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HIGH TEMPERATURE CREEP CAVITATION IMAGING AND ANALYSIS IN 9%Cr 1%Mo P91 STEELS

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Abstract
The creep lives of enhanced high-temperature strength and creep resistance of P91 steels in boiler and piping systems of high-temperature plants are limited by the formation of cavitation. The paper examines the initiation and growth of creep cavities in P91 samples with known exposures using high-resolution imaging and analysis techniques to quantify the amount of cavitation. These results are discussed with respect to the underlying processes that dominate the initiation of creep cavities in 9%Cr 1%Mo steels.

1. Introduction

It is known that power plant applications require long term performance which depends on the integrity and sustainability of the construction materials. So far, most recorded P91 steel system failures indicate creep damage which emanates from the initiation and growth of creep cavities on grain boundaries. Although the process of crack propagation that leads to ultimate failure is better understood, the factors that initiate creep cavities have not yet been clearly established. Ferritic 9%Cr 1Mo steels are characterised by a number of secondary phases, such as $M_{23}C_6$ carbides and MnS sulphides while the martensitic condition presents an even more complex lath microstructure accompanied by Laves phases, MX-type precipitates and Z-phases. The presence and coarsening of these phases, along with the underpinning of dislocation movement at and local to grain boundaries, can lead to regions of enhanced stress-strain concentration which leads to the initiation and early growth of creep cavities. In order to evaluate which factors promote cavity initiation, P91 specimens have been analysed in various creep life stages to provide insight on the microstructure pre-cursors to cavity initiation and, hence, the long-term damage.

2. Results

An ex-service 9%Cr 1Mo steel sample, inititially in martensitic condition and service-exposed at 570˚C, 16.5MPa for 79.000hr, was subjected to renormalisation and tempering in order to obtain a fully-ferritic microstructure – 950˚C for 30min followed by slow-cooling and 760˚C for 3hr followed by air-cooling. Post heat treatment, uniaxial creep specimens were prepared and creep-tested at 625˚C, 60MPa for 5369hr. The strained and ultimately fractured region of the specimen was imaged across its stress axis, obtaining 0.5mm x 0.5mm and 1mm x 1mm high-resolution stitched images which underwent image segmentation with the use of DragonFly® software [1] in order to identify the exact positions and characteristics of the cavities with respect to the microstructure.

Microscopy techniques, such as scanning electron microscopy (SEM) imaging, focused ion beam (FIB) milling and imaging, energy-dispersive x-ray spectroscopy (EDS) and electron backscattered diffraction (EBSD) imaging, combined with computer-based image recognition and analysis methods, have been used in a correlated approach to:

a) Quantify the cavitation in ex-service and creep-tested fully-ferritic P91 samples.
b) Compare the amount of cavitation, cavity size and types of secondary phases between the undeformed head and the creep region of the P91 specimens.
c) Identify the various secondary phases present in the ferritic condition of the P91 specimens and define their link to cavitation susceptibility. Upon EDS analysis, 90% of the inclusions associated

with cavities were found to be MnS sulphide particles and grain boundary $M_{23}C_6$ carbide precipitates.

d) Investigate the cavity initiation and evolution at various creep life fractions for ferritic and martensitic conditions of P91 steel specimens by performing interrupted tests at 5% and 10% strain for the ferritic condition and 0.5% and 1% strain for the martensitic condition.

A particular development has been the use of EBSD mapping correlated to the cavity segmentation results using Dragonfly imaging as described by Martin et al [2]. This approach provides more information regarding the relation of the cavities with respect to the grain boundary positions, orientation Schmid factor etc. The implementation of these results in creep models will also be discussed as well as the interrupted creep test results in both ferritic and martensitic conditions.

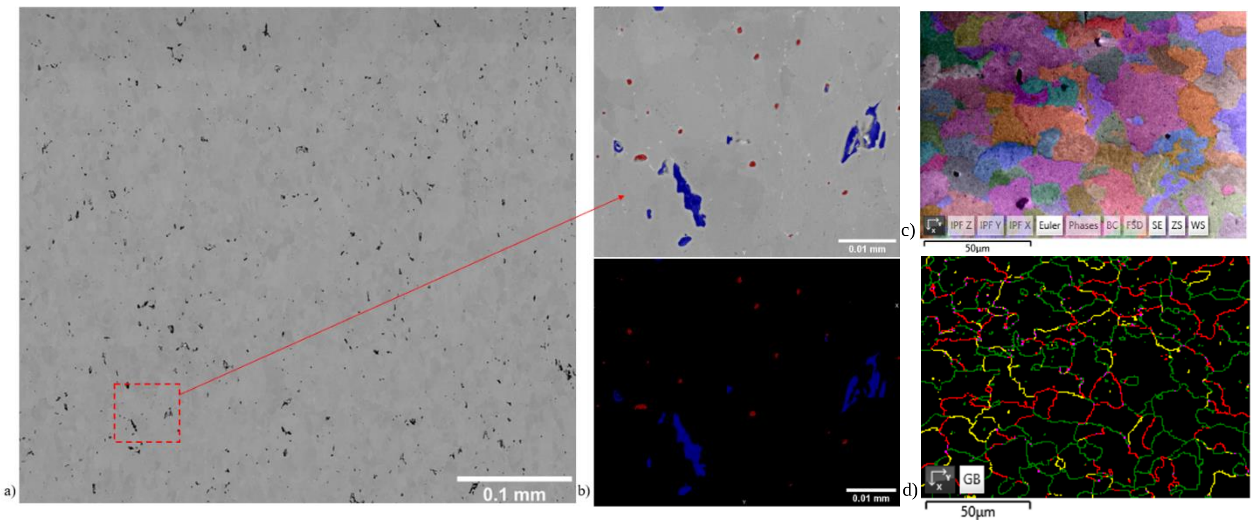

Figure 1: (a) Stitched scanning electron micrograph of area located 8mm from the fracture surface of the creep tested P91 specimen, (b) segmentation of cracks (blue) and individual cavities (red) with the use of Dragonfly software, (c) overlayed EBSD Euler and secondary electron maps depicting inter- and intra-granular cavities and (d) map depicting low angle >15˚ (yellow), mid angle >30˚ (green) and high angle >50˚ grain boundaries (red).

3. Conclusions

The microscopy and image segmentation tools employed resulted in the quantitative description and characterisation of cavitation in 9%Cr 1%Mo P91 steels as well as identification of the susceptibility to cavitation of different secondary phases present in the material.

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References

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