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The influence of pre-compression on the creep deformation and failure behaviour of Type 316H stainless steel ☆

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ABSTRACT

The influence of pre-compression to 8% plastic strain at room temperature has been examined on the tensile properties, uniaxial creep deformation, creep crack initiation and growth behaviour of Type 316H stainless steel at 550 °C. Uniaxial creep and crack growth tests have been performed on the pre-compressed (PC) material and the results compared to existing long term (>15,000 h) and short term test data on as-received (AR) (i.e. uncompressed) material. Pre-compression has been found to increase the materials subsequent yield stress in tension. Therefore the extent of non-linearity observed on the load–displacement curves of uniaxial creep rupture and crack growth tests on PC material is limited compared to AR material. In addition pre-compression causes a significant reduction in creep ductility and rupture time, although similar average and minimum creep strain rates are found in PC and AR materials. The creep crack growth (CCG) data on PC and AR materials have been characterised using the steady state creep C^* parameter employing appropriate validity criteria and geometry dependent fracture mechanics parameter solutions. The CCG results are compared to the creep crack growth prediction models. Based on the creep properties, creep ductility and metallurgical observations of the fracture behaviour of the AR and PC materials, it has been shown that short term creep crack growth tests on PC material may be used to predict long term creep crack initiation (CCI) and CCG behaviour of AR material at 550 °C.

1. Introduction

The creep deformation and crack growth behaviour of Type 316H stainless steel (SS) is of great concern, particularly due to its widespread use in the UK's advanced gas cooled reactor (AGR) power stations. Recently there has been significant interest in characterising the influence of plastic pre-strain on the creep deformation and crack growth properties in 316H SS [1–3] and other materials [4] since pre-compression is often employed to introduce tensile residual stress fields in a fracture sample [5] and plastic strain is generated during component fabrication processes such as bending and welding. The influence of prior plastic pre-straining, introduced in tension, on the subsequent creep deformation behaviour of a range of materials has been examined in [6–8] and smaller values of creep ductility are found in the pre-conditioned material compared to the as-received (AR) material. It has also been shown in [6] that at a given temperature and stress, the creep ductility reduces as the

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Nomenclature

a crack length
a_0 initial crack length
$\dot{a}$ (or da/dt) creep crack growth rate
$\dot{a}_{\text{NSW-MOD}}$ creep crack growth rate predicted by NSW-MOD model
Δa increment of crack growth
A creep stress coefficient in minimum creep strain law
A_A creep stress coefficient in average creep strain law
B specimen thickness
B_n net specimen thickness between side grooves
B_r coefficient of rupture law
C^* steady state creep fracture mechanics parameter
D constant coefficient in creep crack growth correlation with C^*
E elastic (Young's) modulus
E' effective Young's modulus
I_n non-dimensional function of n
K stress intensity factor
n creep stress exponent in minimum creep strain law
n_A creep stress exponent in average creep strain law
P load
r_c creep process zone
$t_{0.2}$ time for 0.2 mm crack extension
$t_{0.5}$ time for 0.5 mm crack extension
t_f creep crack growth test duration
t_i initiation time
t_{red}^{eng} engineering definition of the redistribution time
t_r time to rupture in a uniaxial creep rupture test
t_T transition time from small scale creep to widespread creep conditions
W specimen width
η geometry function in C^* relation
ε_f uniaxial creep strain at failure (creep ductility)
ε_f^* multiaxial creep ductility
$\tilde{\varepsilon}_e$ non-dimensional function of θ and n
$\dot{\varepsilon}_s$ steady state creep strain rate
$\dot{\varepsilon}_A$ average creep strain rate
υ_r creep rupture stress exponent
ϕ exponent in correlation of creep crack growth rate with C^*
Δ load line displacement
Δ_c creep load line displacement
Δ_e elastic load line displacement
$\dot{\Delta}$ load line displacement rate
$\dot{\Delta}^c$ component of displacement rate directly associated with the accumulation of creep strains
$\dot{\Delta}^i$ component of displacement rate directly associated with instantaneous (elastic and plastic) strains
$\dot{\Delta}_e^i$ component of displacement rate directly associated with instantaneous elastic strains
$\dot{\Delta}^T$ total load line displacement rate
σ stress
$\sigma_{0.2}$ 0.2% proof stress
σ_{ref} reference stress
θ crack tip angle
AR as-received material
CCG creep crack growth
CCI creep crack initiation
LLD load line displacement
NSW Nikbin, Smith and Webster creep crack growth model
NSW-MOD modified version of the NSW creep crack growth prediction model
PC pre-compressed material
PE plane strain
PS plane stress
ROA reduction of area
SS stainless steel
UTS ultimate tensile strength