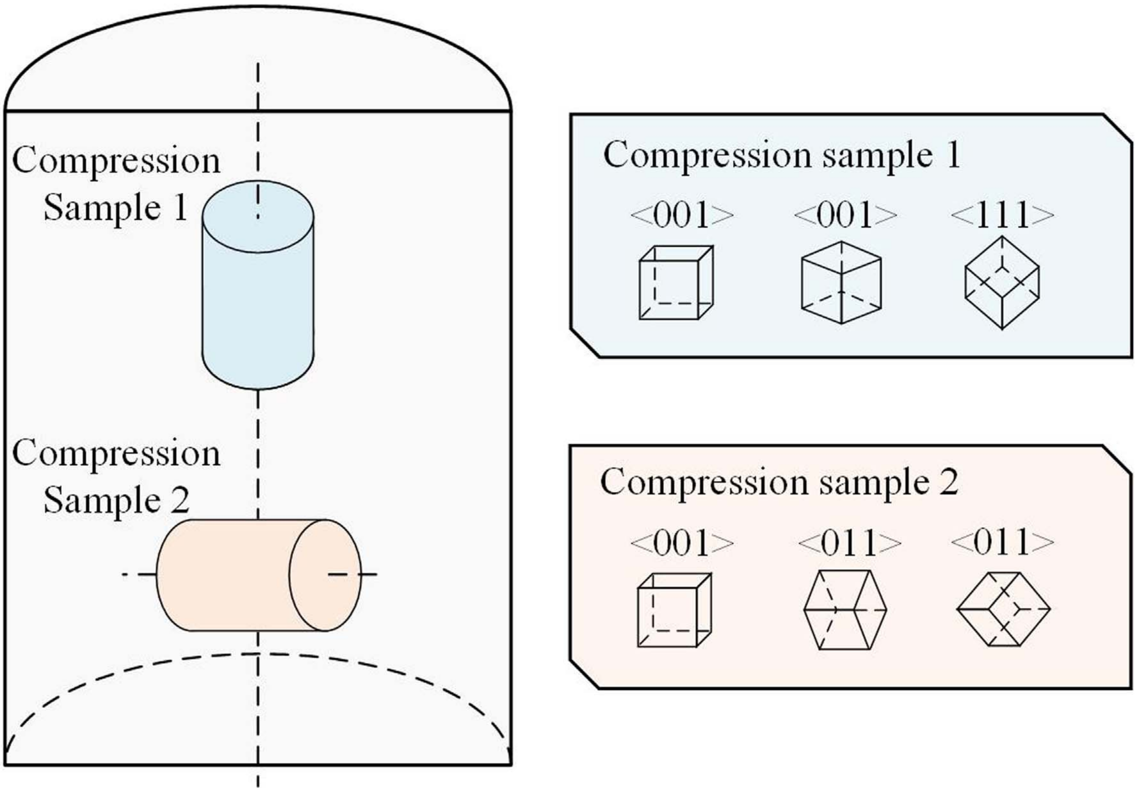

Fig. 1. (a) Illustration of two different cutting methods for preparing samples with different orientation combinations, (b) typical orientations in compression sample 1 and 2.