Effect of Two-Stage Aging on the Mechanical Properties of Al-Li Alloy

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Abstract: In this work, the effect of two-stage aging with low temperature followed by high temperature on the mechanical properties of Al-3.8Cu-1.2Li-0.5Mg-0.15Zr alloy was investigated. The results show that with the increase of the first aging temperature (75-125℃), the time for the alloy to reach the peak hardness in the second aging is shortened, and the peak aging hardness first increases and then decreases. When the first aging temperature is 100℃, with the prolongation of the first aging time (0-32 h), the time for the alloy to reach the peak hardness in the second aging time is also gradually shortened, and the peak aging hardness first increases and then decreases. The strength of the alloy increases significantly after the two-stage aging treatment. With the increase of the first aging temperature, the strength of the alloy after aging first increases and then decreases. The highest room temperature strength of the alloy was obtained when the aging process is 100℃ × 8 h + 175℃ × 32 h, with YS = 685MPa, UTS = 737MPa and EL = 5.58%, respectively. The main reason for the increase in strength and plasticity of double-stage aging alloys is that the first stage of low-temperature aging facilitates the formation of clusters of solute atoms and GP zones in the alloys, which provides more nucleation cores for the formation of the T_1 phase during the subsequent second stage of high-temperature aging. This results in a higher density, smaller size and more uniform distribution of T_1 phase precipitation after the second stage of high-temperature aging.

Keywords: Al-Li alloy; Microstructure evolution; Mechanical properties; Aging treatment

1 Introduction

Al-Li alloys are characterized by low density, high elastic modulus and high specific strength [1]. Studies have shown that the addition of 1% Li can reduce the density of the alloy by 3%, increase the elastic modulus by 6%, and help to improve the strength, fatigue properties and resistance to fatigue crack propagation [2].

However, Al-Li alloys face the problem of strength and plasticity incompatibility, and there is still room for further improvement of their mechanical properties. At present, most of the research focuses on regulating the alloy composition [3], and there is less literature on the optimization of the heat treatment process. Therefore, this paper takes Al-3.8Cu-1.2Li-0.5Mg-0.15Zr alloy as an example to investigate the effect of two-stage aging treatment on the mechanical properties of the alloy and optimize the aging process, to lay a theoretical foundation for the further application of Al-Li alloy.

2 Experimental procedure

The tested alloys were prepared from pure Al, Li, Mg and Al-Cu, Al-Zr master alloys in graphite crucible under the protection of Ar. The melt temperature was maintained at 720°C before being poured into the steel mold.

Harnesses of alloys were tested using a Vickers hardness tester with a load of 5 kg and a dwelling time of 15 s. The tensile properties were conducted on a Z100 testing machine with a constant displacement rate of 1 mm/min. Preparation of specimens for transmission electron microscopy (TEM) observation involves twin-jet electropolishing in a 30% HNO_3 and 70% CH_3OH (volume fraction) solution at -25℃. TEM images were obtained using a transmission electron microscope working at 200 kV.

3 Result and discussion

Fig. 1a shows the hardening curves of the alloys after first-stage aging at different temperatures in second-stage aging at 175°C. The time for the alloy to reach the peak aging at the second-stage of aging decreases with the increase of the first-stage aging temperature when the first-stage aging time is constant. The peak hardness of the alloy in the second-stage of aging increases and then decreases with the increase of the first-stage aging temperature. Fig. 1b shows the hardening curves of the alloys after first-stage aging treatment at the optimized temperature of 100°C for different times of second-stage aging at 175°C. The time to reach peak aging for second-stage aging of the alloy after first-stage aging treatment is gradually shortened with the extension of the first-stage aging time, while the peak hardness first increases and then decreases.

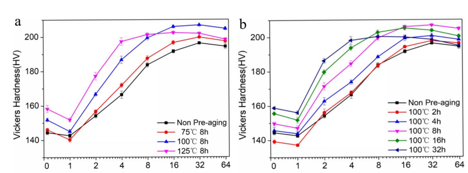

Fig. 1. (a) Age-hardening curves of alloys with different first-stage temperatures at 175°C; (b) Age-hardening curves of alloys with different time aged at 175°C.

Fig. 2a shows that the strength of the alloys increases and then decreases when the second-stage aging time is increased to 32 h. The strength of the alloys with a first-stage aging temperature of 100°C is the highest. The alloy with first-stage aging temperature of 100°C has the highest strength after second-stage aging at 175°C × 32 h as YS = 685 MPa, UTS = 737 MPa and EL = 5.58%. Fig. 2b shows that the strength of the alloy increased when the secondary aging time was increased to 32 h. The strength of the alloy was higher when the second-stage aging time was increased to 8 h. The alloy with first-stage aging time of 8 h (temperature 100°C) has the highest strength after second-stage aging at 175°C × 32 h. The alloy has the highest strength after second-stage aging.

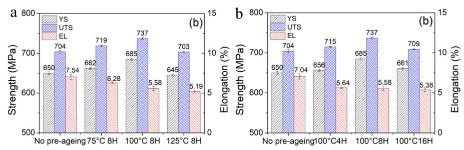

Fig. 2. (a) Mechanical properties of the alloys with different temperature aged at 175°C for 32 h; (b) Mechanical properties of the alloys with different time aged at 175°C for 32 h.

Fig. 3 shows the bright field (BF) image and dark field (DF) image of the alloy after two-stage aging (100°C × 8 h + 175°C × 32 h) and T6 (175°C × 32 h) aging treatment. Obvious T_1 phase diffraction fringes are observed. From the BF images, the main strengthening phases in the alloy are all T_1 phase. From the DF images, the density of T_1 phase is significantly higher than that of the T6 aging treatment after the two-stage aging treatment, and the size of T_1 phase is smaller and more uniformly distributed. The main reason is that first-stage low-temperature aging is conducive to the formation of more solute atom clusters with GP zones, which provides more nucleation cores for the precipitation of T_1 phase.

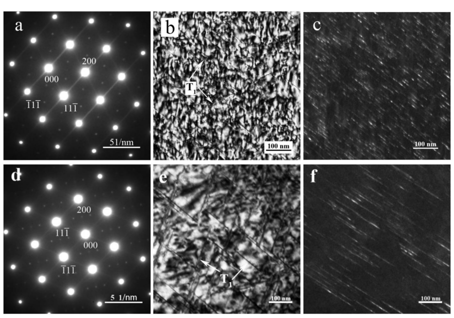

Fig. 3. The SAED patterns with corresponding BF and DF images of the alloys with different aging conditions: (a-c) Two-stage aged; (d-f) Conventional T6 aged.

4 Conclusion

(1) With the increase of the first aging temperature (75-125℃), the time for the alloy to reach the peak hardness in the second aging is shortened, and the peak aging hardness increases first and then decreases. When the first aging temperature is fixed, when the aging time is prolonged (0-32 h), the time for the alloy to reach the peak hardness during the second aging is also gradually shortened, and the peak aging hardness first increases and then decreases.

(2) The strength of the alloy after double-stage aging treatment was significantly increased compared with that of T6 single-stage aging. With the increase of the first aging temperature, the strength of the alloy in the double-stage aging state firstly increased and then decreased, and the highest strength of the alloy was found when the aging process was 100℃ × 8 h + 175℃ × 32 h, which were YS = 685MPa, UTS = 737 MPa, and EL = 5.58%.

(3) Double-stage aging alloy strength and plasticity improvement is due to: the first level of low-temperature aging is conducive to the formation of solute atomic clusters and GP zone, for the subsequent second level of high-temperature aging T_1 phase formation provides more nucleation core. After the second stage of high-temperature aging, the T_1 phase has a higher density, smaller size, and more uniform distribution, which effectively improves the toughness of the alloy.

Acknowledgments

This work was financially sponsored by the National Natural Science Foundation of China (Nos. 51821001 and 51871148).

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