EFFECT OF RECRYSTALLIZATION TEMPERATURE ON MICROSTRUCTURES AND SUPERPLASTICITY OF 2091 Al-Li ALLOY

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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 frequencies of both the low-angle boundaries and the low Σ coincidence boundaries decreased with increasing recrystallization temperature, while the frequency of the random boundaries increased. The effect of the grain boundary structure on the behavior of superplastic deformation was discussed. The main conclusion is that the superplastic deformation temperature can be lowered by lowering the recrystallization temperature.

Keywords: *aluminum-lithium alloy, superplasticity, grain boundary character distribution, recrystallization texture*

1. INTRODUCTION

Recrystallization technology has both scientific and engineering importance because it plays important roles in the evolution of microstructure and the control of bulk properties of polycrystalline materials. The superplasticity of Al-Li alloys depends upon the microstructures, and the microstructures depend upon the pre-treatment process including solution, cold rolling and recrystallization. So the recrystallization temperature is one of the important factors which influence the superplasticity as well as the microstructures of Al-Li alloy[1].

The effect of recrystallization temperature on the grain boundary character distribution (GBCD), the recrystallization texture and the superplasticity of the 2091 Al-Li alloy was studied and the relationship between the microstructures and the superplasticity was discussed in this paper.

2. EXPERIMENTAL PROCEDURE

The material used in the experiment is 2091 Al-Li alloy produced by ingot metallurgy method. The chemical composition (wt%) is Al-2.20Li-2.65Cu-1.20Mg-0.15Zr. The pre-treatment process for superplasticity is as follows: solution(500℃ for 1.5hrs)—over aging(400℃ for 32hrs)—cold rolling to sheet with a thickness of 1.5mm—working into superplastic tensile specimens—recrystallizing (450℃~530℃ for 30min).

The superplastic tensile tests were performed on the SHIMAZU AG-10TA material test machine controlled by computer. The size of the specimens is as follows: the gauge length is 10mm, width is 6mm and the thickness is 1.5mm. The superplastic elongation and the maximum deforming stress of the specimens recrystallized at different temperatures were tested at different deformation temperatures with different tensile rates.

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[2]. About 150 grain boundaries of each specimen were selected for measuring GBCD.

3. EXPERIMENTAL RESULTS

3.1 The effect of recrystallization temperature on GBCD and recrystallization texture

The grain boundaries were sorted to three types. If the misorientation between two grains was lower than 15°, then the grain boundary was defined as a low angle boundary. A boundary having the value of Σ between 3-29 was defined as a low Σ value coincidence boundary. And the boundaries whose Σ value higher than 29 were called random 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[3].

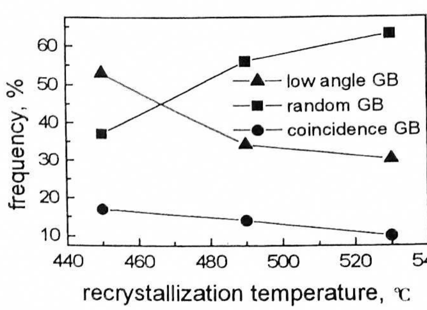

Figure 1. The recrystallization temperature dependence of GBCD

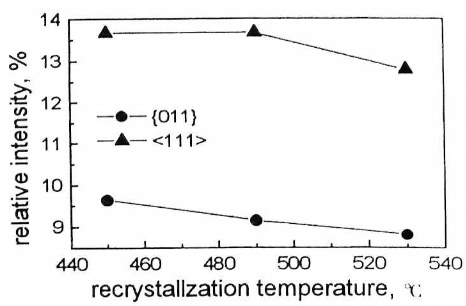

Figure 2. The recrystallization temperature dependence of texture.

The occurrence frequencies of the three type boundaries in the specimens recrystallized at different temperatures were shown in figure1. 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 the extent of recrystallization, the high-energy boundaries would occur with a high frequency, and the low-energy boundaries with low frequency in the structure.

The grain size in the specimens recrystallized at different temperatures was also observed on the TEM. The results showed that the grain size is the scale of micrometer and increases with increasing recrystallization temperature as known as generally.

The measurement result shown that the strongest texture components of the specimens recrystallized at deferent temperatures all are {011}<111>. The relative intensity of the texture tends to decrease with the increasing of recrystallization temperature, as shown in figure 2.

3.2 The superplasticity and superplastic deforming behavior of the specimens recrystallized at different temperatures

The effect of recrystallization temperature and deformation temperature on the superplastic elongation was shown in figure 3(the tensile rate is 0.5 mm/min). 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 as the recrystallization temperature gets lower in the range of deformation temperature tested; 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 temperature can achieve high elongation when deformed within a wide range of deformation temperature, but the specimens recrystallized at high temperature can achieve high superplastic elongation only when deformed at high temperature.

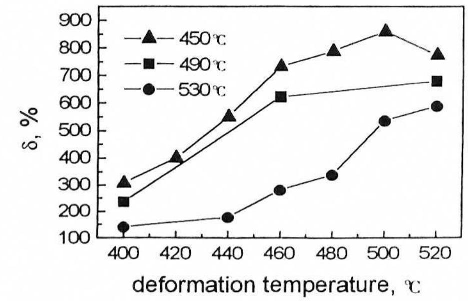

Figure 3. The effect of deformation temperature on the elongation at different recrystallization temperatures.

The figure 4 indicates the dependence of the superplastic elongation measured at deformation temperature 460 ℃ with the recrystallization temperature and tensile rate. The figure shows that the elongation increases as the tensile rate and the recrystallization temperature decreases. Although the superplasticity of the specimens recrystallized at lower temperature is more sensitive to the tensile rate than that of the specimens recrystallized at high temperature, the specimens recrystallized at lower temperatures still can achieve a considerable elongation at high tensile rate. It is very important to lower the deformation temperature and raise the deformation rate for the engineering application of superplastic forming.

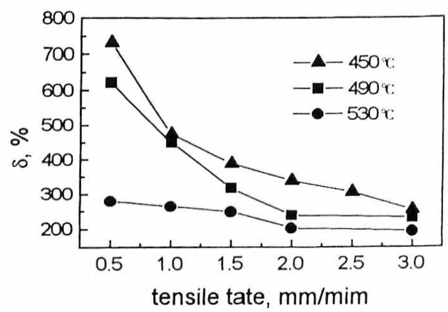

Figure 4. The effect of the tensile rate on the elongation at different recrystallization temperarues.

The effect of the deformation temperature and recrystallization temperature on the maximum deforming stress during superplastic testing are shown in figure5. It can be seen that the lower the recrystallization temperature is, the lower the deforming stress is, and the lower the deformation temperature is, the more obvious the deference is.

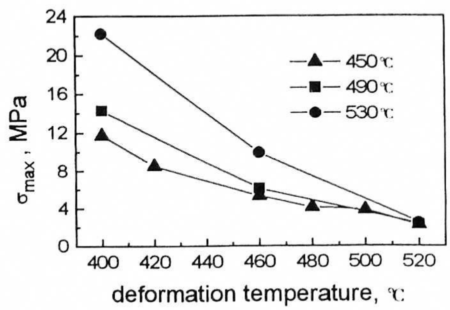

Figure 5. The effect of deformation temperature on the maximum deforming stress at different recrystallization temperatures.

4. DISCUSSION

GBCD and texture as the microstructural parameters describing the grain boundary and the grain orientation of polycrystalline materials play important roles in the evolution of microstructure and the control of bulk properties. Some investigation results on the relationship between GBCD and texture have already been reported. It has been shown that GBCD was closely related to the type and the sharpness of texture and that strongly textured polycrystals contain a high frequency of low angle boundaries and low Σ coincidence boundaries[4]. The results in present work show the same role, that is, both the frequency of low-energy boundaries and the relative intensity of texture decrease as recrystallization temperature rise.

The superplasticity is strongly affected by grain boundary behavior (e.g. sliding and diffusion) and properties (e.g. boundary mobility and energy) because the superplastic deforming is a high temperature process. Therefore the deference of the superplasticity between the specimens recrystallized at low and high temperature should be concerned with GBCD and it is reasonable to consider the mechanism of superplastic deformation should be controlled by GBCD.

Under the condition of 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 temperature exhibited high deforming stress and low superplastic elongation because of the high frequency of random boundaries in them. For the specimens recrystallized at low temperature, the low-energy boundaries are preponderant and the dislocations can easily pass these boundaries and slip continually[5], so these specimens exhibited 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[6], the dislocation density in grains decreases greatly, 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 temperature. Therefore the deference of the elongation and deforming stress between the specimens recrystallized at low and high temperatures is very little.

It is an important significant result that the superplastic deformation temperature can be lowered and the superplastic strain rate can be increased by lowering the recrystallization temperature. In general, the conditions under which the 2091 Al-Li alloy could be deformed superplastically are high deformation temperature and low strain rate. These conditions not only make the superplastic forming of the alloy high cost and low efficient, but also make the alloy easily oxidized because the element lithium is very active especially during the superplastic deformation at high temperatures and low strain rates. The oxidization of the alloy is one of the main problems which restrict the applications of the superplastic forming technique. The oxidization can be efficiently restrained by lowering the deformation and the recrystallization temperature and increasing the strain rate.

5. CONCLUSIONS

As the recrystallization temperature rises, the occurrence frequency of low-angle boundaries and the low Σ coincidence grain boundaries decreases, while the frequency of the random boundaries increases. The strongest component of recrystallization texture in temperature range tested is {011}<111>. The relative intensity of the texture tends to decrease with the increasing of recrystallization temperature. The texture is related to GBCD, that is, the material with high texture intensity contains a high frequency of low-angle boundaries and low Σ coincidence boundaries. The behavior of the superplastic deformation of the alloy is strongly affected by the grain boundary character parameters. When superplastically deformed at low temperature, the materials dominated by low-energy grain boundaries exhibit lower deforming stress and higher elongation than those dominated by high-energy grain boundaries. It can be summarized from the experimental results that the deformation temperature can be lowered by lowering the recrystallization temperature, which is very important for the application of superplastic Al-Li alloy.

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