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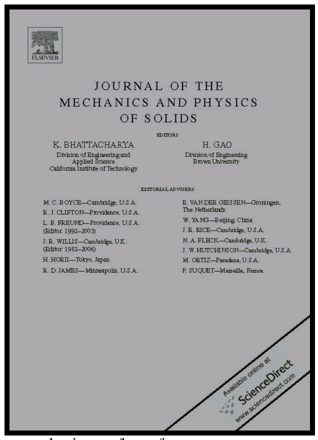

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A multi-scale crystal plasticity model for cyclic plasticity and low-cycle fatigue in a precipitate-strengthened steel at elevated temperature

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Abstract

In this paper, a multi-scale crystal plasticity model is presented for cyclic plasticity and low-cycle fatigue in a tempered martensite ferritic steel at elevated temperature. The model explicitly represents the geometry of grains, sub-grains and precipitates in the material, with strain gradient effects and kinematic hardening included in the crystal plasticity formulation. With the multiscale model, the cyclic behaviour at the sub-grain level is predicted with the effect of lath and precipitate sizes examined. A crystallographic, accumulated slip (strain) parameter, modulated by triaxiality, is implemented at the micro-scale, to predict crack initiation in precipitate-strengthened laths. The predicted numbers of cycles to crack initiation agree well with experimental data. A strong dependence on the precipitate size is demonstrated, indicating a detrimental effect of coarsening of precipitates on fatigue at elevated temperature.

Keywords: Tempered martensite ferritic steels; Strain gradient-based crystal plasticity; Cyclic softening fatigue; Finite element; Crack initiation

1. Introduction

Advances in the understanding of mechanisms of material degradation in cyclic plasticity and in relevant modelling techniques in the past decade have created opportunities for more explicit consideration of the role of microstructure in the formation of fatigue cracks in realistic structural components. Recent trends in structural integrity assessments aim to take these microstructural advances into account (Sangid, 2013; Dunne, 2014) leading to more accurate life prediction and optimised design for cyclically-loaded materials and structural components.

The present study focuses on P91 steel (X10CrMoVNb9-1), which contains 9% Cr, 1% Mo and the balance primarily Fe and is a widely used structural material for power plant components. As discussed by numerous researchers (e.g., Sawada et al., 2011; Fedorova et al.,

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