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Dependence of creep age formability on initial temper of an Al-Zn-Mg-Cu alloy

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Abstract The initial temper of the material may directly affect the whole creep age forming (CAF) process. In terms of creep deformation and stress relaxation, using the constant-stress creep aging and constant-strain stress relaxation aging tests, the relationship between initial temper and CAF formability is investigated for an Al-Zn-Mg-Cu alloy at 165 °C for 18 h. Three tempers are selected as the initial tempers in CAF, viz., solution, retrogression and re-solution. The CAF formability of this alloy with initial temper of retrogression is the best, and the creep strain of the retrogression tempered specimen after creep aging of 18 h is about 1.21 and 1.34 times than that of the solution and the re-solution tempered specimens, respectively. The calculated stress exponents of this alloy with three initial tempers range from 7.3 to 9.5, indicating that the CAF of this alloy is mainly controlled by the dislocation creep. The various formability for three initial tempers are attributed to different inhibitions of the transgranular precipitates on the dislocation movement. For the retrogression temper, the initial fine and uniformly distributed precipitates are seriously coarsened after 6 h of CAF, which minimally inhibit the dislocation movement. While, for the re-solution temper, the fine precipitates are re-precipitated in the matrix of the alloy, which observably hinder the dislocation movement and lead to the worst formability.

1. Introduction

With increasing demands of high performance and lightweight in modern aircraft, large integral panel components of high strength and lightweight aluminum alloys present promising application potential in the aerospace industry. Nevertheless, the large integral panel in airfoil has typical dimensions of 33 m in length, 2.7 m in width and thickness that can vary

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from 2 mm to 32 mm. These structural features bring challenge to traditional sheet metal forming techniques, such as the milling, bending and peen forming.[1] As an advanced manufacturing technology, creep age forming (CAF) has been developed to form large integral panel parts such as the wing skins with complex double curvature aerodynamic surfaces for the A380 passenger aircraft.[2] Compared with the traditional manufacturing processes, CAF technology presents the most unique advantage, viz., the components can be shaped by creeping mechanism and can be strengthened via aging simultaneously. Thus, the synergy effect of improving property while shaping may be achieved in one single process, thereby reducing manufacturing costs.

However, the CAF process becomes complicated due to the interaction between creep and aging. For instance, the nucleation and growth of precipitates during the aging process significantly affect dislocation movement, while the change of dislocation density inversely influences the nucleation and growth of precipitates. This coupling makes the control of both forming precision and material performance very difficult. In addition, it is well-known that there are many heat treatment methods suitable for the heat treatable high strength aluminum alloys. The initial temper of the material may have great effects on the formability, such as it was found that the pre-aged 7010 aluminum alloy had smaller creep deformation than the solution treated in the tensile creep tests at 150 °C.[3,4] Thus, different initial tempers cause more difficulty in understanding the interaction between aging and creep. In order to make the formed integral panel that can meet the requirements of aerostructures for high-precision in dimensions and high-performance in properties, it is urgently needed to investigate the dependence of CAF formability on the initial temper for aluminum alloys.

Early researches was mainly aimed at finding out the effects of processing parameters on CAF and developing the constitutive model for CAF process simulation.[5–7] Jeshvaghani et al.[8,9] studied the effects of time and temperature on microstructure evolution of 7075 aluminum alloy sheet during CAF, and obtained the transmission electron microscope (TEM) bright field images in the matrix and the vicinity of grain boundary of the formed samples in different forming periods, 6 h, 12 h and 24 h, respectively. Based on the damage theory of Kowalewski et al.[10] and the conventional creep damage model,[11] Ho et al.[12] proposed a unified creep constitutive model, and simulated the whole CAF process including loading, forming and unloading by combining this constitutive model with the commercial finite element solver ABAQUS. Lin et al.[13] introduced an integrated process to model stress relaxation, creep deformation, precipitation hardening and springback in CAF. These studies provide beneficial knowledge for the CAF process optimization. However, there are less reports considering the complicated interaction between creep deformation and aging process.

In order to meet the current requirements of the integral panel components in aircraft for precision shape forming while property improving, the strong interaction of creep and aging has been preliminary studied recently. Guo et al.[14] investigated the influence of elastic tensile stress on aging process in an Al–Zn–Mg–Cu alloy, and found that the external stress promotes the formation of precipitates and shortens the aging period of this alloy. Lin et al.[15] studied the influence of external factors on the precipitation of an Al–Zn–Mg–Cu alloy in a creep aging process, and discovered that the main aging η' and η phases are sensitive to the applied stress and creep aging temperature. Zhan et al.[16] investigated the precipitation behavior of 2124 aluminum alloy in a creep aging process and proved that the applied stress promotes the formation and growth of precipitates. It is noted that these studies are concentrated on the effect of creep on aging and the initial temper of the aluminum alloy is solution temper in most cases.[6–8,14,16] The complicated aging process that results from various initial tempers and their effects on creep deformation have not been reported.

It is known that larger amount of creep deformation represents better formability; meanwhile, the larger relaxed stress results in smaller residual stress and thus smaller springback, indicating better formability. In this work, in terms of creep deformation and stress relaxation, the formability of an Al-Zn-Mg-Cu alloy with various typical initial tempers under CAF conditions is evaluated. First, the specimens with three initial tempers are prepared by different heat treatments. Second, the tensile creep and stress relaxation tests are conducted at aging temperature and then the formability of the specimens with three initial tempers are compared. Finally, the influencing mechanism of initial tempers on the formability is articulated.

2. Experimental procedures

2.1. As-received material and microstructure characterization

As a widely used material in aircraft manufacturing, a heat-treatable Al-Zn-Mg-Cu (7xxx) alloy with high specific strength (1.775×10^5 N·m/kg) was chosen in this work. The experimental material was a hot rolled Al-Zn-Mg-Cu alloy plate with 30 mm thickness, which was provided by Northeast Light Alloy Co., Ltd., Harbin, China. As listed in Table 1, the nominal chemical composition (wt%) of this alloy was verified by SPECTRO MAXx direct-reading spectrometer. The yield strength and ultimate tensile strength of this as-rolled Al-Zn-Mg-Cu alloy are 425 MPa and 481 MPa, respectively. Fig. 1 shows its grain structure. The as-rolled Al-Zn-Mg-Cu alloy has been certified as containing coarse constituent particles (Al_7Cu_2Fe and Mg_2Si) and fine intermetallics ($MgZn_2$ and Al_2CuMg). The fine intermetallics can be dissolved by subsequent solution treatment, but the coarse constituent particles are quite stable and insoluble.[17,18] Fig. 2 shows the geometry and size of the specimen machined by the wire EDM cutting along the rolling direction. The specimen has 3 mm thickness and 50 mm gauge length.

The nano-sized transgranular precipitates were observed by TECNAL G2 F30 TEM at 200 kV. A flake was cut from the tensile specimen by wire EDM and mechanically thinned to 60 μm thickness. Then some disks with 3 mm diameter were cut from the flack and twin-jet electro-polished in a solution of 20% perchloric acid and 80% ethanol (in volume) at −20 °C and 20 V to prepare the TEM specimens. The size and number density of the intragranular precipitates were statistically measured in the TEM bright field image using the Image-Pro Plus 6 software, and more than five images were counted for each specimen to calculate an average value.

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