EFFECT OF HEAT TREATMENT ON INTERNAL FRICTION OF GRAIN BOUNDARY IN 2091 Al-Li ALLOY①

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ABSTRACT The grain boundary relaxation and microstructures of 2091 alloy under different heat treatment conditions were studied by means of internal friction test and TEM analysis. The results showed that the grain boundary relaxation exists in the alloy under as-quenched and aged conditions. The internal friction of grain boundary is mainly affected by the existence form and segregation degree of alloying and impurity elements in grain boundaries, and it is affected neither by quenching speed nor by a few amount of torsion deformation because they are not related to the grain boundary state.

Key words Al-Li alloy internal friction of grain boundary microstructure heat treatment

1 INTRODUCTION

The internal friction, which is a physical property, is related to the existence state and motion of molecules, atoms, photons and electrons in a solid (or on the surface of a solid), and it is also referred to the configuration and interaction of the various structural defects, thus the qualitative and quantitative information in various microscopic processes can be obtained through measuring the internal friction[1]. In the field of studying the fine structure of materials, the relation between the internal structure and the macroscopic physical and/or chemical propterty of a solid can be clearly clarified by combination of the technique of measuring internal friction with the other conventional methods of observing and analyzing microstructure.

The internal friction can be utilized to develop the functional damping materials. For instance, the internal friction in steels has been successfully used to manufacture a damping material[2], otherwise, the internal friction in aluminum alloys can be also exploited to prepare a high-damping material, and Al-Li alloys are light alloys of a new generation which have been rapidly developed in recent years. Because of their low density, high specific strength and high specific modulus, these alloys have appeared to many countries of the world.

In this paper, the internal friction of grain boundaries and the effect of heat treatment on it were investigated in 2091 Al-Li alloy; and on the basis of the investigation the conditions of grain boundaries were examined and thus the comprehension about the brittleness nature of grain boundary could be explained.

2 EXPERIMENTAL

The alloy used in this study was produced by the ingot metallurgy (I/M) technique. The ingot of alloy was covered after homogeneizing at 450 ℃ and then was hot rolled into a sheet. The chemical composition of alloy is listed as follows:

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Li	Cu	Mg	Zr	Fe	Si	Al
2.22	2.70	1.14	0.14	< 0.10	< 0.05	balance

The heat treatment procedure of specimens is as follows: after solution heat treatment at 530 ℃ for 30 ~ 120 min, the specimens were quenched into the ambient temperature water, liquid nitrogen and mixture of liquid nitrogen and alcohol, respectively, and then aged at 190 ℃ for 56 h followed by air cooling. The solution and aging were carried out in a salt bath furnace and in a constant temperature and dry chamber, respectively. The internal friction of specimens with demension of 180 mm × 1.8 mm × 1.8 mm was measured by Ge-Low frequency internal friction apparatus in the frequencies of 1 and 1.5 Hz, respectively, and at the heating rate of 1.25 ℃/min. The microstructure was observed in a Philips CM12 transmission electron microscope.

3 RESULTS

3.1 Internal friction of grain boundary in the as-quenched alloy

Fig. 1 shows the curves of internal friction of grain boundary in the as-quenched specimens which were solutionized for 30 min and 120 min, respectively. In comparison with commercial aluminum alloys, the peak value and peak temperature of internal friction are lower in the specimen solutionized, whose peak value is 7×10^{-3} and peak temperature is 240~ 250 ℃.

The peak value of internal friction decreases to about 5×10^{-3} and the peak temparature decreases slightly in the specimen solutionized for 120 min compared with those in the specimen solutionized for 30 min. With the change of measure frequency from 1 to 1.5 Hz, the peak of grain boundary obviously exhibits the boundary relaxation characteristic and the activation energy of grain boundary measured is 1.4 eV.

The peak value and the temperature of internal friction of grain boundary are little altered not only in the specimens which are quenched into ambient temperature water, liquid nitrogen, and mixture of liquid nitrogen and alcohol, respectively, after solution treated at 530 ℃ for 30 min, but also in both untorqued and torqued specimens (the degree of torsion is 0.6% and 0.9%, respectively.) after solution treated at 530 ℃ for 30 min followed by water quenching.

3.2 Internal friction of grain boundary in the aged alloy

Fig. 2 shows the curves of internal friction of grain boundary in the as-quenched specimen and in another aged for 56 h. The peak value of internal friction (about 3×10^{-3}~ 4×10^{-3}) remarkably drops and the peak temperature lowers (about 200 ℃) in the specimen which is solution treated at 530 ℃ for 30 min and water quenched followed by aging at 190 ℃ for 56 h. The activa-

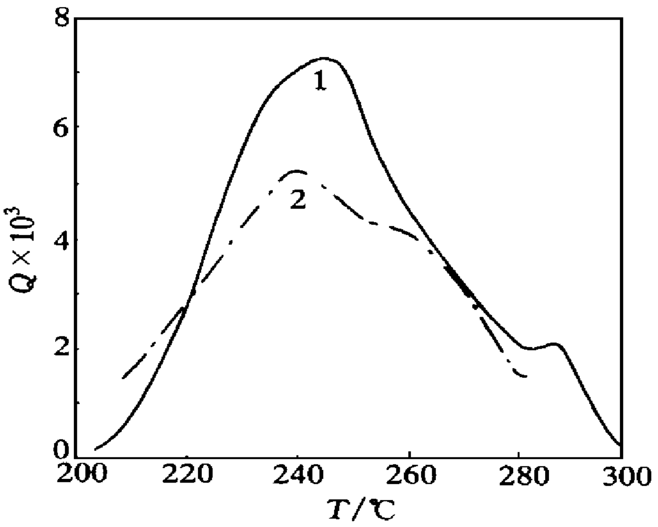

Fig. 1 Effect of solution time on the internal friction of grain boundary(f = 1 HZ)
1 —30 min; 2 —120 min

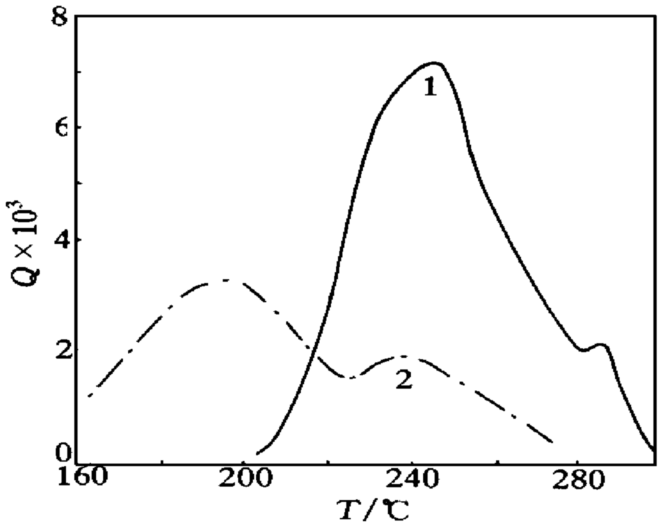

Fig. 2 Effect of aging on the internal friction of grain boundary(f = 1 HZ)
1 —Quenched; 2 —Aged

tion energy of grain bourdary is measured to be 0.7 eV in the specimen aged at 190 ℃ for 56 h, which is lower than that in the as-quenched specimen.

3.3 Microstructures of alloy

Al-Li alloys are typical age-hardening alloys, in which the main strengthening phase is δ'(Al_3Li) phase which is coherent with the matrix. Besides δ' phase, there are a number of T' (Al_2CuLi) and S' (Al_2CuMg) phases in the 2091 Al-Li-Cu-Mg-Zr alloy. A supersaturated solid solution forms after solution and quenching. In addition, the recovery and recrystallization occur during solution heat treatment and so a large quantity of dislocations introduced by hot rolling disappear in grain boundaries or form subgrain boundaries.

Not only a great quantity of δ' particles, but also some S' and T' phases precipitate within grains, or along dislocations and subgrain boundaries during aging, as shown in Fig. 3 and Fig. 4. The stable equilibrium phases, such as δ (AlLi), T_2(Al_6CuLi_3) and T (Al_2LiMg) phases, form along the grain boundaries in 2091 alloy during aging, while the precipitation free zones (PFZs) form near the grain boundaries, as shown in Fig. 5. With further aging, the equilibrium phases coarsen and the PFZs widen.

4 DISCUSSION

4.1 Effects of solution-quenching and torsion on internal friction of grain boundaries

The recovery and recrystallization may occur during solution treatment and the recrystallized grains may grow up with the prolongation of solution time, consequently the internal friction of grain boundary increases. Owing to the presence of constituent Zr in the tested alloy, the Al_3Zr particle forms, which is an infusible, or high-melting phase, and strongly obstruct the motion of grain and/or subgrain boundaries. Thus, the recrystallization is effectively inhibited. The metallographic observation shows that the grain size does not obviously vary with the prolongation of solution time at 530 ℃, therefore the effect of grain size on the internal friction of grain boundaries can be ignored. Another reason which may have influences on the internal friction of grain boundaries is the aggregation of alloying and impurity constituents at grain boundaries.

In the view of Ge Tingsui[3], the peak value and peak temperature of internal friction of grain boundaries decrease with the increase of

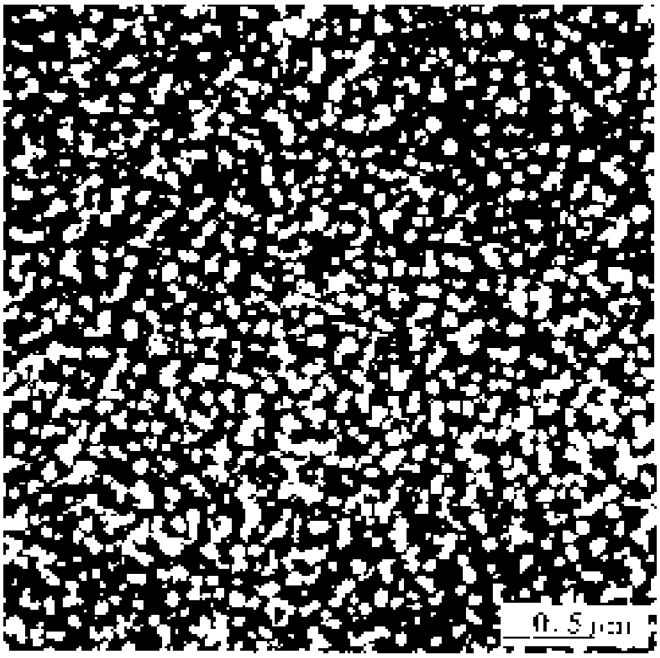

Fig. 3 δ' phase in the aged alloy

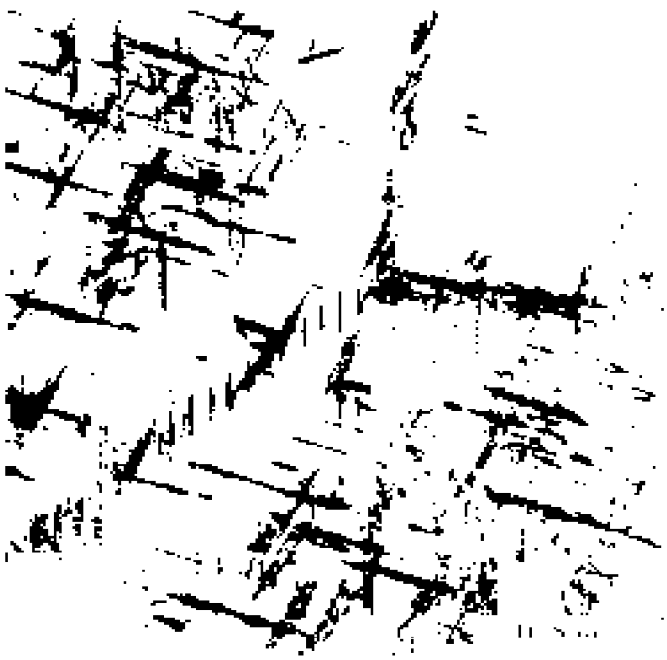

Fig. 4 Precipitated phases within grains and along subgrain boundaries in the aged alloy

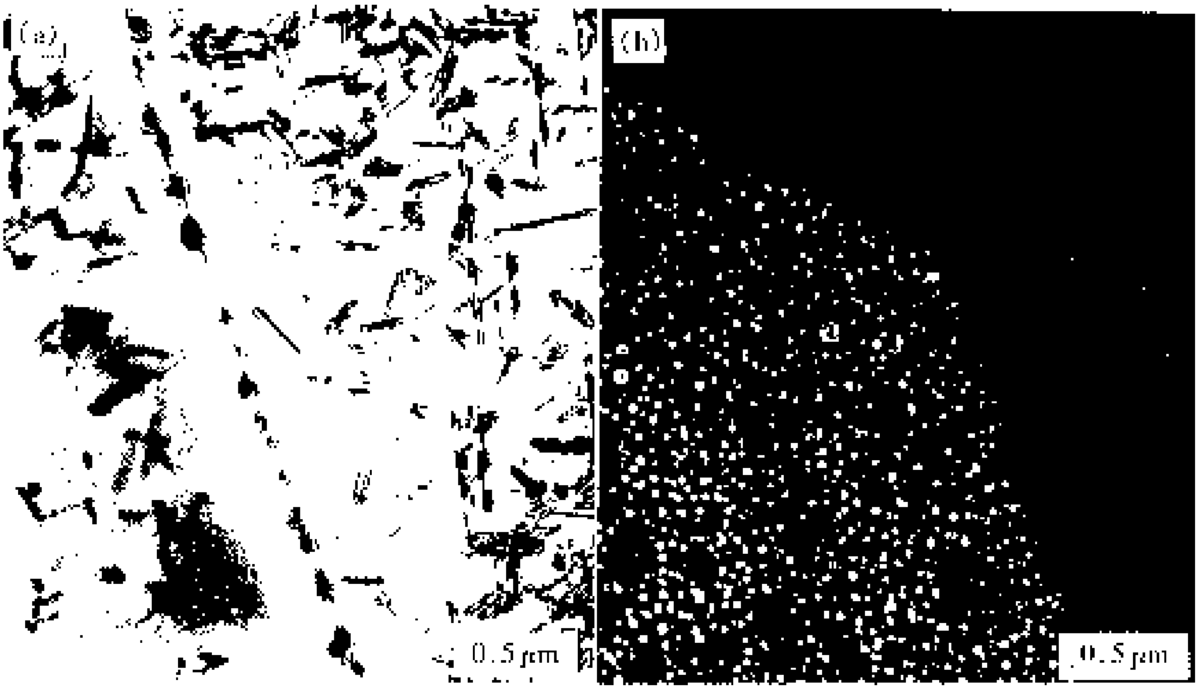

Fig. 5 Equilibrium phases on the grain boundary (a) and PFZS along the grain boundary (b) in the aged alloy

the content of alloying elements when the content is over 0.001%. The alloying elements and impurity elements are liable to aggregate at grain boundaries, where the energy is high and the atoms disorderly arrange. With the prolongation of solution time, the alloying elements and impurity elements aggregate at grain boundaries, therefore the peak value and temperature of internal friction decrease.

As is known, the degree of supersaturation of vacancies depends on the quenching medium, i e the cooling rate of quenching. However, the state and even the internal friction of grain boundaries do not depend on the quenching medium, on the basis of the model of "disordered atoms cluster"[4], which supposes that the arrangement of atoms be irregular and disordered in a grain boundary with width of several atoms and then the supersaturated vacancies be annihilated in it, and thus the internal friction is only related to the behavior of grain boundary relaxation.

A little torsion, whose effect on the internal friction of grain boundaries is similar to that of quenching medium, only produces some deformed dislocations within grains, but it has little influence on the large angle grain boundaries which induce the internal friction.

4.2 Effect of aging on the internal friction of grain boundaries

In comparision with as-quenched specimens, the peak value and peak temperature of internal friction of grain boundaries decrease heavily in aged specimens. The micromechanism of the internal friction of grain boundaries lies in the adhesive glide of grain boundaries, i e the motion of disordered atoms on the grain boundaries.

In the impure metals, because the glide is restricted within the trident grain boundary, the real relaxation time of grain boundaries τ may be calculated by the equation:

$$\tau = \tau_0 \left(1 + \frac{2\pi d r}{\lambda^2}\right) \qquad (1)$$

where τ_0 is the relaxation time in which there are no precipitates on grain boundaries, λ is the distance between the precipitates within grains and/or at the grain boundaries, $2d$ is the average size of grains and r is the radius of the precipitates.

The shorter distance owing to the precipitation on grain boundaries results in the shortened relaxation time, and the peak value/temperature lowerd.

4.3 Activation energy of the internal friction peak of grain boundaries

From the results, it is known that the activation energy of the internal friction peak of grain boundaries in the aged specimen (about 0.7 eV) is lower than that in the as-quenched specimen (about 1.4 eV).

As is known, the relaxation time may be expressed by the equation:

$$\tau = \tau_0 \exp(H/RT) \qquad (2)$$

where H is the activation energy, R is the gas constant and T is the absolute temperature. In correspondence with the results the decrease in the activation energy shortens the relaxation time on the basis of the eq. (2). The low activation energy of grain boundaries implies the low surface activation energy, i e the low strength of grain boundaries may result in intergranular brittle fracture because of the initiation of cracks along the grain boundaries.

In the as-quenched 2091 alloy, whose ductility is high, the fracture is transgranular and tough; but in the aged alloy, the fracture is intergranular and brittleness results from the presence of equilibrium phases on grain boundaries and PFZs. However, the transgranular fracture may consume more energy than the intergranular one. The facts above-mentioned correspond with the results.

5 CONCLUSIONS

(1) The behavior of grain boundary relaxation exists in both as-quenched and aged 2091 Al-Li alloy, but their peak values/temperatures of internal friction of grain boundaries are different.

(2) The peak value/temperature of internal friction of grain boundaries deceases with the prolongation of solution time. The behavior of internal friction is little affected by the replacement of quenching media or by a little torsion.

(3) After aging, the peak value/temperature of internal friction of grain boundaries obviously decreases, and the activation energy of internal friction peak of grain boundaries decreases too.

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