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Experimental studies and constitutive modelling of anelastic creep recovery during creep age forming

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Abstract

This paper presents a study of anelastic creep recovery during creep-ageing of an aluminium alloy AA7050-TAF. Uniaxial Creep-Ageing and Recovery Test (CART) was used to characterise the influence of anelastic creep strain on total creep deformation for determining the actual amount of springback in creep age forming (CAF) process. CART was performed on aluminium alloy AA7050-TAF at 174°C between the stress levels of 137.5 to 162.5 MPa. A constitutive model was developed for the prediction of the creep-ageing and recovery response of material in creep age forming. A 'back stress' variable was used to represent the net effect of the internal stresses of the material which causes anelastic creep recovery. Other microstructural variables were introduced to model complex micro-mechanisms and hardening effects including solid solution hardening, dislocation hardening, and age hardening. It has been found that the permanent strain after creep-ageing depends not only on total creep strain but also on anelastic strain. Simulation results from the constitutive model developed in this study show a good agreement with experimental data.

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Keywords: Creep age forming; Anelastic creep recovery; Springback

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1. Introduction

Creep age forming is a forming technique which applies the creep/stress relaxation deformation on the age hardenable alloys at its proper ageing temperature. Under this condition, materials can be strengthened by age hardening and deformed to the desired shape simultaneously. A main challenge in CAF is dimensional stability issues - springback. The development of springback modelling has been discussed widely in the literature [1, 2]. Some researchers focused on finding out the constitutive relationship of the material and integrating them into numerical process to model springback in CAF [3, 4]. In those studies, the time-dependent creep strain is generally treated as an inelastic strain and the material's behaviour at the unloading stage is usually treated as purely elastic. Springback has often been analysed in terms of the release of internal stress from the stress redistribution during the forming process of loading and unloading. Under this premise, constitutive equations have been developed based on the conventional creep-ageing test and used to predict the amount of springback [5, 6].

Anelastic creep recovery is a time-dependent reversible deformation which occurs when a material is unloaded from creep. When the mechanism behind CAF process is simply dominated by thermally activated diffusional creep [7], anelastic creep recovery can be neglected. The vacancy diffusion through the lattice or the generation and annihilation of vacancies and dislocations create inelastic creep strain rather than recoverable anelastic strain, so creep recovery does not take place. However, other creep mechanisms including shear or slide of grain boundaries, dislocation glide and climb may also play substantial parts in CAF process [8, 9], leading to time dependent creep strain recovery - delayed elastic effect [10]. Nevertheless, researchers in CAF have not paid much attention to how time dependent creep strain recovery could influence springback. To address this, in this paper, creep-ageing and recovery tests were performed on aluminium alloy AA7050-TAF to investigate the anelastic creep recovery behaviour and a constitutive model was developed to facilitate the springback prediction that takes into account the time dependent creep strain recovery.

2. Materials and Experimental

The material used in this study was aluminium AA7050-TAF which follows AMS 4050 specification with a normal composition (wt.%) of 6.247Zn, 2.143Mg, 2.231Cu, 0.049Fe, 0.033Si, and 89Al. The geometry and dimensions of the specimens complied with the ASTM E8 standard with an 8 mm diameter in the 36 mm gauge length. Its heat treatment process is in accordance with AMS 2770 with modifications to obtain an intermediate temper condition for age forming purpose, namely Temper to Age Forming (TAF) condition [11]. Under this temper condition, it takes another 8 h aging at 174 °C to reach T74 temper.

Constant load CART was performed in air at 174°C. An Instron 5584 computer controlled electromechanical load frame with a temperature chamber was used for the tests. Two thermocouples were applied to measure the temperature at the top and bottom of the gauge section of the specimens. The temperature was maintained within ±1 °C. A high temperature extensometer which is capable of measuring strain with a resolution of up to 10^{-5} was used to monitor the strain of the specimen during the test.

Room temperature and high temperature tensile tests were performed first to provide the basis for planning a series of CART. Yield strength of the material at room temperature and high temperature are respectively 573 and 460 MPa. Initial stresses of CART were set at three levels, 137.5, 150 and 162.5 MPa. Room temperature tensile tests were performed on the interrupted pure ageing and creep ageing specimens after 2, 4, 6, 8 h of ageing.

During CART, a tensile load was applied at the rate of 8 MPa s^{-1}. The high speed of loading was adopted to minimise the inelastic strain occurring with time. After loading, specimens were held at constant stress for 2, 4, 6 and 8 h respectively to investigate the influence of creep-ageing time on creep strain recovery. At the end of creep-ageing period, the tensile load was removed rapidly at the rate of 50 MPa s^{-1} and the strain was continued to be monitored until the end of the test. Fig. 1 shows schematically the creep-ageing and recovery curve and the corresponding loading history for the CART. Uniaxial tensile tests were performed on the creep aged, but without recovery, samples at a strain rate of 10^{-4} s^{-1} for measuring the yield strength evolution with the creep-ageing time and the applied stress.