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# The influence of inelastic pre-straining on fracture toughness behaviour of Type 316H stainless steel

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The effects of inelastic deformation, in the form of plastic and creep pre-strain, on the fracture toughness behaviour of Type 316H stainless steel have been investigated in this study. Material pre-conditioning effects on the strain distribution fields ahead of the crack tip have been investigated using digital image correlation technique. Fracture toughness tests have been performed on compact tension specimens made of the as-received, plastic pre-strained and creep pre-strained materials. The influences of specimen side groove and pre-cracking type on the fracture toughness behaviour of 316H stainless steel have also been examined. The test results have shown that the fracture toughness values decrease by increasing the percentage of inelastic pre-strain introduced into the material. Moreover, the generated R-curves and the subsequent fracture toughness values have been found sensitive to the specimen side groove. Finally, it has been observed that local creep damage has more severe impact on the fracture toughness of the material compared to global creep deformation.



## 1. Introduction

Material pre-conditioning can be introduced into engineering components in the form of plastic pre-strain during the fabrication process or in the form of creep pre-strain during operation at elevated temperatures. Type 316H stainless steel (SS) is widely used in the UK's power industry, for example steam headers in advanced gas cooled reactors (AGRs). Many of these components were previously operating for a few decades at high temperatures (i.e. at around 550 °C) in which creep deformation and crack growth is the dominant failure mechanism. However, in order to extend the lifetime of these high temperature components their operating temperatures were reduced to limit the accumulation of in-service creep deformation and damage. In order to assess the structural integrity of these AGR power plant components it is important to consider the influence of prior inelastic (i.e. plastic and creep) pre-straining on the subsequent mechanical response, fracture and crack growth behaviour of the material. The influence of plastic pre-straining, introduced in the form of uniform pre-compression to 8% plastic strain at room temperature, on the tensile, fracture toughness and creep deformation and crack growth behaviour of Type 316H SS has been extensively examined in previous work by authors [1–3]. The experimental results in [1–5] have shown that plastic pre-straining leads to an increase in the yield stress, reduction in tensile strain at failure and also a decrease in fracture toughness of 316 steel. Literature studies on other engineering materials have shown that similar

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**Nomenclature**

| | |
|---|---|
| $a$ | crack length |
| $a_0$ | initial crack length |
| $a_f$ | final crack length |
| $\Delta a$ | increment of crack growth |
| $\Delta a_{max}$ | maximum allowable crack extension in fracture toughness tests |
| $B$ | specimen thickness |
| $B_e$ | effective thickness |
| $B_n$ | specimen net thickness between the side grooves |
| $C$ | unloading compliance |
| $E$ | Young's modulus |
| $E_M$ | effective Young's modulus in fracture toughness data analysis |
| $J_{0,k}$ | fracture resistance at the $k$th interval |
| $J_{0.2/BL}$ | fracture resistance at 0.2 mm of stable crack extension |
| $J_{max}$ | maximum allowable $J$ in fracture toughness tests |
| $J_{IC}$ | critical value of $J$ for fracture under Mode I loading conditions |
| $U_k$ | area under the force *vs.* displacement curve up to the line of constant displacement at the $k$th interval |
| $W$ | specimen width |
| $\eta$ | factor relating $J$ to load and displacement measurements |
| $\varepsilon_c$ | creep strain |
| $\sigma_{0.2}$ | 0.2% proof stress |
| $\sigma_{0.5}$ | 0.5% proof stress |
| AGR | advanced gas cooled reactor |
| AR | as-received material state |
| CCG | creep crack growth |
| DIC | digital image correlation |
| EDM | electrical discharge machining |
| GCD | globally creep deformed material |
| HAZ | heat affected zone |
| LCD | local creep damage material state |
| LLD | load line displacement |
| PC | pre-compressed material state |
| SEM | scanning electron microscopy |
| SS | stainless steel |
| TC | thermocouple |
| UTS | ultimate tensile strength |

changes in mechanical response and fracture behaviour of the material are generally observed when test specimens were subjected to tensile or compressive plastic pre-staining e.g. see [6–11]. The results obtained from these studies have shown that the fracture toughness value decreases as the percentage of tensile or compressive plastic pre-strain increases in the material e.g. [12]. The influence of creep pre-straining, introduced into round bar 316H SS specimens by interrupting uniaxial creep tests at 550 °C, on subsequent room temperature tensile behaviour of the material has been investigated in [13]. The experimental results obtained from crept specimens in [13–15] have shown that creep deformation (i.e. development of uniform creep pre-strain in uniaxial creep deformation tests) increases the yield stress and reduces the tensile strain at failure of 316 material.

The experimental results available in the literature suggest that plastic and creep pre-straining have similar effects on the tensile and fracture behaviour of metallic materials. The previous work by authors on plastically pre-compressed 316H SS has confirmed that the fracture toughness of this material decreases by introducing uniform plastic pre-strain [3]. Although the global response of the as-received (AR) and pre-compressed (PC) material states was studied under fracture loading conditions in [3], further research is required to better understand the local response of the AR and PC material states. Therefore in the present study the authors have investigated the material plastic pre-straining effects on the strain distribution fields ahead of the notch tip using digital image correction (DIC) measurement technique to better understand the global fracture behaviour of the material in relation to local deformation. Moreover, although the influence of local creep damage (LCD) on fracture toughness of Type 316H SS was previously studied in [3] by performing tests on interrupted creep crack growth (CCG) specimens, further experimental work has been conducted in the present study to investigate the effects of uniformly introduced global creep deformation (GCD) on the fracture toughness behaviour of Type 316H SS. The results presented in this paper fill the knowledge gap and provide a better understanding of how inelastic deformation, in the form of uniform plastic and creep pre-strain, influence the fracture toughness behaviour of the material.

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