Journal of Alloys and Compounds 764 (2018) 452–459

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Effects of creep aging upon Al-Cu-Li alloy: Strength, toughness and microstructure

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ARTICLE INFO

Article history:
Received 29 January 2018
Received in revised form
8 June 2018
Accepted 10 June 2018

Keywords:
Al-Cu-Li alloy
Creep aging
Strength
Fracture toughness
Precipitation

ABSTRACT

Effects of creep aging on strength and toughness and microstructure evolution of Al-Cu-Li alloy were investigated by tensile test and Kahn tear test at room temperature, combined with fractograph and transmission microstructure analysis. The specimens of pre-strain creep aging state (CA) have been studied and compared with artificial aging state (AA) and pre-strain artificial aging state (PA). It is demonstrated that pre-strain before artificial aging process can improve the strength property and the fracture toughness of Al-Cu-Li alloy. On top of that, both of them can be further improved by creep aging process: the yield strength was increased by 8.7% and the unit initiation energy of Kahn tear was increased by 11.7%. The increasing of fracture toughness has also been verified by Kahn tear fractographs that the dominating fracture type changes from the ductile intergranular fracture to the ductile transgranular fracture. Transmission electron microscopy revealed that creep aging promotes the nucleation of T_1 phase, resulting in a fine and dense distribution of precipitates in the matrix, and the enrichment of subgrain boundary T_1 precipitates was greatly reduced.

1. Introduction

With the improved requirement on lightweight structural materials of aerospace industry, Al-Cu-Li alloy with characteristics of low density, high stiffness and good match of strength and toughness is considered as an ideal choice [1–3]. A series of Al-Cu-Li alloys with minor amount of Mg, Ag, and Zr known as Weldalite, such as AA2050 [4], which exhibit good comprehensive performance by controlling the content of Li to avoid the formation of δ′ precipitation that may affect thermal stability, and by adjusting the content of Cu to possess sufficient strength and toughness and obtain the maximum balance of strength and toughness [5]. As the main strengthening phases of Al-Cu-Li alloy, the precipitation of T_1 phase (Al_2CuLi) and its distribution characteristics is closely related to the performances of alloy [6,7]. Cassada et al. [8] proposed a dissociated nucleation mode of complete matrix dislocation $B = 1/2<110>$ of T_1 precipitation near the dislocation jog, and the diffusion sliding mechanism of growth ledges composed of partially dislocated $B = 1/6<112>$ on $\{111\}_{Al}$ planes. Deng et al. [9] discovered the T_1p precipitation which is formed by stacking of Li-rich layer and Cu-rich layer alone $\{111\}_{Al}$ planes and structurally identical with Al matrix lattice is the precursor of T_1 phase. It is structurally transformed with the support of energy, which is a transformation of stacking sequence introduced by two Schockley partial dislocation sliding of $B = a/6<112>_{Al}$ on $\{111\}_{Al}$ planes. Gao et al. [10] found that T_1 precipitation directly nucleate in GP_{T1} area and grows and coarsens through unit cell reproduction or variant abnormality of T_1 precipitation. Li et al. [11] studied that main strengthening phases are σ phase and T_1 phase in T6 state (165 °C/60 h); then change into σ phase, θ′ phase and T_1 phase after double aging (150 °C/24 h + 180 °C/12 h); and there are only T_1 phase in T8 state (6% pre-strain+135 °C/60 h).

During the plastic processing of Al-Cu-Li alloy, the interaction of plastic deformation and precipitation of T_1 phase will also cause change of mechanical property. Cassada et al. [12] indicated that plastic deformation before artificial aging reduced the length and thickness of T_1 phase, increased the density around 2 times and increased yield strength about 100 MPa; simultaneously reaching peak strength in 20% of the time required without plastic deformation. Gable et al. [13] also conducted similar research and found that plastic deformation before artificial aging improved aging

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https://doi.org/10.1016/j.jallcom.2018.06.103
0925-8388/

dynamics, strength and densities of very fine precipitated phases by the matrix heterogeneous nucleation was introduced. The relative volume fractions of T_1 phase and θ′ phase increased with increasing levels of plastic deformation, meanwhile the pre-age deformation significantly affects the competitive relationship of precipitation of the two phases. The larger unit volume free energy and the accommodation of the $\{111\}_{Al}$ shear strain for T_1 versus the $\{100\}_{Al}$ shear strain for θ′ aids in its preferential nucleation on dislocations over that of θ′. Deng et al. [14] studied and found that inhibited dynamic recovery would generate mass dislocation after low temperature cold rolling, which would promote the precipitation of T_1 phase during aging. The T_1 phase with high density had an effective pinning function on dislocation to improve the strength and plasticity of alloy.

Creep aging, an advanced integral forming technology of lightweight structural parts, which synchronically performs metal creep and Al alloy aging strengthening to substantially improve manufacturing efficiency [15,16]. During the creep aging of Al-Cu-Li alloy, the interaction between precipitation of T_1 phase and creep deformation affects the formation of final mechanical property. Currently, the application of creep aging to Al-Cu-Li alloy is insufficient, so investigation of strength and toughness and corresponding microstructure characteristics after creep aging is a necessary research direction. Through the comparison of artificial aging, the effect law of creep aging on strength and toughness and microstructure of Al-Cu-Li alloy at room temperature and precipitation characteristics of T_1 phase has been investigated to provide a basis for the application of creep aging to Al-Cu-Li alloy.

2. Material and methods

2.1. Materials and procedures

The Al-Cu-Li alloy material used in this work was AA2050 hot rolled plate, its chemical components are shown in Table 1. The specimens machined out from the plate which geometry dimensions are shown in Fig. 1, and its length direction was parallel to the rolling direction, strictly according to ASTM E139-11 test standard. After solution heat-treatment at 510 °C for 1 h and water-quenching (with the transferring time less than 5 s), all specimens were divided into three groups. The first group of samples were carried out creep aging at 160 °C and 200 MPa for 24 h after 2% pre-strain (CA) which conducted on RWS50 creep machine. The second group of samples were artificial aging at 160 °C for 24 h after 2% pre-strain (PA) and the third group of samples were directly artificial aging at 160 °C for 24 h (AA). Pre-strain was stretched on RWS50 creep machine and deformations were recorded by two linear capacitance gauges.

2.2. Property tests

Mechanical properties test were conducted employing CSS-44100 testing machine at tensile speed of 2 mm/min after different age treatment, which measured value equals to the average value of five specimens. According to the standard ASTM B871-01, the tear resistance were measured on Kahn Tear Test method (five samples for each test and cracking direction perpendicular to the rolling direction of the plate), the relevant parameter were the unit initiation energy as UIE (the energy dissipated before crack propagation) and tear strength (TS).

Table 1
Chemical composition of Al-Cu-Li (AA2050) alloy (wt%).

Si	Fe	Cu	Mn	Mg	Zr	Ag	Li	Zn	Al
0.03	0.04	3.5	0.38	0.36	0.08	0.38	0.9	<0.1	Bal

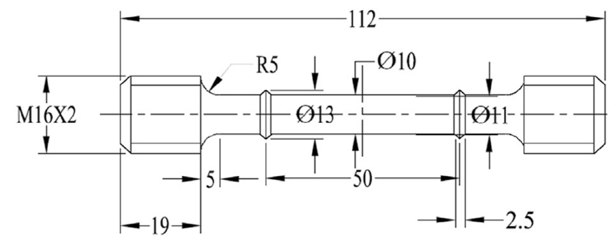

Fig. 1. Dimension of creep bar specimens.

2.3. Tear fracture and microstructure evolution observation

Tear fracture was observed by ZEISS EVO MA10 scanning electron microscope. Samples for TEM imaging analysis were prepared by mechanical grinding to a thickness of 80 μm and cut to 3 mm diameter disks. Then electropolishing using a Tenupol 5 machine (Struers) with a solution of 30% nitric acid and 70% methanol at −30 °C to −20 °C and 15–20 V. The microstructural features were characterized using a FEI Titan F20 G^2, operating at 200 kV.

3. Results and discussions

3.1. Mechanical property

Fig. 2 shows the chart of tensile property and Kahn tear property of Al-Cu-Li (AA2050) alloy under three aging tempers at room

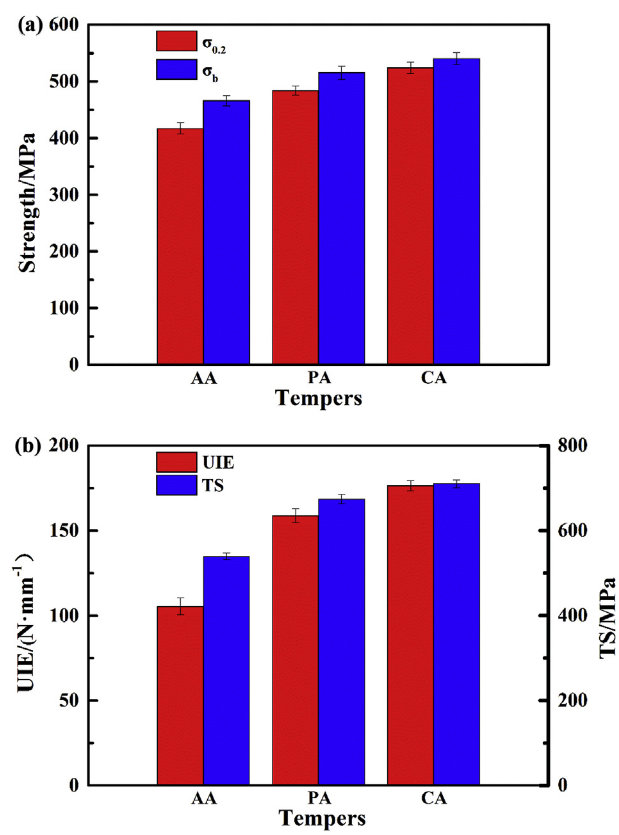

Fig. 2. Mechanical Property: (a) Tensile properties of room temperature, (b) Properties of kahn tear.