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Effect of aging treatment on the exfoliation corrosion and stress corrosion cracking behaviors of 2195 Al–Li alloy

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ABSTRACT

2195 Al–Li alloy was processed by solid solution heat treatment and then aged at different temperatures, and its microstructure, mechanical properties, inter-granular corrosion (IGC), exfoliation corrosion (EXCO) and stress corrosion cracking (SCC) behaviors were observed and determined by scanning electron microscopy (SEM), transmission electron microscopy (TEM), immersion test in IGC and EXCO solutions, electrochemical impedance spectroscopy (EIS) and slow strain rate tensile (SSRT) test. The results reveal that the size and density of T1 precipitates at grain boundary are increased with increasing aging temperature whereas the density of T1 phases in grain is increased firstly and then reduced slightly. The IGC and EXCO susceptibility of 2195 alloy is increased while its SCC susceptibility in 3.5% NaCl solution is low and hardly influenced by the aging temperature. The hardness and tensile strength are increased at first and then decreased, but the elongation and static toughness values are declined with aging temperature. The optimum heat treatment for the practical application of 2195 alloy is the aged at 155 °C for 14 h temper.

1. Introduction

2195 Al–Li alloy is widely used in aerospace and aeronautic field for its light weight, high specific strength, good ductility and toughness. However, 2195 alloy is highly susceptible to inter-granular corrosion (IGC) and exfoliation corrosion (EXCO) in severe corrosive circumstance and moisture atmosphere. So it is important to improve the corrosion resistance of 2195 Al–Li alloy for its safety and effective application [1].

It is well known that the IGC and EXCO properties of 2195 alloy are closely related to grain boundary microstructure, and can be improved through varying aging treatment. The effects of artificial aging on the IGC and EXCO behaviors of 2195 alloy have been substantially investigated [2,3]. It is found that IGC and EXCO of 2195 alloy are caused by the anodic dissolution of T1 phases and precipitate-free-zone (PFZ) at the grain boundaries. And the IGC and EXCO resistance can be improved by reducing aging time and lowing temperature.

The effects of aging treatment on the tensile properties of 2195 alloy in air and in salt spray have been researched by Chen [4,5] and Ward et al. [6]. It is proved that lower aging temperature favors uniform dispersion of fine T1 phases in the matrix and reduces T1 (Al_2CuLi) precipitation at the sub-grain or grain boundary, resulting in better strength and ductility. And the 2195 samples exposed in salt fog test have around the same strength values as the non-exposed samples. Li et al. [7] have investigated the corrosion behaviors of 2195 alloy with or without tensile stress in neutral 3.5% NaCl solution, and found that IGC, pitting corrosion and general corrosion occur on unstressed 2195 alloy. Then IGC is aggravated and pits are connected for the stressed alloy. But until now, the effect of aging treatment on SCC property of 2195 alloy is rarely reported.

The objective of this paper is to explore the effect of aging treatment on the IGC, EXCO and SCC behaviors of 2195 alloy. And meanwhile the microstructure, mechanical properties and electrochemical impedance spectroscopy (EIS) of 2195 alloy were also observed and determined. Based on these experiments, the optimum heat treatment condition for 2195 alloy with comprehensive corrosion and mechanical properties could be obtained.

2. Experimental details

2.1. Material and heat treatment

2195 alloy used is composed by 4.0%Cu, 1.0%Li, 0.4%Mg, 0.4%Ag, 0.14%Zr and balanced aluminum. The cold rolled 2195 alloy with a

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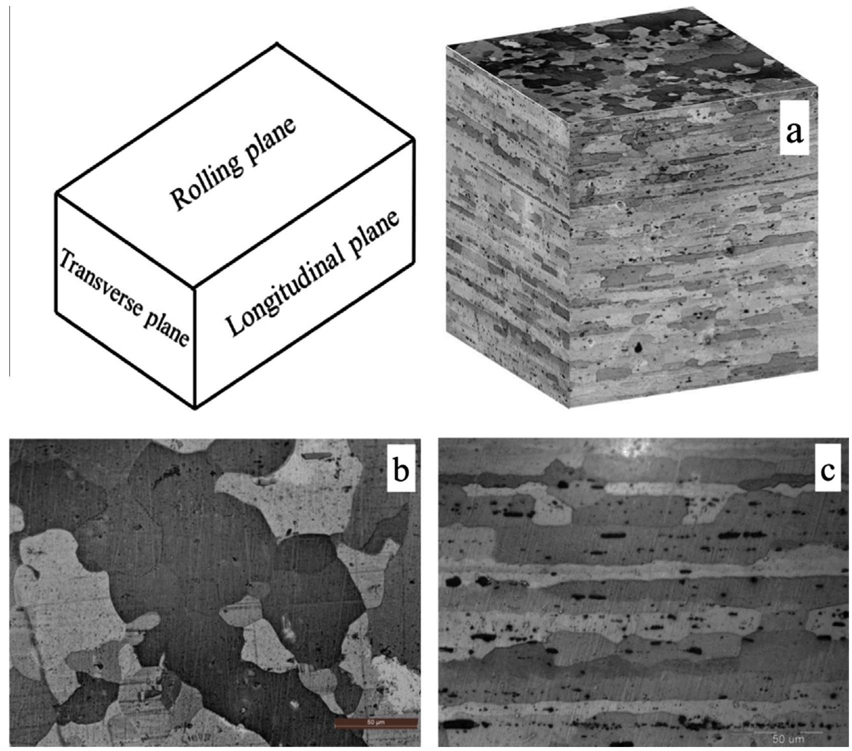

Fig. 1. Tri-planar optical micrographs of 2195 aluminum alloy 200× (a), and the grain structure in rolling plane (b) and longitudinal plane (c) 1000×.

thickness of 2 mm was firstly processed by solid solution heat treatment at 515 °C for 30 min, and then quenched in water, and followed by aging treatments at 135 °C, 155 °C, 170 °C and 200 °C for 14 h respectively.

2.2. Characterization of microstructure

The microstructure of 2195 alloy was observed via a BX41RF-LED optical microscope. Before observation, the specimens were abraded by silicon carbide paper (from 400# to 2000#), polished and chemically etched in the Keller's reagent. The precipitate distribution for 2195 alloy under different aging conditions was observed by a Tecnai G2F20 transmission electron microscope.

2.3. Inter-granular corrosion

According to the standard of GB 7998-1987, 2195 alloy was firstly immersed in 0.5 mol/L NaCl + 0.1 mol/L HCl solution at 35 ± 2 °C for 24 h, and then the corroded specimens were cut off by 5 mm at the end of the vertical rolling direction. The cross-section of corroded specimens was grinded and polished and then observed by BX41RF-LED optical microscope. The inter-granular corrosion behavior of 2195 alloy was evaluated by the maximum corrosion depth of alloy.

2.4. Exfoliation corrosion

According to the standard of ASTM-G34-79, 2195 alloy was immersed in EXCO solution (4.0 mol/L NaCl + 0.5 mol/L KNO_3 + 0.1 mol/L HNO_3) continuously for 72 h at 25.0 ± 0.5 °C. After immersion, the corrosion morphology of 2195 alloy was observed by digital camera, and the exfoliation corrosion behavior of 2195 alloy was determined by the corroded surface morphology.

2.5. EIS measurement

In order to explore the process of exfoliation corrosion, EIS spectrum of 2195 alloy in EXCO solution was conducted by using a VersaSTAT4 electrochemical workstation at open-circuit potential with the perturbation voltage amplitude of 10 mV and measuring frequency from 10^5 Hz to 0.01 Hz. The reference electrode was a saturated calomel electrode and the counter electrode was platinum plate. The exposed area of working electrode was 2 cm^2. The measured EIS data were analyzed in terms of an appropriate equivalent circuit using the ZSimpWin software, and the values of the parameters were determined by the simulation. In our circuit, capacitance was mathematically modeled using a constant phase element Q in order to obtain a better simulation between the model and the experimental data. Then the impedance was defined by the equation:

$$Z(j\omega) = (Y_0)^{-1} j\omega^{-n} \tag{1}$$

where Y_0 was the Q-constant, j the imaginary unit, ω the angular frequency ($\omega = 2\pi f$, f was the frequency) and n the Q-power which can range from −1 to 1. For $n = 1$, Z represented an ideal capacitance; $n = 0$, a resistance; $n = -1$, an inductance; and $n = 0.5$, a Warburg impedance.

2.6. Hardness and slow strain rate tensile tests

The Rockwell hardness (HRB) of 2195 alloy was determined by HR150A hardness tester. The mechanical properties and SCC behaviors of 2195 alloy were evaluated by SSRT tests which were conducted on a slow strain stress corrosion testing machine.

The SSRT test, with a strain rate of $1 \times 10^{-6}\ s^{-1}$, was conducted in air and 3.5% NaCl solution at ambient temperature respectively. The test specimen was 25 mm in the original gauge length with its longitudinal axis perpendicular to the rolling direction, 4 mm in

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