THE EFFECT OF Be ADDITIONS ON PRECIPITATION RESPONSE IN Al-Li ALLOYS

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Abstract

The investigation has been carried out for clarifying the effect of Be additions on precipitation response in Al-Li alloys by means of the measurements of tensile strength, electrical resistivity, hardness and the observations of transmission electron micrographs.
Following obtained the results, second peak phenomenon which developed after maximum peak stage of ageing due to secondary T_1 phase was observed at the hardness and tensile tests in Be bearing alloy. The precipitation of secondary T_1 phase may be estimated because of the phase stability changes of precipitates(δ', θ', T_1) by Be addition. This consideration may be positive value as a result of accelerated resolution of δ' and θ' phases. From the comparison of strength with elongation, the second peak condition showeded most optimum mechanical property because of the remarkable improvement of elongation. And very small precursor-phases were observed in Be free alloy at early stage of ageing, but larger δ' phases were already observed in Be bearing alloy. Therefore, it may be estimated that the early stages of decomposition process of δ' phases were promoted by Be addition.

Introduction

In recent years, the Al-Li alloys of representative aerospace alloys of high strength and light-weight have been spotlighted, and have already been developed into commercial alloys. However, these alloys have shown poor toughness due to the strain localization associated with shearable δ' phase[1-2] and the formation of low melting point compound by Na and K[3-5]. Therefore, many studies have been focused on these problems up to the present[6-7]. In the one of these studies, especially, the effect of Be addition has showed more significant improvement than other studies[8]. However, the concrete reasons of this result have not been completed until now. On the other hand, Be in Al-Cu-Mg alloy[9] could lead to change the stabilities of GPB zone and S′ phase. And that is why double peak phenomenon was observed at the hardness test. Therefore, Be addition to commercial 2090(Al-Li-Cu-Zr)alloy may be also anticipated to change both the precipitation response of δ', θ' and T_1 phases and mechanical properties. The purpose of this study was to investigate the effect of Be additions on the precipitation response and microstructural changes in two alloys, the 2090 alloy and the 2090 alloy containing 0.39Be by using electrical resistivity measurement and transmission electron micrographs.

Experimental Procedure

The Al-Li-Cu-Zr-(Be)alloys were melted and cast in a high frequency melting furnace under Ar atmosphere using 99.99%Al and 99.9%Li and master alloys of Al-40%Cu, Al-5%Zr and Al-2.5%Be. The alloy designs and the chemical compositions of these alloys are shown in Table I.

Table I Alloy Designs and Chemical Compositions of Al-Li-Cu-Zr-(Be) Alloys.

Alloy design	Chemical composition (wt%)				
	Li	Cu	Zr	Be	Al
Al-2.00Li-2.50Cu-0.13Zr	2.01	2.32	0.13	--	Bal.
Al-2.00Li-2.50Cu-0.13Zr-0.40Be	1.96	2.12	0.12	0.39	Bal.

After all as-cast ingots were scalped and homogenized at 550℃ for 16hrs, these ingots were hot rolled and cold rolled to plates approximately 1mm thick. All the alloys were solution treated for 0.5hr at 550℃ and quenched in cold water. All ageing treatments were carried out at 190℃ in silicon oil. After ageing treatment, ageing response was based on results of Micro Vickers hardness measurements. Room temperature tensile tests were performed on ASTM E8 subsize specimens with Instron type tensile tester, and conformed to the specifications of ASTM Tension Testing of Metallic Materials (KS B 0802). For the resistivity measurements, 1.5mm thick sections were cut from the rolled samples and drawn to the rods of 1mm diameter with a ratio of 8:1. To remove cold work, these samples were solution treated for 0.5hr at 550℃ and quenched in cold water. All the thin foil specimens for TEM analyses were electropolished in a solution of 40 vol% HNO_3-60 vol% CH_3COOH cooled to -40℃ at a DC voltage of 18 to 20V. The thin foil specimens were examined by JEM200CX electron microscope operating at accelerating voltages of 160kV.

Results and Discussion

Mechanical properties in Al-Li-Cu-Zr-(Be) alloys

Figure 1 shows the plot of hardness with ageing time in Al-Li-Cu-Zr-(Be) alloys aged at 190℃. The maximum hardness of both alloys was obtained at 16hr, and the hardness of Be bearing alloy is generally higher than that of the Be free alloy. Especially, the hardness of Be bearing alloy slightly increased once again at the latter half of ageing time. This observation was confirmed by subsequent tensile testing.

Figure 2 shows the plots of tensile strength and elongation with ageing time in both alloys at the same conditions. The behaviors of tensile strength were similar to those of hardness, that is, the second(lower) peak was also observed at the latter of ageing time in Be bearing alloy. However, the tensile strength of Be free alloy was higher than that of Be bearing alloy because the segregations at grain boundary and matrix were caused by Be added more than maximum solid

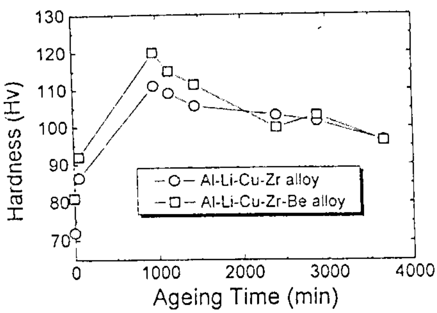

Figure 1 Hardness changes with ageing time in Al-Li-Cu-Zr-(Be) alloys aged at 190℃.

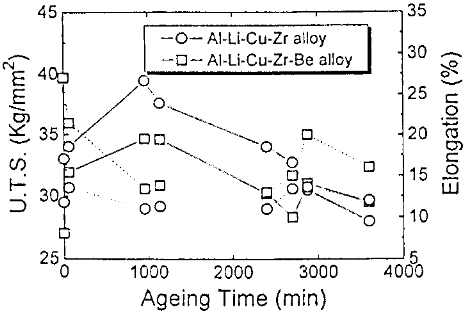

Figure 2 Ultimate tensile strength and elongation changes with ageing time in Al-Li-Cu-Zr-(Be) alloys at 190℃. (—— : U.T.S., ------ : Elongation)

solubility limit(0.08wt%)[10]. And the elongation of Be bearing alloy was higher than that of Be free alloy, especially, remarkably increased elongation was observed at the second peak condition.

Microstructural changes in Al-Li-Cu-Zr-(Be) alloys

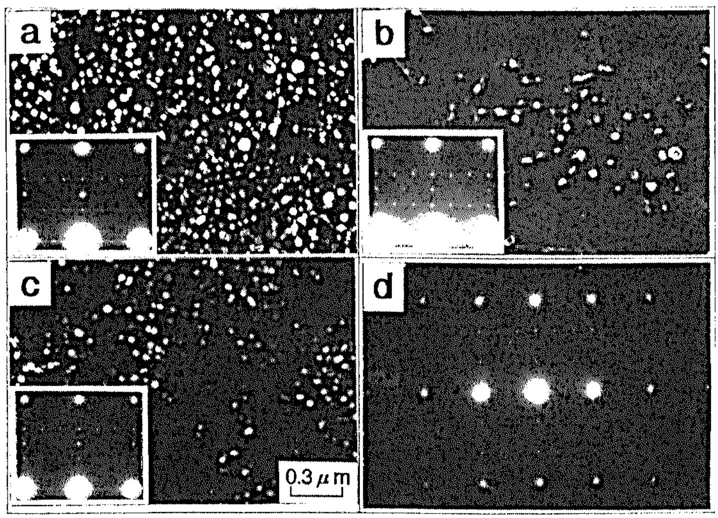

Figure 3 Dark field images of δ' phases and [112] diffraction patterns in Al-Li-Cu-Zr-(Be) alloys aged at 190℃ for various times.
(a),(b) : Al-Li-Cu-Zr alloy (c),(d) : Al-Li-Cu-Zr-Be alloy
(a) 16hr (b) 40hr (c) 16hr (d) 40hr

Figure 3 shows the δ' phases with ageing time on the DF images and [112] SAD patterns of TEM micrographs of both alloys aged at 190℃. With the observation of DF image of 16hr, the distribution of δ' phases was different from each other. The δ' phases of Be free alloy more homogeneously distributed, but those of Be bearing alloy heterogeneously distributed with the precipitated and non-precipitated regions. And the existence of δ' phases of Be free alloy was confirmed from the DF image of 40hr, but the δ' phases of Be bearing alloy at the same ageing condition were never observed from the DF image and SAD pattern.

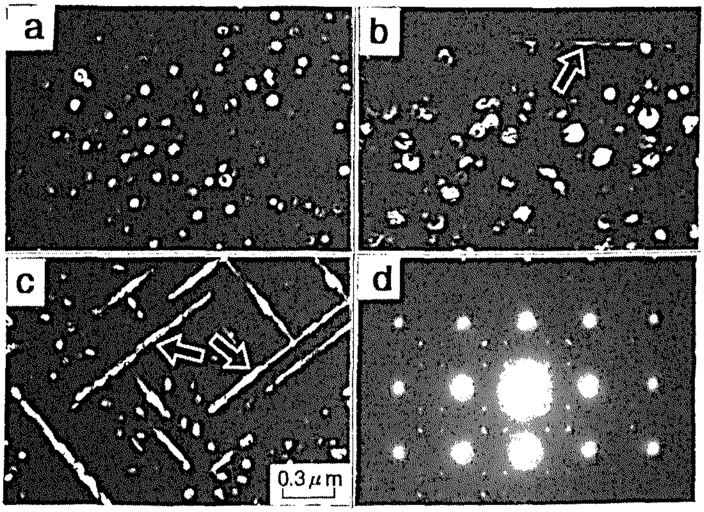

Figure 4 Dark field images of δ' and θ'/δ' phases in Al-Li-Cu-Zr-(Be) alloys aged at 190℃ for various times.
(a),(b) : Al-Li-Cu-Zr alloy (c),(d) : Al-Li-Cu-Zr-Be alloy
(a) 16hr (b) 40hr (c) 16hr (d) 40hr

Figure 4 shows the δ' and θ'/δ' composite phases with ageing time on the DF images of TEM micrographs of both alloys aged at 190℃. From the DF images of 16hr, we could know θ phases were not observed in Be free alloy and many θ'/δ' composite phases (Arrowed) were found in Be bearing alloy. At the DF images of 40hr, however, these phases were observed in Be free alloy and were not found in Be bearing alloy. From the above results, it may be thought that the resolutions of δ' and θ' phases with ageing time were accelerated by Be addition.

Figure 5 shows the T_1 phases with ageing time on the DF images of TEM micrographs of both alloys aged at 190℃. As the ageing time was increasing, the T_1 phases of Be free alloy were gradually grown. However, the T_1 phases of Be bearing alloy at 40hr were very fine with higher density and grown T_1 phase(Arrowed) also coexisted. And T_1 phases with more various size were observed at the DF images of 48hr in Be bearing alloy. Considering ageing condition, these fine T_1 phases in Be bearing alloy may not be estimated by the resolution of already precipitated T_1 phases but by the new precipitation of T_1 phase at the just before 40hr.

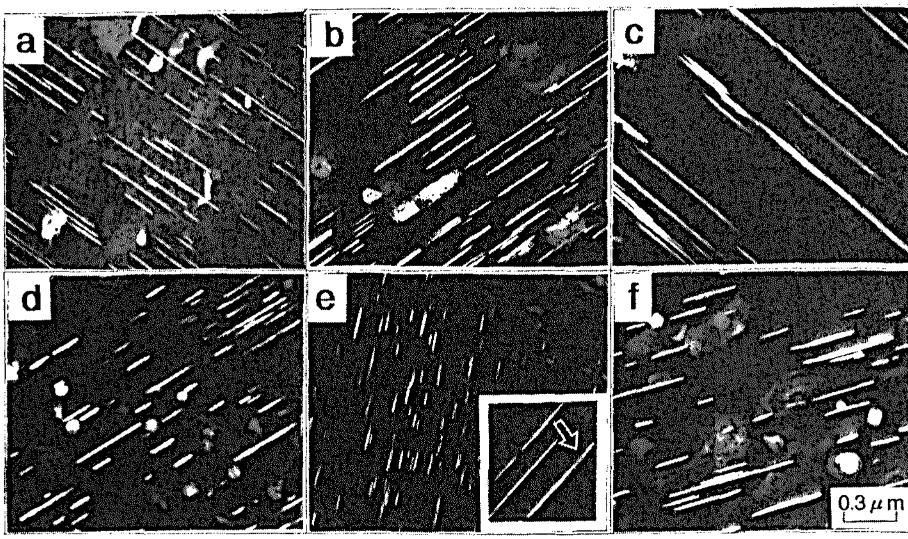

Figure 5 Dark field images of T_1 phases in Al-Li-Cu-Zr-(Be) alloys aged at 190℃for various times.
(a),(b),(c) : Al-Li-Cu-Zr alloy (d),(e),(f) : Al-Li-Cu-Zr-Be alloy
(a) 16hr (b) 40hr (c) 48hr (d) 16hr (e) 40hr (f) 48hr

In the present study, therefore, these fine T_1 phases different from already precipitated T_1 phases were specified as secondary T_1 phases. The reason of these changes of precipitation response by Be addition could be confirmed by the kinetic analysis caused the diffusivity changes of solute atoms and by the phase stability changes of precipitates caused micro-segregated Be atoms at the interface between matrix and precipitates. Illustration from works of Youdelis et al.[9] in Al-Cu-Mg-(Be) alloys may be informative to the analysis of this phenomenon. They analyzed the changes of precipitation behaviors with resistivity measurement and reported the Be addition did not affect the growth-dependent parameter or activation energy of S′ phase. Considering these results and the more heterogeneously dissolved δ' phases of Be bearing alloy at 16hr in this study, the explanation of the latter may be estimated to be more reasonable. Accordingly, the resolutions of δ' and θ' phases with ageing time in Be bearing alloy were accelerated by the increase of phase instabilities of these phases caused micro-segregated Be atoms at the interface between matrix and these precipitates. And it may be thought that T_1 phases with lower critical nucleation energy were homogeneously precipitated as the fine secondary T_1 phases at the resolved regions of δ' and θ' phases. Therefore, T_1 phases with more various size at 48hr and the double peak phenomenon at hardness and tensile tests in Be bearing alloy were also caused by the precipitation of secondary T_1 phase. These phases newly acted as strengthening precipitates after 40hr. It may be thought that remarkably increased elongation at second peak condition was caused because various size T_1 phases were helpful to homogeneous deformation. Therefore, it was considered that the second peak condition with the remarkable improvement of elongation was the optimum heat treatment condition.

Precipitation response in Al-Li-Cu-Zr-(Be)

Figure 6 shows resistivity changes in both alloys during continuous heating up. The heating rate was 24℃/hr. Two resistivity peaks were observed in Be free alloy, but the horizontal region of resistivity at below 200℃ and another resistivity peak at above 300℃ were found in Be bearing alloy. According to the results of DSC in 2090 alloy by Cho et al.[8], they confirmed that one peak at below 200℃ was caused by the precipitation and resolution of δ' phase and the other peak at above 300℃ was caused by the precipitation and resolution of θ' and T_1 phases. These results show very good agreement on the this resistivity changes of Be free alloy. Considering the previous microstructural changes, the horizontal region of resistivity at below 200 ℃ and another resistivity peak at above 300℃ in Be bearing alloy were associated with the increased solute atoms caused by the more accelerated resolution of δ' phase and the precipitation of secondary T_1 phase respectively.
Figure 7 shows resistivity changes in both alloys with ageing time aged at 50℃. Resistivity with ageing time were slightly increased in Be free alloy, but decreased in Be bearing alloy. In order to find out this phenomenon concretely, TEM analysis was followed.

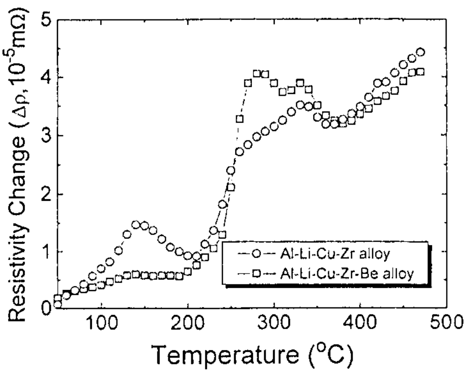

Figure 6 Resistivity changes in Al-Li-Cu-Zr-(Be) alloys during continuous heating up. $[(\rho_a - \rho_0)-(\rho_{a+20} - \rho_a) : T_{a+10}]$

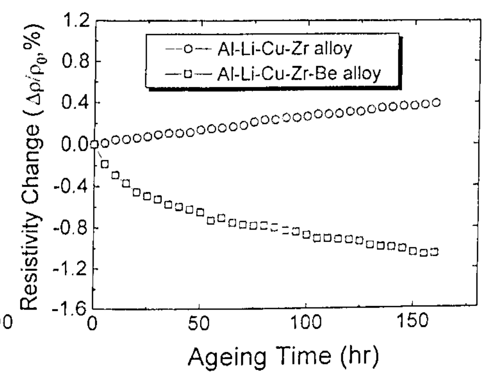

Figure 7 Resistivity changes in Al-Li-Cu-Zr-(Be) alloys aged at 50℃.

Figure 8 shows the DF images and SAD patterns of δ' phase in both alloys aged at 50℃ for 100hrs. Superlattice diffraction spots caused by δ' phases were observed in the SAD patterns of both alloys. The DF image of Be free alloy showed the precipitates with relatively finer and irregular morphology, but that of Be bearing alloy showed the precipitates of larger(50~70Å) and more spherical(Arrowed). In the recent investigations, the early stages of decomposition process of metastable δ' phases were explained as the process of congruent ordering → secondary decomposition → secondary disorder[11-12]. And Sato et al.[13] also proposed that fine ordering structure formed at the early stage of metastable δ' phase were specified as the ordered domain, δ' precursory structure. In the present study, therefore, the precipitates of Be free alloy may be estimated as δ' precursory structures. And these fine precipitates resulted in the slight increase of resistivity. Therefore, it could be considered that the precipitates of Be bearing alloy

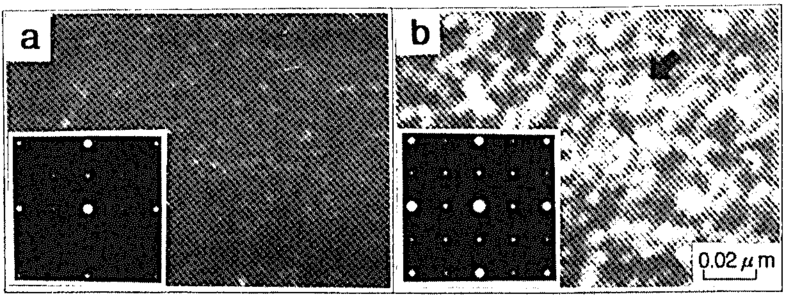

Figure 8 Dark field images of δ′ phases and [100] diffraction patterns in Al-Li-Cu-Zr-(Be) alloys aged at 50℃ for 100hrs.
(a) Al-Li-Cu-Zr alloy b) Al-Li-Cu-Zr-Be alloy

was metastable δ′ phases and these phases caused resistivity to increase. From the above results, it may be estimated that the early stages of decomposition process of δ′ phases were promoted by Be addition.

Conclusions

1. Because of secondary T_1 phase, second peak phenomenon which developed after maximum peak stage of ageing was observed at the hardness and tensile tests in Be bearing alloy.
2. The precipitation of secondary T_1 phase may be estimated because of the phase stability changes of precipitates(δ′ , θ′ , T_1) by Be addition.
3. From the comparison of strength with elongation, the second peak condition showed most optimum mechanical property because of the remarkable improvement of elongation.
4. Very small precursor-phases were observed in Be-free alloy at early stage of ageing, but larger δ′ phases were already observed in Be bearing alloy. Therefore, it may be estimated that the early stages of decomposition process of δ′ phases were promoted by Be addition.

Acknowledgement

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