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Numerical simulation for creep age forming of aluminium alloy 7050 saddle-shaped part

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Abstract

Unified creep-ageing constitutive equations for aluminium alloy 7050 (AA7050) determined from experimental data were implemented into the finite element (FE) code, ABAQUS, through the user-defined subroutine, CREEP, for creep age forming (CAF) process modelling. The outer contour and yield strength of a saddle-shaped component were predicted, and the accuracy of FE prediction was analysed with experimental results. The research results show that, stress relaxation and creep deformation occur mainly in the early stage of the CAF process. A close agreement has been achieved between the simulation results and measurement data for the formed shape. More than 90% of the area has a surface gap less than 0.5 mm, and the relative error of the yield strength is between -1.18% and +7.22%, which prove the validity of the numerical computation.

Keywords: aluminium alloy 7050; creep age forming; constitutive model; numerical simulation; springback; yield strength;

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1. Introduction

As one of the most important structures of aircraft, aluminium alloy integral panels such as fuselage and wing-skin have been used extensively in aerospace industry because of its characteristic properties including light weight,

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high stiffness and high structural efficiency [1]. Creep age forming (CAF) is an efficient processing method that has been proven viable for fabricating integral panels with large size, varied thickness and complex structure. CAF has advantages, such as lower residual stress, cheaper manufacturing cost and higher repeatability, over traditional metal forming techniques [2-3].

During CAF, elastic strain cannot be fully transformed into creep strain due to the limited ageing period, which is required to achieve proper mechanical properties. Therefore high springback usually happens when the load is released [4]. Stress levels affect the ageing microstructure and properties which, in turn, influence the springback. Non-uniform stress distribution within a part can cause significant difference in microstructure and mechanical property of the formed part. Therefore, it is crucial to investigate the deformation behaviour and microstructural evolution so as to predict the springback and material strength after CAF. A great deal of research has been carried out to model the CAF process. Lin et al. [5] presented a set of newly developed unified creep-ageing constitutive equations which was then used for CAF simulation to predict the precipitate growth and yield stress evolution in addition to creep deformation. A material model for analysing and simulating the correlation between the mechanical properties and ageing parameters of aluminium alloy 7B04 (AA7B04) was established by Li et al. [6], which showed a good agreement with experimental data in different stress levels. Based on experimental observations, Zhan et al. [7] modelled the creep-ageing behaviour of AA7055 considering a variety of strengthening mechanisms. The determined equations were then integrated with MSC.MARC for predicting springback and precipitation hardening.

Previous research on CAF has been focused on the constitutive equations coupled with macroscopic deformation and microstructural evolution. In forming workpieces with a complex surface, however, there has been little study about mechanical strength and the prediction accuracy of numerical calculation. In this paper, material constants of creep-ageing constitutive equations for AA7050 were determined and a finite element (FE) model for CAF was built. The variation of creep deformation, stress relaxation, precipitates and yield strength in a saddle-shaped part during CAF were analysed numerically using ABAQUS/Standard. Verification test was subsequently carried out, and the outer surface and the yield strength at room temperature were measured from the formed part and compared with the simulation results.

2. Creep-ageing constitutive equations

The material used in this study was AA7050 rolled plate with the T451 temper. Uniaxial tensile creep tests had been carried out at 160 °C for 20 h under the stress levels of 179, 202, 225 and 246 MPa. Tensile tests were conducted for the interrupted samples creep-aged for 5, 10 and 15 h. In order to describe the behaviour of AA7050 in CAF, the following set of unified constitutive equations proposed in [8] was adopted:

$$\dot{\varepsilon}_c = A\sinh\left\{B(\sigma-\sigma_0)(1-H)^{m_0}\left(1-\frac{\sigma_{ss}}{\sigma_{ppt}}\right)^k\right\} \tag{1}$$

$$\dot{H} = \frac{h}{\sigma^{m_1}}\left(1-\frac{H}{H^*}\right)\dot{\varepsilon}_c \tag{2}$$

$$\dot{r} = C_r \dot{\varepsilon}_c{}^{m_2}(Q-r)^{m_3} \tag{3}$$

$$\dot{f}_r = C_f \dot{\varepsilon}_c{}^{m_4}(1-f_r)^{m_5} \tag{4}$$

$$\sigma_{ss} = C_{ss}(1-f_r)^{m_6} \tag{5}$$

$$\sigma_{ppt} = C_{ppt} r^{m_7} f_r{}^{0.5} \tag{6}$$

$$\sigma_y = \sigma_i + \sigma_{ss} + \sigma_{ppt} \tag{7}$$

where $\dot{\varepsilon}_c$ is the equivalent creep strain rate, σ is the equivalent stress, and A, B, σ_0, m_0, k, h, m_1, H^*, C_r, m_2, Q, m_3, C_f, m_4, m_5, C_{ss}, m_6, C_{ppt}, m_7 are material constants. Eqs. (1)-(2) describe the rate of creep strain accumulation, which is not only a function of stress but also of solution strengthening (σ_{ss}) and precipitation strengthening (σ_{ppt}). Eqs. (3)-(7) describe the inter-relationship amongst the average size of precipitates (r), the relative volume fraction of precipitates (f_r) and equivalent creep strain rate, as well as the strength contributions from intrinsic strength of aluminium (σ_i), solution strengthening and precipitation strengthening.