DYNAMIC RECRYSTALLIZATION AND SUPERPLASTICITY IN Al–Li ALLOY①

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ABSTRACT

The behavior of dynamic recrystallization in the superplastic deformation of 8090 and 2091 aluminum-lithium alloys have been investigated. TEM observations indicated that dynamic recrystallization occurs at the triple junction of grain boundaries. The measurement of grain boundary angle showed that recrystallization in dynamic equilibrium exists in the process of superplastic deformation of 8090 Al–Li alloy. It is also indicated that, besides the role of refining grains and the grain boundary sliding, dynamic recrystallization plays concurrently a role of stablizing microstructure. Thus dynamic recrystallization can be used to induce metals superplasticity, which leads to a simplification of pretreatment for superplastic deformation.

Key words: dynamic recrystallization superplasticity Al–Li alloy mechanism.

1 INTRODUCTION

The role of dynamic recrystallization in superplastic deformation has already been recognized yet the comprehensive understanding for dynamic recrystallization is still imperfect[1–3]. The role of accommodation of grain boundary sliding by dynamic recrystallization was also mentioned[4–5], but no experimental data ware given so far. In this project, two kinds of 8090 and 2091 Al–Li alloy were chosen to further confirm the accommodation role of grain boundary sliding and the role in stablizing microstructure of dynamic recrystallization, and attempt to reveal the possibility of dynamic recrystallization-induced-superplasticity for simplifying the pretreatment processes of superplasteity.

2 EXPERIMENTAL

The experimental materials were 8090, 2091 Al–Li alloys. Their chemical compositions are shown in Table 1.

Table 1 Chemical composition of experimental

Alloy	Al	Li	Cu	Mg	Zr	Fe	Si	Na
8090 (wt-%)	–	1.91	1.25	0.46	0.21	0.031	0.032	–
2091 (wt-%)	–	2.2	2.6	1.2	0.15	0.1	0.1	<10ppm

After 450 ℃ hot rolling (from 35 to 10mm), 530 ℃ × 0.5 h solid and 400 ℃ × 8 h overaging, 8090 Al–Li alloy was cold rolled to a plate of 2 mm in thickness (from 10 to 2 mm), with total reduction up to 83%. In order to confirm the possibility for inducing superplasticity by dynamic recrystallization and simplify the pretreatment processes for superplastic deformation, a normal plate of 2091 Al–Li alloy with increased reduction was adopted. The processes for normal plate were as follows: 530 ℃ × 24 h homogeneous treatment, 500 ℃ hot rolled from 35 mm to 10 mm, and then cold rolled from 10 mm to 0.7 mm. The gauge sizes of the specimens of 8090, 2091 Al–Li alloys were 10 mm x 6 mm x 2 mm, 10 mm x 6 mm x 0.7mm. Superplastic deformation was

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carried out on an electron tension machine made in Japan. The testing temperature was 500 ± 1 ℃. The dynamic recrystallization was observed with a TEM, The grain boundary angle was measured with the same method as Ref.[6].

3 EXPERIMENTAL RESULTS

Fig.1 shows that both 8090 and 2091 Al–Li alloys exhibit superplasticity at test temperature (500 ℃). Fig.2 shows the superplastic flow curves of 2091 Al–Li alloy. Fig.3 gives the TEM observations, which indicate that there is a high density of dislocation in block grains at triple junction of grains, and a few dislocations in other two grains. Fig.4 shows that dynamic recrystallization in 8090 and 2091 Al–Li alloys took place at triple junction of grains. Grain boundary angle measuring results (Fig.5) indicate that the high angle boundary fraction and average boundary angle nearly lie in a stable value in the superplastic deformation of 8090 Al–Li alloy. In addition, the large grains refined by dynamic recrystallization were also seen in aother pictures.

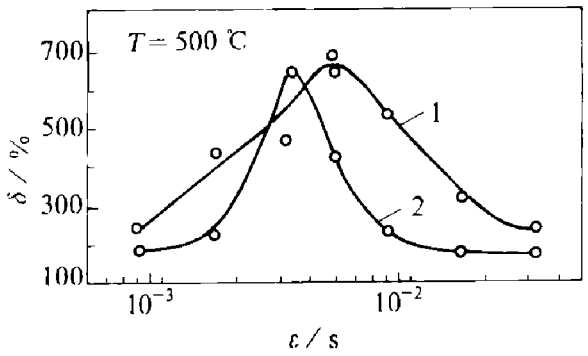

Fig. 1 Results of superplastic deformation of 8090 and 2091 alloy

1—2091 alloy, 2—8090 alloy

4 ANALYSES AND DISCUSSIONS

4.1 *The Accommodation of Grain Boundary Sliding*

Superplastic deformation with large strains is a process in which flow hardening is equilibrated by flow softening. Namely, the hardining caused by grain boundary sliding is softened by accommodation mechanism. Large stress concentration is created at the triple junction of grains due to the grain boundary sliding, which hinders the actuationof slip systems of dislocation and relax the stress concentration to some

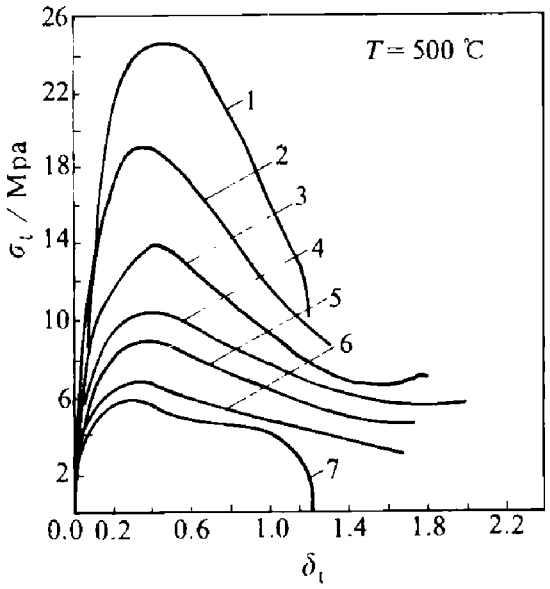

Fig. 2 Flow curves of superplastic deformation (2091 alloy)

1—$8.33\times10^{-4}s^{-1}$; 2—$1.67\times10^{-3}s^{-1}$; 3—$3.33\times10^{-3}s^{-1}$; 4—$5.0\times10^{-3}s^{-1}$; 5—$8.33\times10^{-3}s^{-1}$; 6—$1.67\times10^{-2}s^{-1}$; 7—$3.33\times10^{-2}s^{-1}$;

Fig. 3 Dislocation created at triple junction of grains

Fig. 4 Dynamic (recrystallization at triple junction of grains

(a)—8090 alloy (δ = 630%); (b)—2090 alloy (δ = 320%)

extent; Meanwhile the dislocations in block grains are increased. The process is carried out with the action of external stress, and dislocation density becomes higher and higher in block grains, as shown in Fig.3. From the viewpoint of energy, the stored energy increased in block grains, which provided a driving force for dynamic recrystallization. In the condition of mobile grain boundary, recrystallization nucleation and growth take place, as shown in Fig.4 (a), (b).The grains with high density of dislocation at triple junction of grains are replaced by no strain grains, which in no doubt decreases the energy of the system, relaxes the stress concentration at triple junction of grains and accommodates the grain boundary sliding. Fig.5 shows that dynamic recrystallization is in equilibrium in the process of superplastic deformation of 8090 Al–Li alloy. This dynamic equilibrium is macroscopically manifested as a stable flow stress, as shown in Fig.2. Intrinsically, it is certain that recrystallization is accompanied by grain boundary migration. In superplastic deformation, a certain amount of grain boundary migration is, in no doubt, favorable for obtaining smooth grain boundary to relax stress concentration and promote grain boundary sliding, but too rapid grain boundary migration easily creates uneven boundary, which is disadvantageous to the grain boundary sliding[7]. So does the recrystallization in stable superplastic flow. At the condition of externally imposed large stress, the recrystallization is too rapid, which increases the migration rate of recrystallization boundary, turns smooth boundary to uneven boundary and blocks grain boundary sliding. This is the reason why high elongation does't exist in the recrystallization process under large stress.

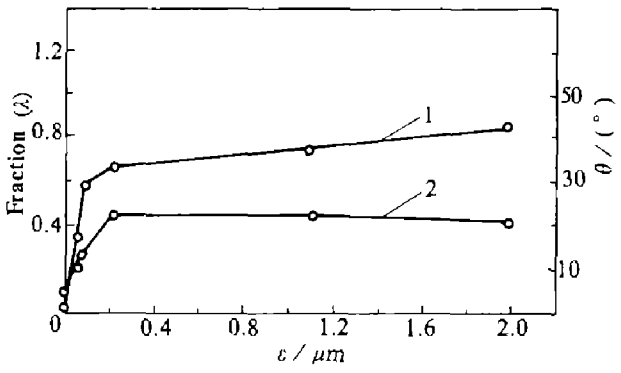

Fig. 5 Relationship of high angle boundary fraction and average boundary angle with strains (8090 alloy)

1—High angle boundary fraction (λ)

2—Average boundary angle (θ)

Whether dynamic recrystallization is active to accommodate grain boundary sliding or not lies in that recrystallization boundary migration relaxes stress concentration and affects the fla-

tness of grain boundary. Recrystallization boundary migration in approprite rate not only relaxes stress concentration caused by grain boundary sliding, but also provides even boundary. If the imposed stress is too high, recrystallization boundary migration becomes too rapid, and creates many ledges of grain bounderies, which is difficult to adjust by dislocation slip and diffusional creep, and causes grain boundary to unsmoothly slide, although recrystallization contributs in releasing stress concentration. It shouled be pointed out that different material and deformation temperature correspond to different appropriate boundary migration rate of recrystallization. The higher optimum strain rate in superplastic deformation of 2091 Al–Li alloy probably related to higher content of Cu and Mg.

4.2 *Dynamical Recrystallization-Induced-Superplasticity*

Generally, to obtain superplasticity must satisfy two conditions: One is refined grains; the other is stability of microstructure. If the stability of microstructure can not be guaranteed in the deformation, the high superplasticity is difficult to be obtained. For grain refining, Al–Li alloy must be refined by means of recrystallization whether undergoing superplastic pretreatment or not. For microstructure stability, recrystallization can also play its role in the deformation, because the flow at high temperature in these alloys with dynamic recrystallization must satisty the following relation[8]:

$$\sigma d = c \qquad (1)$$

Where σ—flow stress; d—grain size; c—constant

Eq. (1) indicates that a given flow stress corresponds to a given grain size. In superplastic deformation, fine grains till grow due to stress and diffussion, and grown grains will be refined by dynamic recrystallization. That is the stablizing role of microstructure of dynamic recrystallization. Of course, the larger the stress, the finer the grains of dynamic recrystallization, which, however does not imply better superplasticity, because superplastic deformation is a flow process in low stress. High stress promotes cavity nucleation and growth, and leads to premature fracture. The lower flow stress corresponds to larger grains, which leads to decrease in proportion of grain boundary sliding and superplastic property. Therefore, only in the condition of an appropriate stress externally imposed (i.e. an appropriate strain rate), the maximum elongation is obatined, as shown in Fig.2. That is the essential process for dynamic recrystallization to induce superplasticity. It is, therefore, avaibable for superplasticity to be induced by dynamic recrystallization for those alloy in which recrystallization can take place.

5 CONCLUSIONS

(1) The dynamic recrystallization of Al–Li alloy accommodates its grain boundary sliding;

(2) Dynamic recrystallization can induce superplasticity in 2091 Al–Li alloy.

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