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Effects of process parameters on mechanical properties and microstructures of creep aged 2124 aluminum alloy

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Abstract: A series of tests were carried out to investigate the effects of process parameters on mechanical properties and microstructures of 2124 aluminum alloy in creep aging process. The results show that creep strain and creep rate increase with the increase of aging time, temperature and applied stress. The hardness of specimen varies with aging time and stress in a low-to-peak-to-low manner. No significant effect of temperature on hardness of material is seen in the range of 185−195 °C. The optimum mechanical properties are obtained at the conditions of (200 MPa, 185 °C, 8 h) as the result of the coexistence of strengthening S'' and S' phases in the matrix by transmission electron microscopy (TEM). TEM observation shows that applied stress promotes the formation and growth of precipitates and no obvious stress orientation effect is observed in the matrix.

Key words: aluminum alloy; creep aging behavior; age hardening; mechanical property; microstructure; process parameter

1 Introduction

In aerospace industry, increasing large integral structures with complex curvature and high ribs are required in order to reduce the weight and manufacturing cost [1]. For these reasons, creep age forming (CAF), also called aging forming, is explored and has been used to fabricate large-scale integral parts in military and civil airplanes [2,3]. This forming method is a process consisting of mechanical formation and aging treatment of part, which takes place in the autoclave [4]. In CAF process, once the part to be formed attaches the tool configuration, it is then held by pressure or mechanical load for a certain time at a selected temperature. During this period, the elastic strain is in part converted to plastic strain due to stress relaxation and the constituents of metal precipitate, improving mechanical strengths. Different from other conventional forming techniques, the prominent feature of this technology is that the loading stress in the component is normally less than its yield strength and less residual stress occurs in the formed part [5]. Most importantly, shaping of part and property enhancement are accomplished simultaneously [6,7].

Extensive researches on creep aging behavior of metals and alloys (such as creep mechanism, microstructure and constitutive equation) have been carefully carried out over the past decades. LI et al [8] studied creep mechanisms of as-cast Mg−5Zn−2.5Er alloy by analysis of stress exponent and activation energy, and found that there is a transition region between grain boundary sliding (GBS) dominated creep and dislocation creep. LIN et al [9] investigated the effects of applied stress and creep aging temperature on the precipitation in 2124-T851 aluminum alloy. They found that the precipitation is very sensitive to the applied stress and creep aging temperature. SKROTZKI et al [10] claimed that a threshold value of stress has to be exceeded for the formation of preferentially-oriented, plate-shaped precipitate phases in the tensile stress aged samples of Al−Cu−Mg−Ag alloy and Al−Cu alloy. CHEN et al [11] suggested that external stress induces the precipitation of preferred orientation of precipitates θ'

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and Ω in Al−Cu and Al−Cu−Mg−Ag alloys, respectively. ZHU et al [12] pointed out that the stress-orientation effect is associated with the applied stress, aging temperature and time, and copper content in creep aging of Al−Cu alloy. HUANG et al [13] built the constitutive model for 7B04 aluminum alloy from uniaxial tensile creep aging tests. HO et al [4] developed a set of unified aging-creep constitutive equations based on creep damage model to describe creep behavior for 7010 aluminum alloy.

Although many investigations were performed on creep aging, there are a few reports with regard to process parameters and their effects on mechanical properties and microstructure evolution. In this work, using 2124 aluminum alloy as model material, the effects of process parameters including aging time, aging temperature and loading stress on mechanical properties and microstructures of 2124 aluminum alloy in creep aging process are examined in detail, which can provide a basic theory for practical applications of CAF in industry.

2 Experimental

2.1 Specimen preparation

The chemical composition of the commercial 2124 aluminum alloy applied in this work is listed in Table 1. The specimens were machined from as-received sheet with 3 mm in thickness, as shown in Fig. 1. Then the specimens with gage length of 50 mm were subjected to solution heat treatment at 490 °C for 50 min followed by water quenching at room temperature.

Table 1 Chemical composition of 2124 aluminum alloy (mass fraction, %)

Cu	Mg	Mn	Fe	Zn	Ti	Cr	Ni	Al
4.67	1.46	0.63	0.18	0.04	0.06	<0.01	<0.01	Bal.

2.2 Creep aging test

Constant-stress creep aging tests were carried out for 2524 aluminum alloy using creep machine. The specimen was fitted and aligned in the middle of the furnace and then the furnace was gradually heated to the aging temperature. It took about 30 min to heat the specimen from room temperature to aim temperature. When the temperature reached the goal value, the dwell time of 15 min for furnace was needed prior to creep aging test. The extensometer was then calibrated to record the creep value of specimen and external stress was applied in the whole process. Experimental data could be obtained from computer after creep tests.

2.3 Mechanical property measurement and microstructure observation

Vickers hardness measurement was made on all creep aged samples. The hardness was measured by the average value of 5 different positions using a digital microscope dimension optical hardness tester (HXD −1000TM/LCD). Tensile tests for aged samples were carried out with DDL100 electronic universal testing machine and corresponding yield strength of sample was determined by the average value of two samples aged under the same condition. Thin foils for TEM analysis were cut in the gauge length of aged specimen and machined to a thickness of 60−80 μm. Then these samples were punched to disk slices of 3 mm in diameter and continually thinned using the MIT II twin-jet electropolisher in a solution of 70% ethanol and 30% nitric acid operated at −30 °C and 15 V. Finally, JEM2100 TEM operated at 200 kV was employed to observe the microstructures.

3 Results and discussion

3.1 Creep aging behaviors of 2524 aluminum alloy

Figure 2 shows the creep strain−time curves of 2124 aluminum alloy at different temperatures (185, 190 and 195 °C) and stress levels (200, 225 and 250 MPa). From Fig. 2 it is evident that all creep curves are separated into two phases. In the first phase, the initial creep rate is extremely high and decreases gradually with time, and the second phase is steady-state creep stage with

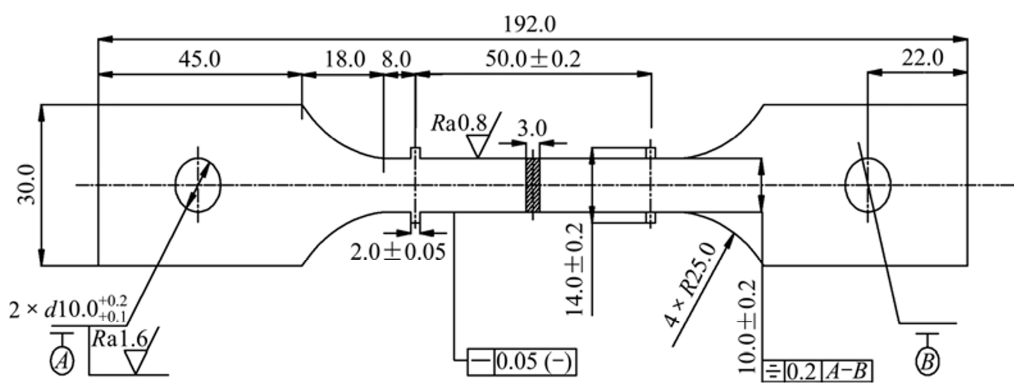

Fig. 1 Specimen geometry (unit: mm)