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ScienceDirect

Procedia Engineering 207 (2017) 281–286

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on the Technology of Plasticity, ICTP 2017, 17-22 September 2017, Cambridge, United Kingdom

Constitutive modelling of a T74 multi-step creep ageing behaviour of AA7050 and its application to stress relaxation ageing in age formed aluminium components

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Abstract

This work focuses on validating a model, which is defined using load controlled creep ageing data, from strain-controlled stress relaxation ageing tests. A set of phenomenological constitutive equations were proposed. The material constants within the equations were determined from multi-step (120 °C× 6 h +177 °C ×7 h) creep-ageing test data. Temperature effects on the internal state variables (i.e. precipitate size, volume fraction and dislocation density) were also considered. This model was further used to predict the stress relaxation phenomena under the same ageing condition. Although similar stress reduction trends and features were observed, the stress reduction was significantly over-predicted. The over-prediction of the stress reduction magnitude suggests that improvements should be applied to the current modelling method for simulating spring-back after creep age forming.

Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.

Keywords: Creep ageing, constitutive modelling, T74, stress relaxation ageing, AA7050, CAF

1. Introduction

Creep-age forming (CAF) is a forming technique used for fabricating extra-large lightweight aircraft panel components. It deforms the aluminium alloy inelastically through exploiting the stress relaxation mechanism at ageing temperatures, thus efficiently producing a part with the target dimensions and required mechanical properties.

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1877-7058
Peer-review under responsibility of the scientific committee of the International Conference on the Technology of Plasticity.
10.1016/j.proeng.2017.10.775

Over the decades, extensive research has been conducted on CAF, in order to determine a suitable method to characterise the CAF coupling mechanism (i.e. precipitate hardening and creep) and to predict the spring–back in CAF. At the early time, Ho et. al. [1], used creep damage constitutive equations [2] to predict spring-back in CAF, where the particle-coarse ageing mechanism was introduced into the model. To consider age hardening and dynamic nucleation and growth of precipitates, Lin et al. [3] proposed the first creep ageing constitutive equations specifically for CAF application, where material hardening is dynamically linked with the precipitation of the material in CAF processes. Further improvements were made by Zhan et al. [4], who proposed a model by introducing normalised internal variables for precipitation. All these models were determined from constant-load/stress uniaxial creep-ageing test data and used for predicting spring-back in CAF processes. However, the constant load/stress creep-ageing (CA) tests do not reflect the actual loading condition in CAF, where a plate is aged at constant displacement conditions and stress-relaxation-ageing (SRA) occurs. Therefore, it is necessary to validate the feasibility of the current CAF modelling method, by directly applying the creep-ageing calibrated constitutive equations to predict the stress-relaxation-ageing behaviour and examining the difference.

This work concentrates on firstly determining and calibrating a set of temperature dependent constitutive equations, which is an improved version of Zhan's equations [4], for AA7050 using the data obtained from constant-load multi-step creep-ageing tests. The calibrated equations are then used to predict the stress-relaxation-aging behavior under the same multi-step ageing conditions. Comparison between predicted and experimental stress relaxation curves were detailed discussed.

2. Model development

2.1. Creep ageing mechanisms in 7050 during T74 heat treatment

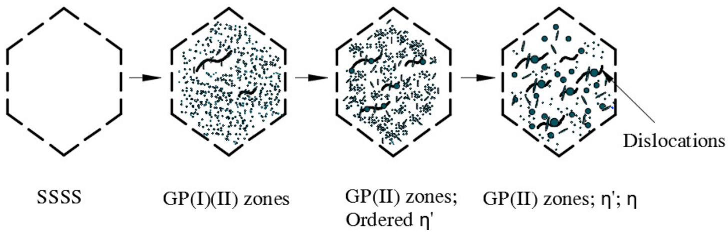

Fig. 1 Schematic illustration of microstructure evolutions during creep ageing

For AA7050, T74 over–aged temper is commonly employed to harden the alloy as well as improve its corrosion resistance. The temper is achieved by applying a two-step temperature profile (120 °C ×6 h+ 177 °C ×7 h) to an as-quenched AA7050, and enabling a precipitation evolution, shown in Fig. 1, where the super saturated solid solution (SSSS) transforms into GP zones, η' and η in sequence [7]. For creep-ageing, a constant stress is applied together with the T74 temperature profile to the as-quenched AA7050, triggering both the precipitate evolution and creep. These two phenomena interact with each other, as illustrated in Fig. 1. In this process, the dislocations created by creep facilitate the precipitation process by altering the precipitate characteristics, such that coarser precipitates form around dislocations. This dislocation-impacted precipitate evolution (nucleation and growth) determines the alloy's strength and creep resistance response, thus in turn affecting the creep generation during the whole period.

2.2. Development of unified creep ageing constitutive equations

To quantitatively describe the coupling effects between creep and precipitation hardening discussed in Section 2.1, a set of constitutive equations, Equations (1-16), were proposed. The creep equation originates from the basic power–law creep expression, Equation (1), where ε_c represents the creep strain, σ denotes the stress and n is the stress exponent. The precipitation and dislocation effects on the generation of creep are considered through introducing the yield strength, σ_y, and normalized total dislocation density[4, 5], $\bar{\rho}$. For dislocation creep, the creep resistance is supposed to vary in the same way as the yield strength, σ_y, since both of them reflect the material