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Effect of pre-strain on creep aging behavior of 2524 aluminum alloy

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ABSTRACT

As an advanced manufacturing technology, creep age forming (CAF) has been developed to form large aluminum panels. However, industrial processes often involve complex thermo-mechanical treatments. For instance, it is necessary to impose a plastic strain after solution heat treatment to relieve quench stresses. In this work, the effect of tensile pre-strain before CAF on creep aging behavior of 2524 aluminum alloy is investigated by constant-stress creep aging test, Transmission Electron Microscope (TEM) and mechanical properties test. It is found that the magnitude of creep strain is greatly increased with the increase of pre-strain. Moreover, the peak strength of the creep aged AA2524 is enhanced and the time to reach the peak strength is decreased with the increases of pre-strain. TEM observations revealed that the precipitation process of AA2524 is accelerated due to pre-strain treatment. With the increase of pre-strain, the average size of S (Al_2CuMg) phases is reduced. Meanwhile, the density and homogeneity of S phases are improved. Thus, it can be concluded that the pre-strain can evidently improve the formability, mechanical properties and microstructures of AA2524 in creep age forming process.

1. Introduction

Al–Cu–Mg alloys are widely used in aircraft panels because of their low density, high damage tolerance and excellent workability [1]. An excellent example is AA2524, which was developed by Alcoa in the 1990s and has been used as wing and fuselage skin on Boeing 777 and Airbus A380 [2,3]. These aircraft components are generally manufactured by creep age forming process (CAF), which simultaneously changes the part shape and strengthens its performance in a one-step forming and heat treatment process [4–6]. However, controlling of both forming precision and material performance is very difficult due to the heavy interaction between creep and aging in the CAF process. Especially, industrial processes often involve complex thermo-mechanical treatments [7,8]. For instance, it is necessary to impose a plastic strain after solution heat treatment to relieve quench stresses. The pre-strain treatments before CAF may lead to the interaction between creep aging behavior and dislocations. In order to acquire high performance and the high precision of the creep age formed components, it is urgently to investigate the effect of pre-strain on creep aging behavior of Al-Cu-Mg alloy for their CAF application.

Nowadays, the effects of creep aging process on creep aging behavior of Al-Cu-Mg alloys were widely investigated by many researchers [9–15]. Quan et al. [9] studied the effect of stress on microstructures of creep aged AA2524 and found that the value of peak hardness is increased, while the time to reach the peak hardness is reduced under an external stress. Meanwhile, the length of S (Al2CuMg) phase is shorter and number density of S phases is larger in the creep aged alloy. Zhan et al. [10] studied the effects of process parameters on mechanical properties and microstructures of creep-aged 2124 aluminum alloy, and it is shown that creep strain and creep rate increase with the increase of aging time, temperature and applied stress. Lin et al. [11] investigated the effects of creep-aging temperature and external stress on the hardness and precipitation process in 2024-T3 aluminum alloy and found that the external stress can accelerate the precipitation hardening of 2024-T3 aluminum alloy. Chen et al. [12]investigated the precipitation behavior of S'phase in Al-Cu-Mg single crystals during stress-free and stress aging. Lin et al. [13] investigated the effect of creep-aging processing on the corrosion resistance and mechanical properties of 2024 aluminum alloy, and found that the corrosion resistance and the elongation decrease, while yield

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strength and ultimate tensile strength increase with the increase of creep aging temperature. Liu et al. [14] studied the effects of two-stage creep-aging processing on the precipitation behavior of 2024 aluminum alloy. Zhan et al. [14] studied the combined effects of aging temperature, time and part thickness features on the springback, mechanical properties and microstructures of creep age forming of 2524 aluminum alloy sheets. Maximov et al. [15] studied the strain hardening and creep behavior of 2024-T3 aluminum alloy at room and high temperature. In views of these reports, most of the experimental materials are solution temper [9,10,12–14] (un-strained) before creep aging process, and the effects of pre-strain on creep aging behavior of Al-Cu-Mg alloy has rarely been manipulated experimentally.

The aim of this work is to reveal the effect of pre-strain on the creep aging behavior of Al–Cu–Mg alloy for their CAF application. In this study, creep aging behavior of 2524 aluminum alloy with various pre-stain (0%, 1.5%, 4% and 6%) has been experimentally investigated by creep aging tests, transmission electron microscope (TEM) observations and mechanical properties tests. The rule of creep behavior under different pre-strain conditions and the effects of pre-strain on the mechanical properties and microstructures were obtained by analyzing the experimental results. Additionally, the creep aging behavior of 2524 aluminum alloy with pre-strain was discussed. This work could contribute to the manufacturing of aircraft panels and the development of CAF technology of Al–Cu–Mg alloys.

2. Material and methods

2.1. As-received material and pre-treatments

A commercial high strength 2524 aluminum alloy was used in this study with the chemical compositions listed in Table 1. The as-received material is a 3 mm thick cold-rolled plate provided by Southwestern Aluminum (group) Co., Ltd, China. The test samples with the gauge length of 50 mm were machined by the wire-electrode cutting along the rolling direction of the cold-rolled plate, the geometry and size of the specimens are shown in Fig. 1.

The test samples were solution treated at 500 °C for 35min in a furnace, quenched into cold water, and then stretched with an SUST-CMT5105 machine to different strains at room temperature with a strain rate of 2 mm/min. The stresses used for pre-strains of 1.5%, 4% and 6% are 305.75 MPa, 360.98 MPa and 386.44 MPa, respectively. Also, the traditional un-strained (solution temper) samples were carried out in order to compare the creep age behaviors between the pre-strained and un-strained AA2524.

2.2. Constant-stress creep aging tests

The constant-stress creep aging tests were carried out on a SUST-D5 creep testing machine with an assisting furnace. The pre-strained samples were immediately creep aged at 180 °C with the stress of 180 MPa for different creep-aging time to minimize the natural aging effect. Two linear capacitance gauges were fitted onto the ridges of the specimen to measure the displacement during the tests. The load was applied after temperature of the specimen reached a steady state of 180 °C with a heating rate of 5 °C/min. After creep-aging test, the applied loading was released and the

Table 1
Chemical composition of 2524 aluminum alloy (wt%).

Zn	Mg	Cu	Mn	Si	Fe	Ti	Cr	Al
0.01	1.38	4.4	0.66	0.03	0.05	0.03	0.01	Bal.

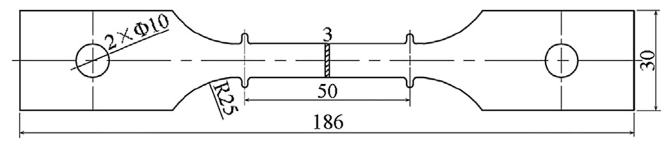

Fig. 1. Specimen geometry and size (unit: mm).

specimen was naturally cooled down to the room temperature in the furnace.

2.3. Microstructure characterization

TEM observations of creep aged AA2524 were carried out under different pre-strain conditions: the pretreated materials with various pre-strains of 0%, 1.5%, 4% and 6%, the 2 h and 12 h creep aged samples with various pre-strains under 180 MPa at 180 °C. The specimens for TEM were frictional thinned down to 60 μm, and cut to 3 mm-radius. Then twin-jet-electro-polishing them to perforation with a mixture of 33% nitric acid and 67% methanol at −25 °C, with a potential of 15 V. The prepared TEM specimens were examined on a Tecnai-F20 (200 kV) field-emission-gun transmission electron microscope (FEG-TEM).

2.4. Mechanical property tests

In order to obtain the effects of pre-strain on the mechanical properties and to reveal the relationship between the microstructure and the mechanical properties of the studied material after creep aging process, the room temperature tensile tests were conducted on the SUST-CMT5105 machine at a strain rate of 2 mm/min. In order to minimize the natural aging effect, the as-pretreated samples with various pre-strains were immediately tested. Furthermore, the room temperature tensile tests of the creep aged samples were conducted as quickly as possible after natural cooling in the furnace.

3. Results and discussion

3.1. Effect of pre-strain on creep strain behavior

The creep strain curves of the studied Al-Cu-Mg alloy with various pre-strains under the applied stress of 180 MPa at 180 °C are shown in Fig. 2, and the elastic strains were removed [16]. Corresponding creep strain rate curves are shown in Fig. 2(b). Generally, a creep curve is usually divided into primary, secondary and tertiary stages [17]. It can be found in Fig. 2(a) that the samples with different pre-strains all present the typical two-stage creep behavior, which comprises of a primary creep stage and a secondary creep stage. However, the effect of pre-strain on the magnitude of creep strain of the creep aged alloy is significant. With the increase of pre-strains, the creep strain increase obviously. After tensile creep aging for 12 h, the magnitude of creep strain of the un-strained sample is about 1.46%. The creep strains of the studied alloy with the pre-strains of 1.5%, 4% and 6% is about 1.27, 1.44 and 1.57 times as much as the un-strained one, respectively. By using the amount of creep strain to evaluate the formability [18], it indicated that the pre-strain after solution treatment can improve the formability of AA2524 in creep age forming.

In the primary creep stage, the creep strain rate is relatively high, but slows with increasing time. This is due to work hardening. It can be seen from Fig. 2(b) that the creep strain rate curves of the pre-strained sample are almost coincident with each other in the primary creep stage. In addition, the creep rates of pre-strained