A Combined Experimental and Modelling Approach to Examine the Microstructural Deformation Experienced in Ex-Service 9Cr-1Mo Steel at Elevated Temperatures

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Abstract. The microstructural deformation of ex-service 9Cr-1Mo steels, with a tempered martensitic microstructure consisting of prior austenite grains, packets, blocks, and laths, has been examined in this study. Through the combined use of electron back-scattered diffraction (EBSD) and multiscale finite-element modelling, the high temperature microstructural deformation of these materials has been examined and the measured deformation compared with that predicted from the multiscale models.

Introduction

In recent years there has been an increased emphasis on the thermal efficiency of conventional (fossil fuel) power plant operating under flexible loading conditions. The development of materials capable of withstanding flexible (cyclic) loading conditions at high temperatures is therefore needed, coupled with an understanding of how the material microstructure changes when subjected to conditions representative of the operating temperatures and pressures of conventional power plants. The microstructural deformation of a modified 9Cr-1Mo steel (P91) has been examined experimentally at 500 ºC using a combination of mechanical testing, electron backscatter diffraction (EBSD), and finite element analysis (FEA). The measured experimental microstructural deformation is then compared with the predictions from a microstructural model using a representative volume element (RVE) approach, incorporating a crystal plasticity material model. A similar approach taken in previous work in this area has examined the deformation behaviour of this material at room temperature [1,2]. A modified Voronoi tessellation (VT) approach has also been adopted in this work in an effect to predict the microstructural deformation using a randomised microstructure, which incorporates the interaction of microstructural features within this material such as prior austenite grains, packets and blocks [3].

Experimental approach

The microstructural deformation of these materials was examined experimentally by testing a notched specimen at 500 ºC. To examine the microstructural deformation at elevated temperatures an EBSD scan of the initial microstructure at the notch root of the test specimen was taken. Following unloading a second EBSD scan was taken of the same area after deformation, as illustrated in Fig. 1. Comparison of these EBSD scans allows the microstructural deformation experience in the material to be determined. Examination of block orientation before and after deformation shows a significant change in orientation in the area of large deformation close to the notch root. Changes in block shape are also noted.

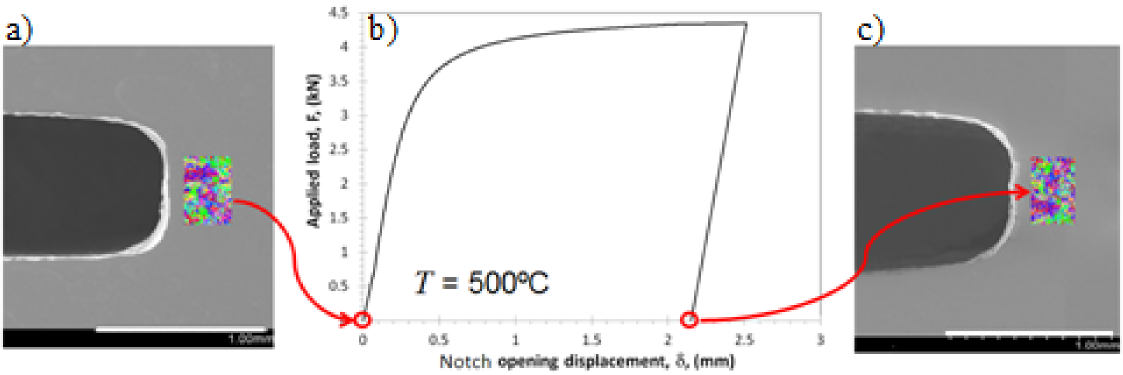

Fig 1: Experimental proceedure: a) Position of the inital EBSD scan, b) Force vs notch opening displacement respons at 500C, c) position of the EBSD scan taken after unloading

Multiscale modelling approach

The global force displacement behaviour is validated through an isotropic elastic plastic 3D finite element model of the specimen geometry. This model was calibrated using the stress/strain response of the material during a tensile test at the relevant temperature. Good agreement has been achieved between results of the macroscale model and the experimental force vs notch opening displacement curves.

The nodal displacements around the area of interest in the macroscale model are applied to the boundary of a microscale representative volume element (RVE). The model produces a simulated deformed microstructure which can be compared with the EBSD scan of the actual deformed microstructure through the use of inverse pole figures (IPF). The results of this analysis of a small region within the area of interest can be seen in Fig. 2.

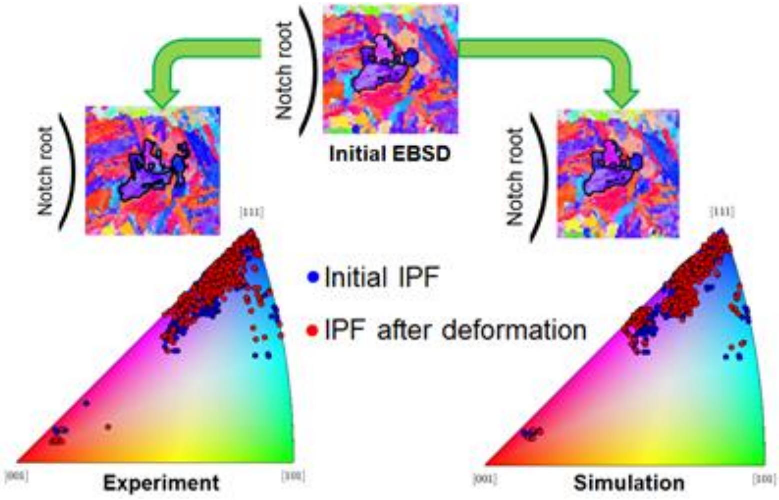

Figure 2: Experimental and simulated change in inverse pole figures (IPF) after deformation at 500C

A model has been developed in [3] which makes use of a modified Voronoi tessellation method to generate a random microstructure which represents the key microstructural features of these materials. Packets and blocks are generated within prior austenite grains, following the Kurdjumov-Sachs orientation relations [4].

Conclusions

The microstructural deformation of ex-service 9Cr-1Mo steel has been captured experimentally through the use of electron backscattered diffraction (EBSD). Good agreement has been obtained at the global (macro) level between the experimental force vs notch opening displacement and that obtained from the experimentally calibrated FE model. At the micro-scale the crystal plasticity model IPF results for a number of blocks also shows reasonable agreement with the experimental results, demonstrating the applicability of multiscale approaches in the prediction of local deformations in engineering components.

Acknowledgements

This publication has emanated from research conducted with the financial support of Science Foundation Ireland under Grant Number 14/IA/2604. The modelling work was supported by the Irish Center for High-End Computing (ICHEC).

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