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An approach to modeling time-dependent creep and residual stress relaxation around cold worked holes in aluminium alloys at room temperature

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A B S T R A C T

Creep behaviour of aluminium alloys is also observed at room temperature. As a result, a relaxation occurs of deliberately introduced beneficial residual stresses around fastener holes, before the relevant structural component is subjected to exploitation. Therefore, to adequately asses the life-time of the component with cold worked holes, it is necessary to quantify this relaxation. In this paper a combined iterative approach for building a time-dependent creep constitutive model of aluminium alloys at room temperature has been developed in order to be used in finite element (FE) simulations of the cold hole working process. The approach is based on an experimental study of the change in diameters of cold worked holes through mandrel cold working method and a subsequent series of FE simulations of the cold working process and of the following creep behaviour to determine the necessary equivalent stresses in the constitutive model. The obtained creep constitutive model has been founded on the power-law model. The model parameters *A*, *n* and *m* have been determined on the basis of a developed by the authors algorithm. The approach has been illustrated on D16T aluminium alloy widely used in the airspace industry. The material behaviour in the plastic field has been described by the nonlinear kinematic hardening model, obtained through a uniaxial tensile test. Both constitutive models have been used in FE simulations of the cold working processes and of subsequent residual stress relaxation around the cold worked open holes due to creep at room temperature. On the base of the FE results, mathematical models describing the residual stress relaxation have been obtained. Thus, the residual stresses are adequately evaluated immediately before introducing the structural component in operation.

1. Introduction

The aluminium alloys have enough strength at relatively low weight, big corrosion resistance and good workability. Because of that, they are widely used in responsible structures, due to their optimum combination of physical and mechanical properties [1]. The aluminium alloys in sheet metal form have a wide application in the airspace industry for various structural elements, and more specifically for wing and fuselage structures, characterized by multitude fastener holes.

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Nomenclature

A	a constant in the power-law model
C	initial kinematic hardening modulus
D	outer diameter
D_m	mandrel major diameter
d	diameter immediately after cold working
d_i	current diameter during the creep
d_{init}	initial hole diameter
E	Young's modulus
h	hole length
k_{ij}	known constants
ℓ_i	known constants
m	a constant in the power-law model
n	a constant in the power-law model
p	number of the experimental points
$\tilde{q}$	Mises equivalent stress
REL	residual stress relaxation
t	time
x_i	unknown

Greek symbols

α_{ij}	back-stress tensor
γ	material parameter
μ	Poisson's ratio
ε^{cr}	uniaxial equivalent creep strain
$\varepsilon_{\ln}$	logarithmic strain
$\varepsilon_{\ln}^{p}$	logarithmic strain in the plastic field
ε_{nom}	nominal strain
$\bar{\varepsilon}^{p}$	equivalent plastic strain
ε_{θ}	hoop linear strain
$\varepsilon_{\theta}(t)$	smooth approximating function (curve)
$\varepsilon_{cr}^{\theta}$	hoop creep strain
σ^{0}	stress defining the size of the yield surface
$\sigma\|_0$	yield limit
σ_{nom}	nominal stress
σ_{true}	true stress
σ_{ij}	stress tensor
σ_{res}^{θ}	residual hoop stress
τ	current time

Subscripts

cr	creep
i	1, 2, 3, etc.
init	initial
ln	logarithmic
m	mandrel
nom	nominal
p	plastic
res	residual
θ	hoop (circumferential)

Since the holes are natural stress concentrators, they are a critical spot for initiation and growth of fatigue cracks. The cold plastic deformation of the material around holes in metal structural components, with the purpose of introducing the beneficial residual compressive hoop stresses, is widely used in the airspace industry as prevention against fatigue failure of the corresponding component [2–6]. The beneficial effect from the introduced through various methods residual compressive stresses is expressed in a significant enhancement of fatigue life, respectively the number of cycles to failure, of the corresponding structural component. Depending on the applied method for introduction of these stresses and the magnitude of the applied tensile load, the increase is up to 10 times [7–9].

One of the effective approaches for achieving this effect is pulling a tool with a diameter greater than the diameter of the preliminary drilled hole. After ceasing the action of the tool on the hole, the plastically deformed layer of metal around the