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The behavior of structures based on the characteristic strain model of creep

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A B S T R A C T

There has been much work over the past two decades to aid the design and assessment engineer in the selection of a suitable material model of creep for high temperature applications. The model needs to be simple to implement as well as being able to describe material response over long times. Familiar creep models, as implemented in the majority of nonlinear finite element analysis systems, are still widely used although not always accurate in modeling creep behavior at the end of the secondary phase. The Characteristic Strain Model (CSM) has been shown to be able to effectively model creep behavior at long times; it is simple to implement and requires a minimum of creep data. This paper examines the ability of the CSM to model the recognized behavior of the steady state creep of simple structures under multiaxial stress.

1. Introduction

High temperature design continues to be a problem for many industries and the appropriate characterization of material creep behavior remains fundamental to this. Over the past few decades the development of constitutive relations for highly nonlinear time dependent inelastic material behavior has become increasingly sophisticated, often requiring several kinds of mechanical testing. The work of the European Collaborative Committee (ECCC) and the Japanese National Institute of Materials Science (NIMS) have been notable in collecting high quality verified creep data to allow researchers to develop and test suitable constitutive models. In the past the use of such advanced material models for design and assessment was not feasible due to the lack of suitable computational resources: instead simplified design methods were derived from a knowledge of component behavior using simple constitutive models such as time- and strain- hardening combined with power law creep [1–3]. These simplified methods have informed the development of several high temperature design rules [4,5]. In more recent years the ready availability of nonlinear finite element computational tools has made the use of advanced material models much more accessible, in particular through user material capabilities as found in software such as ABAQUS. Nevertheless most nonlinear finite element software continue to include the classical time- and strain- hardening models together with the power law for steady creep amongst several others which have been around for many years. Anecdotal evidence is that these simple models are still widely used for complex finite element design studies. It appears that design engineers continue to prefer simple material models for the analysis of complex, as well as simple, structures.

Part of the work of the ECCC was to provide a source of verified and technically robust creep data for detailed finite element creep analysis and to aid the design engineer in material model selection. A paper by Holdsworth et al. [6] examined the issue of the choice of the most appropriate creep model. They investigated the performance of a wide range of creep models on a number of creep datasets - several of these models being modern developments of the classical creep models. No one creep model was identified as having the best performance in terms of representing the creep data over all three stages of creep (primary, secondary and tertiary) with some being more reliable for the primary/secondary stages and some more reliable for tertiary creep, with a few models suitable for both. They concluded that '….. as a generality, it is more important for design and assessment engineers for the model equation to be simple to implement and effective in its description of creep deformation at long times …". A particular example of such a creep model which satisfied these practical constraints was identified as Bolton's Characteristic Strain Model [7]. The Characteristic Strain Model (CSM) remarkably requires a minimum of creep data – essentially two values of rupture strength from creep rupture data in the tertiary creep regime and, from the primary/secondary regime of a single creep test, the stress required to bring the material to a 'characteristic strain', nominally half the value of creep strain at rupture. Despite the simplicity of the CSM, it was shown to achieve satisfactory predictions of creep strain at constant stress over all three stages of creep deformation in

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