GRAIN BOUNDARY CHARACTER DISTRIBUTION, TEXTURE AND SUPERPLASTIC DEFORMATION BEHAVIOR OF AN Al-Li ALLOY①

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ABSTRACT The grain boundary character distribution and the texture of 2091 Al-Li alloy recrystallized at different temperatures were measured by TEM and X-ray techniques respectively. The occurrence frequency of low-energy boundaries decreases with increasing recrystallization temperature, while the frequency of high-energy boundaries increases. The strongest component of recrystallization texture in the test temperature range is {011}⟨111⟩. The relative intensity of the texture tends to decrease with increasing recrystallization temperature. The material which contains a high frequency of low-energy boundaries exhibits lower deforming stress and high elongation.

Key words aluminum-lithium alloy grain boundary character distribution recrystallization texture superplasticity

1 INTRODUCTION

The superplasticity is related to the high temperature deformation behavior of superplastic materials so that the grain boundary behavior (e.g. sliding and diffusion) and properties (e.g. boundary mobility and energy) play important roles in the evolution of superplastic deformation mechanism and the control of superplasticity. Grain boundary character distribution (GBCD) proposed by Watanabe[1] is a new microstructural parameter quantitatively describing the structure types of grain boundaries. It is reasonable to expect that boundary-dependent superplasticity of 2091 Al-Li alloy should be controlled by GBCD. Texture as a parameter describing grain orientation of polycrystalline materials was found to be related to GBCD[2]. Therefore it is very important to investigate the effect of GBCD and texture on superplastic deformation behavior. Until recently, there has been little similar work reported.

Recrystallization process as an important superplastic pre-treatment step[3] has strong effect on the microstructure, especially the grain boundary structure of the material. In present work, a 2091 Al-Li alloy was recrystallized at different temperatures to obtain different GBCDs and textures, and their effects on the behavior of superplastic deformation were studied to try to improve the superplasticity of this alloy.

2 EXPERIMENTAL

The material used in our experiment is a 2091 Al-Li alloy produced by ingot metallurgy method. The chemical composition (mass fraction, %) is Al-2.20 Li-2.65 Cu-1.20 Mg-0.15Zr. The pre-treatment technology for superplasticity was as follows: solution (500 ℃, 1.5 h) —over aging (400 ℃, 32 h) —cold rolling to sheet with a thickness of 1.5 mm —recrystallizing at 450, 490 and 530 ℃ respectively for 30 min, then working into superplastic tensile specimens with the size of gauge length 10 mm, width 6 mm and thickness 1.5 mm.

The superplastic tensile tests were performed on the SHIMAZU AG-10TA material

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test machine controlled by computer. The superplastic elongation and the maximum deforming stress of the specimens recrystallized at different temperatures were tested at different deformation temperatures with a constant initial strain rate $8.33 \times 10^{-4} s^{-1}$.

Grain boundary character distribution (GBCD) and recrystallization texture of the specimens recrystallized at different temperatures were measured by EM-400T transmission electron microscopy and X-ray diffraction techniques respectively[4]. About 150 grain boundaries of each specimen were selected for measuring GBCD.

3 EXPERIMENTAL RESULTS

3.1 Effect of recrystallization temperature on grain size

The grain size was examined by microscopic test. The results show that the grain size is in the scale of micrometer, and increases with the recrystallization temperature, as shown in Fig.1.

3.2 Effect of recrystallization temperature on GBCD

The grain boundaries were sorted to three types. When the disorientation between two grains is lower than 15°, the grain boundary is often defined as a low-angle boundary. A boundary having the value of Σ between 3 ~ 29 is defined as a low Σ coincidence boundary. And the boundaries whose Σ value is higher than 29 is called random general boundary. The first type, low-angle boundary, and the second type, low Σ coincidence boundary, are usually called low-energy boundary, and the third type, random boundary, is also called high-energy boundary[5]. The effect of recrystallization temperature on the frequencies of the occurrence of three types boundaries is shown in Fig.2. It can be seen from the figure that GBCD was greatly affected by the recrystallization temperature. Both frequencies of the low-angle boundaries and the low Σ coincidence boundaries decrease with increasing recrystallization temperature, while the frequency of the random boundaries increases. On the other hand, with increasing extent of recrystallization, the high-energy boundaries would occur with a high frequency, and the low-energy boundaries with low frequencies in the structure.

3.3 Effect of recrystallization temperature on recrystallization texture

The measurement results show that the strongest texture components of the specimens recrystallized at different temperatures all are {011}⟨111⟩. The relative intensity of the texture tends to decrease with increasing recrystallization temperature, as shown in Fig.3.

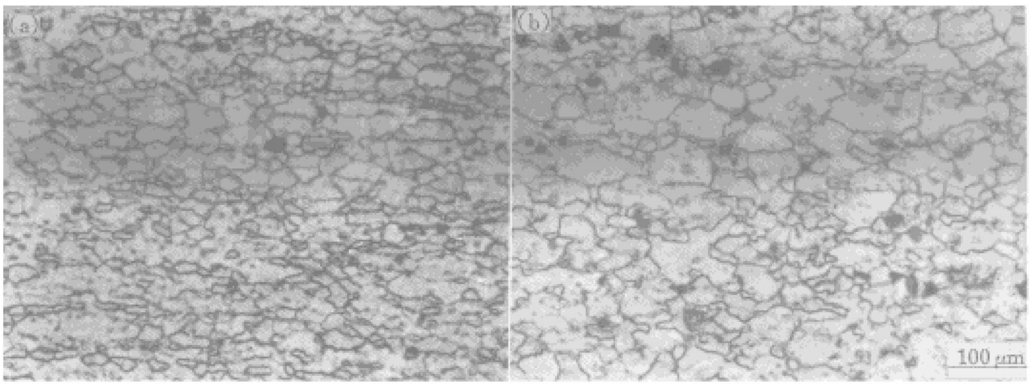

Fig.1 Recrystallization temperature dependence of grain size

(a) —450 ℃; (b) —530 ℃

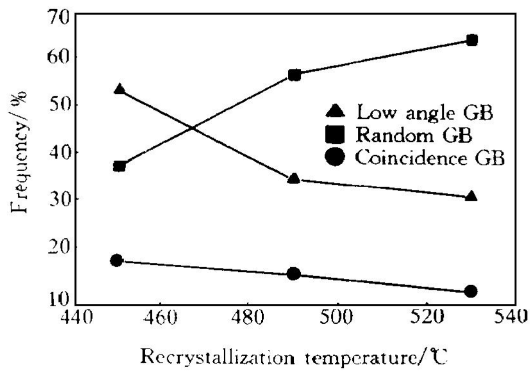

Fig.2 Recrystallization temperature dependence of GBCD

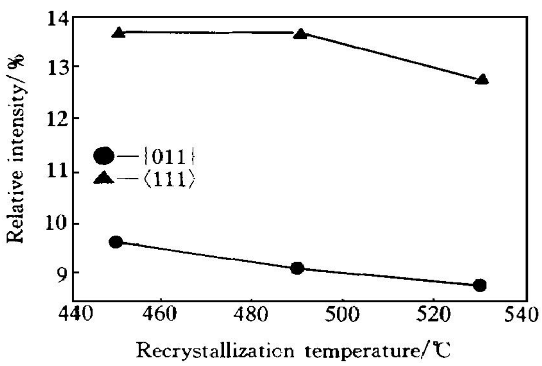

Fig.3 Recrystallization temperature dependence of texture

3.4 Superplasticity and superplastic deforming behavior of specimens recrystallized at different temperatures

The effect of recrystallization temperature and deformation temperature on the superplastic elongation is shown in Fig.4. The results show that (1) the superplastic elongation of the specimens recrystallized at different temperatures decreases as the deformation temperature decreases; (2) the elongation increases in the range of deformation temperature tested as the recrystallization temperature lowers; and (3) the superplasticity of the specimens recrystallized at lower temperatures is much less sensitive to the deformation temperature. In other words, the specimens recrystallized at low temperatures can achieve high elongations when deformed within a wide range of deformation temperature, but the specimens recrystallized at high temperatures can achieve high superplastic elongations only when deformed at high temperatures.

The effect of the deformation temperature and recrystallization temperature on the maximum deforming stress during superplastic tensile is shown in Fig.5. It can be seen that the maximum stress decreases with increasing deformation temperature, and the lower the recrystallization temperature is, the lower the deforming stress is, and it is more obvious at lower deformation temperatures than at high temperatures.

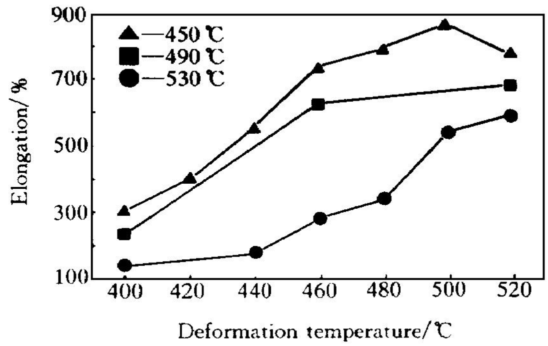

Fig.4 Effect of deformation temperature and recrystallization temperature on elongation

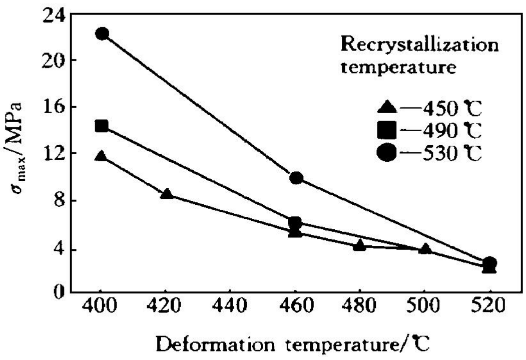

Fig.5 Effect of deformation temperature on maximum deforming stress at different recrystallization temperatures

4 DISCUSSION

4.1 Effects of recrystallization temperature on

GBCD, grain size and texture of Al-Li alloy

As the holding time is invariable, the higher the temperature is, the fuller the recrystallization is, and the bigger the grain size is as well known. But the fact that the frequency of occurrence of random boundaries increases with recrystallization temperature indicates that the subgrain merging mechanism might play an important role during the recrystallization. When recrystallized at high temperatures the sub-boundaries formed at the initial stage transform into high-angle boundaries through subgrain merging, and the grain growth occurs.

It seems to be inevitable that there is a relation between GBCD and texture which describes the grain boundary character and the grain orientation of polycrystal respectively. The experimental results as shown in Figs. 2 and 3 show that GBCD is closely related to the texture and that the specimen with a high intensity of texture contains a high frequency of low-angle boundaries and low Σ coincidence boundaries, which coincides with the investigation work on other materials reported[2].

4.2 Effect of GBCD on mechanism of superplastic deformation of Al-Li alloy

The general mechanism of superplastic deformation is closely related to grain boundary sliding, dislocation movement, grain boundary migration and diffusion. And all of these behaviors can be closely related to the microstructural parameter of grain boundary, GBCD. Therefore it is reasonable to consider that the difference of the mechanism of superplastic deformation between the specimens recrystallized at low and high temperatures was caused by different GBCDs.

At a low deformation temperature, the high-energy grain boundaries become the barriers to the movement of dislocations so that the dislocations pile-up against the boundaries to form stress concentration which resists the emission and movement of the subsequent dislocations. Thus the cavities would easily form at the high-energy boundaries. Therefore the specimens recrystallized at high temperatures exhibits high deforming stress and low superplastic elongation because of the high frequency of random boundaries in them. For the specimens recrystallized at low temperatures, the low-energy boundaries are prominent and the dislocations can easily pass these boundaries and slip continually[6], so these specimens exhibit low deforming stress and high superplastic elongation.

Under the condition of high deformation temperature, for one thing that the activation energy of the diffusion of defects decreases greatly makes the lattice dislocations easily transform into the grain boundary dislocations through the process of diffusion[7], the dislocation density in grains decreases greatly[8], so that the grain boundary sliding becomes the main mechanism of deformation, and for another, most of the low-energy boundaries can transform into high-energy boundaries at the initial stage of deformation through the dynamic recrystallization at high temperatures. Therefore the difference of the elongation and deforming stress between the specimens recrystallized at low and high temperatures is very little.

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