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Temperature dependant polycrystal model application to bainitic steel behavior under tri-axial loading in the ductile–brittle transition

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ABSTRACT

A polycrystal finite element (FE) model describing the temperature evolution of low carbon steel is proposed in order to forecast the local mechanical fields as a function of temperature, for bainitic microstructure submitted to tri-axial loading. The model is designed for finite strains, large lattice rotations and temperatures ranging into the brittle–ductile transition domain. The dislocation densities are the internal variables. At low temperature in Body Centred Cubic (BCC) materials, plasticity is governed by double kink nucleation of screw dislocations, whereas at high temperature, plasticity depends on interactions between mobile dislocations and the forest dislocations. In this paper, the constitutive law and the evolution of the dislocation densities are written as a function of temperature and describe low and high temperature mechanisms. The studied aggregates are built from Electron Back Scattering Diffraction (EBSD) images of real bainitic steel. The aggregate is submitted to a tri-axial loading in order to describe the material at a crack tip. Mechanical parameters are deduced from mechanical tests. The local strain and stress fields, computed for different applied loadings, present local variations which depend on temperature and on tri-axial ratio. The distribution curves of the maximal principal stresses show that heterogeneities respectively increase with temperature and decrease with tri-axial ratio. A direct application of this model provides the evaluation of the rupture probability within the aggregate, which is treated as the elementary volume in the weak link theory. A comparison with the Beremin criterion calibrated on experimental data, shows that the computed fracture probability dispersion induced by the stress heterogeneities is of the same order than the measured dispersion. Temperature and stress tri-axiality ratio effects are also investigated. It is shown that these two parameters have a strong effect on fracture owing to their influence on the heterogeneous plastic strain. These inhomogeneities can initiate cleavage fracture.

1. Introduction

Several crystal plasticity models were already developed to describe the effects of microstructure on mechanical fields and orientation textures (Peirce et al., 1983; Beaudoin et al., 1995; Tabourot et al., 1997; Barbe et al., 2001a,b; Hoc et al., 2001; Bhattacharyya et al., 2001; Stainier et al., 2002; Erieau and Rey, 2004). These polycrystal plasticity approaches did not explicitly describe the temperature effect on plasticity.

The main contribution of this paper is to include the mechanisms of plasticity depending on temperature in a BCC polycrystal model. The aim of our approach is to describe the local stress strain field evolution of a complex microstructures such as bainite with temperature and loading. At low temperature, plastic deformation is controlled by the mobility of screw dislocations, whereas at high temperature, plastic deformation hardening results from interactions between the mobile dislocations and the forest dislocations (Kocks et al., 1975; Kubin et al., 1978). The transition temperature separating these two mechanisms of deformation belongs to the brittle–ductile transition of low carbon steel. For a given microstructure, the model can predict the domains undergoing larger principal local stresses (thus, more sensitive to damage).

The model is designed within the framework of finite plastic strain and of large lattice rotation. It is based on a viscoplastic constitutive law for each slip system and depends on internal variables: the dislocation densities. The model is implemented in Abaqus® FE code.

The evolution of local behavior depends on:

– Thermally activated flow laws, based on two different mechanisms, according to the involved temperature. At low temperature, a double kink mechanism (due to the lattice friction

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