MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AN Al-Li-Cu-Mg-Zr ALLOY CONTAINING MINOR LANTHANUM ADDITIONS [①]

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ABSTRACT

The effect of the addition of minor amounts of La on the microstructure and mechanical properties of an Al-Li-Cu-Mg-Zr alloy was studied. The results showed that in Al-Li alloys some impurities, such as Fe, Si and Na segregated on the grain boundaries, and the addition of minor amounts of La decreased the segregation of these impurities. In addition, La could give rise to grain refinement, and retard the growth of δ' precipitates. The tensile properties and toughness of the Al-Li alloy containing minor amounts of La were improved compared with the La-free Al-Li alloy.

Key words: microstructure mechanical properties Al-Li-Cu-Mg-Zr alloy lanthanum

1 INTRODUCTION

Compared with 2000 and 7000 series commercial aluminium alloys, Al-Li based alloys have higher specific strength, lower density and higher elastic modulus. This is very attractive for aerospace applications because of their potential for reducing the weight of airframe components. However, the ductility and toughness of Al-Li alloys are lower than those of 2024 and 7075 type aluminium alloys. Therefore, much recent research has been directed towards improving the ductility and toughness of Al-Li alloys by optimization of various processing and heat treatments and modifications in alloy compositions, such as the additions of Cu and Mg together with a small quantity of cadmium, zirconium and silver.

It is known that rare earth elements have high chemical activity. If these elements are added to the alloys, they can play the role of grain refinement and, purification of alloys and microalloying; thus the properties of the alloys can be improved. The purpose of this paper is to report the effect of minor amounts of La on the microstructures and mechanical properties of an Al-Li-Cu-Mg-Zr alloy.

2 EXPERIMENTAL PROCEDURE

The materials used in this study were melted in a graphite crucible and cast under an argon atomosphere. The chemical compositions of the alloys are given in Table 1. The ingots were homogenized at 520 ℃ for 20 h, scalped and then hot rolled into 5 mm

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sheets after reheating at 500 ℃ for 2h. Earlier work showed that intermediate thermomechanical treatment can improve the toughness of Al-Li system alloys[1]. So after hot rolling, the processes and heat treatments were carried out by the method illustrated schematically in Fig. 1.

Table 1 Chemical compositions of the alloys (wt. -%)

Sample No.	Li	Cu	Mg	Zr	La
A	2.44	2.01	1.38	0.16	---
B	2.51	2.07	1.33	0.11	0.05
Sample No.	**Fe**	**Si**	**Na**	**Al**	
A	0.09	0.16	0.0032	bal.	
B	0.11	0.11	0.0034	bal.	

The microstructures and fractographs were observed by transmission and scanning electron microscope. Thin foils for TEM observations were prepared using a twin-jet polisher in a solution of 33% HNO_3- 67% methanol at −25 ℃ and DC voltage of 12 V. The distribution of elements in some fracture surfaces was determined using energy dispersive X-ray analysis (EDXA). The tensile test was carried out using a WD-10 A electron tensile machine. Fracture toughness was measured by Kahn tear test method[2].

3 RESULTS AND DISCUSSION

3.1 *Microstructure*

Optical microstructures are shown in Fig. 2. The grain size of the La-containing alloy is smaller than that of the La-free alloy. Some unrecrystallized grains are present in the La-containing alloy. This implies that the addition of minor amounts of La gave rise to both grain refinement and inhibition of recrystallization.

TEM investigations indicated that homogeneous distribution of δ' precipitates occured in the La- containing and La- free alloys. There was no significant difference in the distribution and morphology of δ' particles between the La- containing and La- free alloys. This may be related with the fact that metastable δ' phase has a very low matrix to particle misfit, and the nucleation of δ' is homogeneous and occurs during the quenching process[5]. It is unlikely that the addition of minor amounts of La can change the nucleation mechanism of δ' particles. However, in the same aging condition the size of δ' particles in the La-containing alloy appears to be smaller than that in the La-free alloy (see Fig. 3). This implies that the addition of minor amounts of La to Al-Li alloys seems to reduce the growth rate of δ' precipitates. This may be associated with the fact that the minor lathanum additions slow the rate of

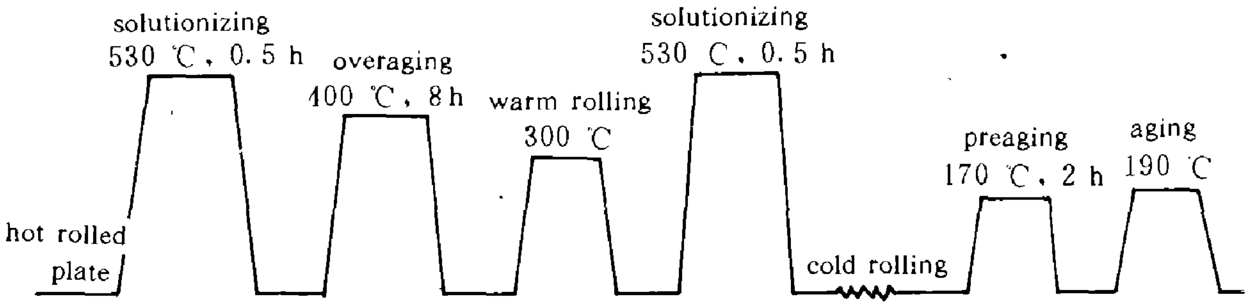

Fig. 1 A schematic diagram showing the treatment processes for the specimens

solute atoms diffusion. Because the atom radius of La is 1.877 Å, this is 31 percent larger than that of Al, therefore, when La is added into Al, it would have the trend of combining with vacancy in order to reduce the lattice distortion energy. Strong La atom/vacancy binding resulted in decreasing free vacancy concentration and slowing the rate of solute atoms diffusion. Thus, the growth of δ' particles is slower. Present results are consistent with those reported by other researchers[4].

The lath-shaped S' precipitates were also observed in both alloys. Fig. 4 shows S' precipitates in the La-containing and La-free alloy aged at 190 ℃ to peak. From this it can be seen that in the La-containing alloy the amounts of S' precipitates within the matrix are less and S' lath spacing appears to be larger compared with the La-free alloy. It is known that in the Al-Cu-Mg alloys, the nucleation of S' precipitates occurs mainly on the dislocation loops and helical dislocations by vacancy condensation, the S' precipitation process is controlled by the quantity of these defects[5,6]. However, such defects are less in Al-Li-Cu-Mg alloys because Li atom has a very high binding energy to the vacancy[7]. In order to develop a sufficiently dense distribution of S' precipitates the stretch prior to aging is required to increase heterogeneous nucleation sites. As mentioned above, the addition of minor amounts of La to Al-Li alloys decreased the free vacancy concentration. This would suppress the vacancy condensation on quenching, thereby inhibited the formation of dislocation loops and helices. Therefore, nucleation sites for S' precipitation decreased further in the La-containing alloy. In addition, the decrease of free vacancies was unfavourable for diffusion of Cu, Mg atoms for the formation of S' phase, thus the

Fig. 4 δ' **precipitates aged to peak**
(a)—alloy A; (b)—alloy B

density of distribution of δ' precipitates was somewhat decreased.

3.2 *Tensile Properties*

Fig. 5 shows the tensile properties of both alloys aged finally at 190 ℃. It can be-seen that the ultimate tensile strength, yield strength and elongation of the La-containing alloy are higher than those of the La-free alloy at whole aging periods. In addition, the differences of strength between the peak aged specimens and over aged specimens are smaller for the La-containing alloy. In contrast, the decrease of strength of the La-free alloy is large during over aging. These results imply that the minor La additions can improve the tensile properties of the Al-Li alloy, and slow the softening rate during over aging. This is attributed to the more fine grains and smaller size of δ' precipitates in the La-containing alloy because of the addition of minor amounts of La.

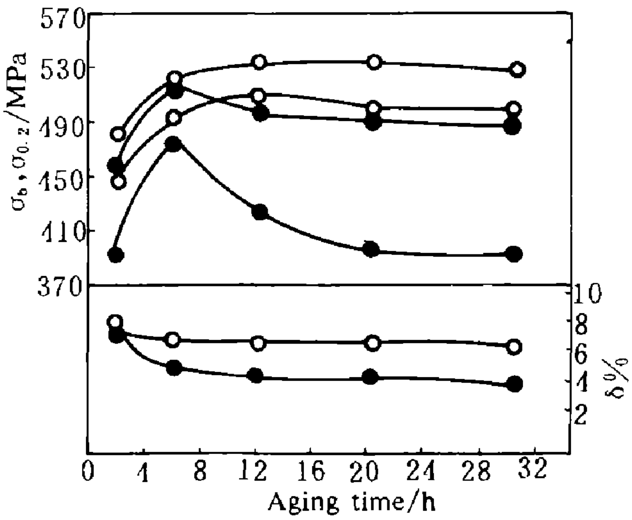

Fig. 5 Changes in tensile properties of the La-containing and La-free alloys during aging at 190 ℃
∘ —0.05La; •—La-free

3.3 *Fracture Toughness*

The variation in fracture toughness with aging time is shown in Fig. 6. Both alloys had higher toughness values in the underaged condition. With increasing aging time up to over aging, the toughness values of the La-free alloy decreased progressively. The toughness values of the La-containing alloy also decreased with increasing aging time up to peak- aging, thereafter, increased somewhat during over aging. At whole aging periods, the toughness values of the La-containing alloy were significantly higher than that of the La-free alloy. These results suggest that the addition of minor amounts of La has the apparent benificial effect on the improvement of fracture toughness of Al-Li alloys, especially can improve the toughness of Al-Li alloys in overaged condition.

Some works indicated that grain boundary segregation of some low melt point metals, such as Na, K and Ca and impurities Fe and Si was one of the main reasons resulting in lower ductility and toughness of Al-Li alloys[8]. In this study, the distribution of Fe, Si, Na and La on the grain boundaries and matrix was investigated by energy dispersive X-ray analysis (EDX). The results are shown in Table 2.

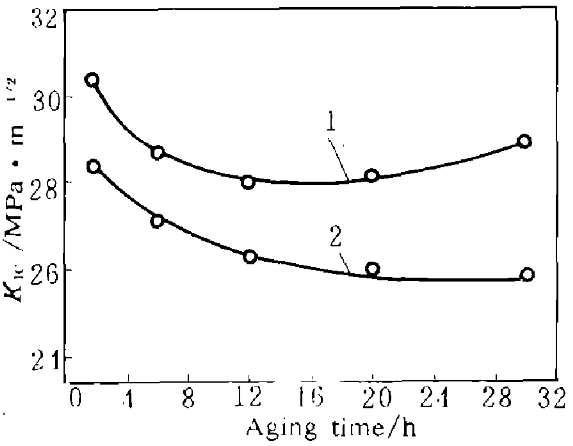

Fig. 6 Variation of fracture toughness (K_{IC}) with aging time at 190 ℃
1—0.05 La; 2—La-free

Table 2 EDX analysis for Na, Fe, Si and La in the grain boundaries and matrix (wt. -%)

Elements	Alloy A (La-free)		Alloy B (0.05 La)	
	grain boundaries	matrix	grain boundaries	matrix
Na	0.009	0.002	0.004	0.003
Fe	0.33	0.07	0.18	0.13
Si	0.42	0.09	0.12	0.08
La	—		0.11	0.04

The concentrations of Fe, Si and Na on the grain boundaries were greatly higher than those within the matrix in the La-free alloy. In contrast, the segregation of Fe, Si and Na on grain boundaries decreased and the differences of the distribution of these impurities between the matrix and grain boundaries were small in the La-containing alloy. This implies that La could reduce grain boundary segregation of Fe, Si and Na, thus, reduce the harmful effect of these impurities on the ductility and toughness of the Al-Li alloys. The reason of reducing the segregation of the impurities is probably due to the fact that La has considerable affinity with these elements and can easily form stable rare earth compounds with Fe, Si and Na, therefore, free Fe, Si and Na impurties present on the grain boundaries were decreased.

3.4 *Fractographs*

SEM observations of fracture surfaces indicated that in the underaged condition, both La-containing alloy and La-free alloy exhibited a mixed fracture mode, i.e., transgrainular shear and intergranular fracture. For the La-free alloy, the peak and overaged samples exhibited intergrainular fracture (see Figs. 7(a), (b)). Small and shallow diamples associated with grain boundary precipitates were observed on the grain boundaries at higher magnifications. Extensive secondary cracking was also found along the grain boundaries. This was because in the peak and overaged conditions deformation was mainly localized in the soft precipitate free zones adjacent to the grain boundaries. This led to high stress concentrations at grain boundaries. Cracks would nucleate either at the grain boundary precipitates or at grain boundary triple junctions and propagate along grain boundary within the PFZ. This led to the decrease in fracture toughness. In the peak and overaged conditions the fracture features of the La-containing alloy were basically similar to those of the La-free alloy. However, the area fractions of intergranular fracture of the La-containing alloy seem to be smaller (see Figs. 7 (c), (d)) This fracture mode appears to increase the toughness of the La-containing alloys due to the increased strength of grain

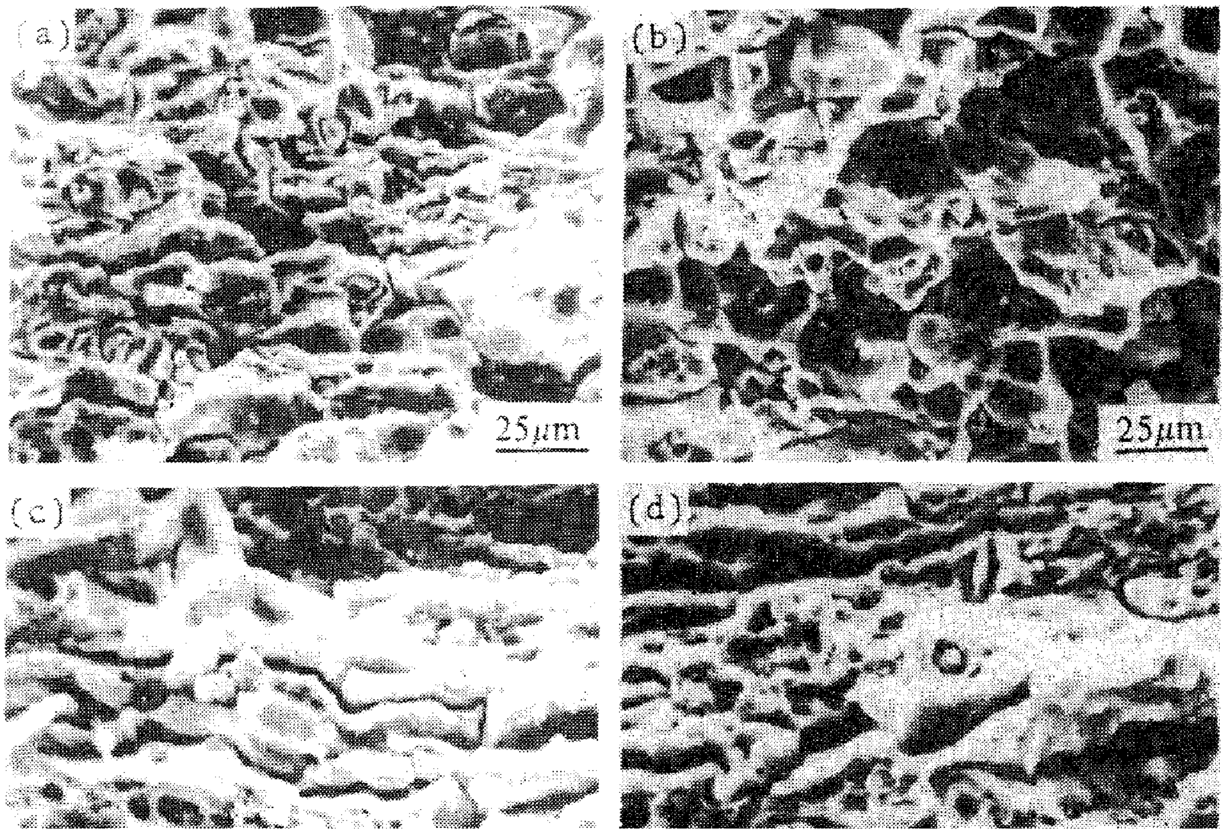

Fig. 7 SEM micrographs of fractured surfaces

boundaries.

4 CONCLUSIONS

(1) There is grain boundary segregation of Fe, Si, and Na in Al-Li alloys. The addition of minor amounts of La can decrease the segregation of these impurities.

(2) The addition of minor amounts of La to Al-Li alloys can refine the grains and retard the growth rate of δ' precipitates.

(3) The tensile properties and fracture toughness were greatly improved by adding minor amounts of La to the Al-Li alloys, especially the toughness of the overaged Al-Li alloys was improved.

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