# Effect of Double-Ageing on Precipitation Hardening of Li Containing AI-Zn-Mg-Cu Alloys

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## Abstract

Al-5.6%Zn-1.9%Mg-1.6%Cu-0.3%Er alloy and Al-5.6%Zn-1.9%Mg-1.6%Cu-1.0%Li-0.3%Er alloys (in wt%) were single-aged at 110 $^{\circ}$ C,120 $^{\circ}$ C and 160 $^{\circ}$ C, and the Li containing alloys were also aged at 110 $^{\circ}$ C for 5h, and followed at 160 $^{\circ}$ C. The hardness of the single aged Li containing Al-Zn-Mg-Cu alloys is much lower than that of the Li free alloys. The most significant hardening is obtained by double ageing, and there are two hardness peaks during the second ageing at 160 $^{\circ}$ C.

# 1. Introduction

Al-Zn-Mg-Cu alloys are widely used for structure application in the aerospace due to their high specific mechanical properties. The maximum strength of Al-Zn-Mg(-Cu) alloys and the pronounced hardening response to peak ageing at  $120^{\circ}$ C is generally associated with precipitates of n' phase and its precursors [1]. Double ageing is also used to obtain homogeneous distribution of microstructure to improve toughness and fatigue properties [2]. Lithium is the lightest metallic element; addition of lithium to aluminum alloys increases the specific strength and modulus and decreases the density. Li containing Al-Zn-Mg-Cu Alloys were studied [3-6], and it is found that single-ageing process cannot make the Li containing Al-Zn-Mg-Cu alloys high strength and hardness. In this paper, 1.0%Li containing Al-Zn-Mg-Cu alloy were treated by single-ageing and double-ageing, and it is found that the alloy can get higher hardness by double-ageing.

# 2. Experimental

The composition of the alloy in weight percent is: Al-5.6Zn-1.9Mg-1.6Cu-1.0Li-0.3Er. The alloys were melted in a vacuum furnace and cast in a water-cooled mould under protective argon conditions. The ingots were homogenized in two steps:  $430^{\circ}$ C for 24h and  $470^{\circ}$ C for 36h, then hot rolled at about  $430^{\circ}$ C to 2mm thickness.

Specimens were solution treated at 490  $^{\circ}$ C for 1h, and then water quenched. After ageing at room temperature for 48h, the specimens were then artificially single aged at 110  $^{\circ}$ C, 120  $^{\circ}$ C, 160  $^{\circ}$ C, or in double ageing:5h at 110  $^{\circ}$ C, followed by further ageing at 160  $^{\circ}$ C.

The hardness was determined by Vickers measurement, using 1000g loads. Microstructure was observed by transmission electron microscopy (TEM).

## 3. Results and Discussion

The hardening curves of the Li containing Al-Zn-Mg-Cu alloys aged at different processes is shown in Figure.1, and the hardening curve for the Li free alloy aged at 120 °C is illustrated, too. Artificial ageing was carried out after room temperature ageing for 48h. With single ageing, the hardness for the Li containing alloys increases at the beginning, however, the hardness will hardly change after ageing for a duration. Comparing hardening behavior of single ageing at 110 °C,120 °C and 160 °C, the higher the ageing temperature, the lower the hardness of the alloy is. The alloys do not reach maximum hardness for the three single ageing temperature investigated.

The Li containing Al-Zn-Mg-Cu alloy aged at  $120^{\circ}$ C for 40h was observed under TEM, as shown in Figure.2(a). It can be seen that precipitates are homogeneously distributed in the matrix and appear approximately equiaxed, or spherical. With the low precipitation density, the diameters of the precipitates are about 6nm. Low precipitation results in low hardness. Figure.2(b) shows the microstructure of the alloy aged at  $160^{\circ}$ C for 40h, from which very coarse precipitates can been seen. Most of the precipitates appear equiaxed or rectangular, but there are some rods or laths. The precipitation density is very low. Showing coarse and sparse particles in the matrix, it is not surprising that the alloy possesses low hardness during ageing at  $160^{\circ}$ C.



Figure 1: Hardening curves of the Li containing AI-Zn-Mg-Cu alloys and the Li free alloy.



Figure 2: Precipitates in matrix of the Li containing Al-Zn-Mg-Cu alloys aged at (a) 120°C for 40h and (b) 160 °C for 40h.

Pre-ageing for 5h at 110°C, followed by artificial ageing at 160°C was carried out for the alloy. The hardness of the double ageing alloys is higher than that of single ageing alloys. It should be noted that there are two hardness peaks, which implies that there are twice precipitation during the second ageing at 160°C. The first period in which intensified hardening behavior is presented is just extended to 12h, and then the hardness decrease slightly as the ageing proceeded; the second ageing hardening starts from 22h, and the hardness increase with prolonged ageing, there is a plateau ageing up to 34h.

Figure.3 (a) illustrates the microstructure of the alloy pre-ageing at 110 °C for 5h, followed by ageing at 160 °C for 40h. Approximately equiaxed and plate-like precipitates are homogeneously distributed and with high precipitation density, which contributes to fairly high hardness. Selected area diffraction with [111]<sub>Al</sub>, as shown in Figure.3(b), indicate that the precipitates are T'. Precipitates near grain boundary are coarser than those inside the matrix, and coarse continuous plate-like precipitates are present in the grain boundary.



Figure 3: (a) microstructure and (b) SAD pattern with  $[111]_{AI}$  of Li containing Al-Zn-Mg-Cu alloy aged at  $110^{\circ}C\times5h+160^{\circ}C\times40h$ .

The artificial ageing behavior of the Li containing Al-Zn-Mg-Cu alloys is different from that of the lithium free alloy, which implies that addition of lithium to Al-Zn-Mg-Cu alloy modifies the kinetics. The heat treatment processes for Al-Zn-Mg-Cu alloy might be not adapted to Li containing Al-Zn-Mg-Cu alloy. The most significant hardening is obtained by double ageing. It is double ageing that can be used for Li containing Al-Zn-Mg-Cu alloy to obtain higher hardness.

#### 4. Conclusion

The hardness of Li containing Al-Zn-Mg-Cu alloys single-aged is much lower than that of Li free alloys, the most significant hardening is obtained by double-ageing due to high precipitation density. The double ageing can be used for the Li containing Al-Zn-Mg-Cu alloy to obtain higher hardness.

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