Experimental and Computational Material Characterisation for High Efficiency, High Flexibility Power Generation

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Abstract

The development of advanced materials for increased steam temperatures and pressures is the key step to achieving high flexibility and efficiency for next generation power plants. MarBN is a new 9-12Cr martensitic steel, with improved creep strength via (i) increased tungsten solute strengthening and (ii) boron enriched grain boundary precipitates, to provide microstructure stabilisation during long-term creep. The focus of this study is to characterise, for the first time, the fatigue performance of MarBN via experimental testing, microscopy and computational modelling. A high temperature low cycle fatigue (HTLCF) experimental program is performed at 600 ºC across multiple strain-rates and strain-ranges. Comparisons with P91 steel are presented, with MarBN demonstrating significantly increased strength but increased softening rate. To enable realistic component simulations, a unified cyclic viscoplastic material model is calibrated and validated against the experimental data. Scanning electron microscopy (SEM) is conducted to characterise the microstructure of MarBN in the 'as-received' and tested conditions, and determine the mechanisms of deformation.

1. Introduction

The primary requirements for development of advanced ferritic steels include increased long-term creep strength resistance to microstructural degradation, oxidation resistance at high temperatures, Type IV cracking resistance in welded joints and increased thermal cycling capabilities [1]. MarBN is a 9Cr-3W-3Co-V-Nb steel with boron added to improve the stability of $M_{23}C_6$ precipitates for application in thick section boiler components of ultra-supercritical (USC) power plants. Characterisation of advanced materials via a reliable material model over a range of loading conditions is increasingly important to accurately predict failure and reduce the need for long test times, as realistic plant conditions can be difficult to emulate under test conditions [2].

2. Methodology

An experimental program of HTLCF testing is performed on cast MarBN test specimens at 600 °C. A set of material parameters for MarBN is obtained from experimental data, and calibration and validation is performed over a range of test conditions using a novel unified cyclic viscoplastic material model. Microscopic and macroscopic comparisons between MarBN and P91 are presented.

3. Results

A comparison of the constitutive behaviour between cast MarBN and rolled P91 steel is presented (Fig 1); MarBN demonstrates a reduced rate of stress relaxation and significantly increased stress-range.

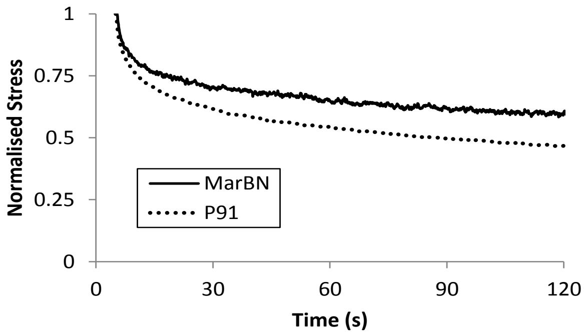

Figure 1. Comparison of experimentally measured stress relaxation behaviour in MarBN and P91 at 600°C.

Calibration and validation of unified cyclic viscoplastic material parameters is achieved over a range of strain-rates and strain-ranges. SEM of metallographic and fracture surfaces is performed to determine mechanisms of deformation.

4. Discussion & Conclusion

A novel unified cyclic viscoplastic material model is calibrated and validated from measured results, and accurate prediction of material response is presented across a range of loading conditions. Microstructural analysis of MarBN shows a coarser microstructure than P91, and fracture surface analysis demonstrates mechanisms of deformation, such as fatigue striations and dimple rupture. MarBN exhibits a significantly increased stress range than that of P91, where its improved creep strength and superior performance indicate the potential applications in flexible power plants at elevated temperatures and pressures.

8. References

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