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PII: S0142-1123(17)30112-3
DOI: http://dx.doi.org/10.1016/j.ijfatigue.2017.03.018
Reference: JIJF 4281

To appear in: *International Journal of Fatigue*

Received Date: 13 May 2016
Revised Date: 15 February 2017
Accepted Date: 21 March 2017

Please cite this article as: Barrett, R.A., O'Donoghue, P.E., Leen, S.B., A physically-based constitutive model for high temperature microstructural degradation under cyclic deformation, *International Journal of Fatigue* (2017), doi: http://dx.doi.org/10.1016/j.ijfatigue.2017.03.018

A physically-based constitutive model for high temperature microstructural degradation under cyclic deformation

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Keywords: 9Cr Steels; High temperature fatigue; Dislocation density; Precipitate hardening; Martensitic laths

Abstract

This paper presents a dislocation-mechanics cyclic viscoplasticity model which incorporates the key physical micro-mechanisms of strengthening and softening for high temperature deformation of 9Cr steels. In particular, these include precipitate and grain boundary strengthening, low-angle boundary dislocation annihilation and martensitic lath width evolution, using dislocation density as a key state variable. The new model is applied to P91 steel across a range of strain-rates, strain-ranges and temperatures in the range 400 °C to 600 °C, for power plant header applications, to demonstrate the effect of key microstructural parameters on high temperature low cycle fatigue performance.

1. Introduction

The rapid transition in operation of fossil fuel power plants from base-load to flexible loading mode and the drive to higher temperatures, to accommodate renewable energy sources and to reduce CO_2 emissions, has led to increased importance of creep, fatigue and oxidation in the design of next generation plant. Advanced materials, such as tempered martensitic-ferritic 9Cr steels, are a common material of choice for heavy section boiler components due to (i) their high creep strength at high temperatures as a result of a precipitate- and solute-strengthened hierarchical microstructure, (ii) their enhanced oxidation and corrosion resistance, primarily due to the relatively high Cr content, (iii) a favourable coefficient of thermal expansion and (iv) relatively low cost compared to other candidate materials, such as Ni-based superalloys. However, due to the diversity and severity of current and future loading conditions, there is a requirement to reliably predict the life of components under more demanding flexible operation at higher temperatures.