# 1 Constraint Effects on Creep Crack Growth Behaviour in 316H Stainless Steel

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## 1.2 Project Description

Life extension of the UK's advanced gas cooled reactors (AGRs) is dependent on the assurance of the safety of their structural components. As many AGR components operate in the creep range, it is important to understand and to be able to predict creep and creep-fatigue crack growth for real or postulated defects in these components. The R5 Volume 4/5 procedure gives advice on the prediction of creep and creep-fatigue crack growth for defects in components operating in the creep range. In order to predict crack growth behaviour using this advice, it is necessary to use appropriate crack growth properties obtained from suitable laboratory test specimens.

Significant work has been performed to characterise the creep crack growth (CCG) rate with the steady state creep fracture mechanics parameter C* in laboratory tests on fracture mechanics specimens. In most cases, the crack growth properties are obtained by testing high constraint (side-grooved) Compact Tension C(T) specimens. However, these data may be overly conservative when used to assess lower constraint scenarios relevant to some plant components, particularly those with small section thicknesses.

The effect of different levels of in-plane constraint can be examined by testing different specimen geometries. For example, samples loaded with significant bending give high constraint conditions and samples subjected predominantly to remote uniform tensile loading give low crack tip constraint conditions. Out-of-plane constraint variability can be achieved by considering samples with different thickness and with and without side-grooves.

### 1.2.1 Previous Research

Work has been completed previously examining the effects of specimen geometry on CCG rates in 316H stainless steel. However, in order to complete creep test programmes within a reasonable timeframe it is often necessary to accelerate the tests by increasing either the test stress or temperature, usually stress. This can result in the generation of significant plasticity on loading, which reduces the levels of constraint in samples designed to have high constraint. Hence the correlation between CCG rate and specimen geometry only started to become evident for long term low-load tests.

Pre-compressed material is thought to be appropriate to examine specimen (in-plane) constraint effect on CCG rates. Indeed, when loading a CCG test on a pre-compressed material, the load-displacement curve is generally linear as pre-compression increases the yield strength of the material (via dislocation hardening), although the creep failure strain (ductility) is reduced. This increase in yield allows loading during subsequent CCG tests on the material to remain elastic.

Further, it has recently been shown that C(T) specimens manufactured from a block of 316H which has been uniformly plastically strained at room temperature have similar CCG rates vs C* relationships in both short term and long term tests.

### 1.2.2 PhD Project Plan

The main aim of this work is to investigate the effects of constraint (in-plane and out-of-plane) on creep crack growth in 316H steel at 550°C, with particular emphasis on developing an improved understanding of crack growth behaviour in thin section components. This will first require constraint levels to be quantified for part-through and through cracks in typical thin section AGR components (e.g. boiler tubes). Laboratory test specimens can then be designed to replicate these constraint levels, which will allow relevant creep crack laws to be disovered to more accurately predict creep crack growth rates in thin section AGR 316H steel components.

This PhD will require a combination of novel experimental techniques and finite element methods.

### 1.2.3 Finite Element Studies

Crack tip characterising parameters such as K, J, the time dependent contour integral C(t), and widespread creep parameter C*, will be quantified for part-through and through cracks in typical thin section AGR components. Laboratory test specimens will then be designed (by considering K, J and T, Q, Q*, $\sigma_{zz}$ stresses) to replicate these constraint levels. C(t) and C* will also be quantified for these test specimens under relevant test conditions.

A similar analysis should be performed for a side-grooved C(T) specimen to allow comparison between low and high constraint test specimens.

### 1.2.4 Experimental Studies

CCG testing will be performed on suitably designed laboratory test specimens. These will generally be low constraint specimen geometries e.g. middle cracked tension, M(T), and single edge notched tension, SEN(T) geometries. These specimens will have a variety of thicknesses to allow consideration of both in-plane and out-of-plane constraint. The material from which samples are manufactured will be pre-compressed to around 8% plastic strain. The results will be benchmarked against existing CCG results performed on C(T) samples.

The CCG tests results will be studied in terms of the CCG parameters C(t) and C*. The results will be interpreted to quantify the influence of in-plane and out-of-plane constraint on CCG rates.

### 1.2.5 Assessment Methodology

Based on the quantification of constraint discovered from FE analyses and CCG rates discovered from experimental tests, constraint specific CCG rate models will be developed. These models may be incorporated into FEA to enhance the prediction of CCG rates in components with varying levels of constraint.

Existing assessment methodologies for predicting the influence of constraint on CCG will be examined (i.e. based on correlation of CCG rates with C(t) and C* or the alternative time dependent failure assessment diagram (TDFAD) approach). Recommendations will be made to improve the R5 Volume 4/5 procedures for assessing the remaining lifetime of cracked components subjected to a range of in-plane and out-of-plane constraint levels.