Low cycle Fatigue and Creep-Fatigue Interaction of Modified 9Cr-1Mo Steel Weldments

EXECUTIVE SUMMARY

The influence of hold time on the high temperature low cycle fatigue (LCF) behavior of modified 9Cr-1Mo ferritic steel in the normalized and tempered condition is addressed. Total axial strain controlled LCF tests at 873 K with hold times at peak strain up to 10 min in tension and compression were carried out employing total strain amplitude of ±0.6%. The alloy in general, showed a gradual and continuous softening regime. Fatigue life was found to decrease with increase in the duration of hold time in both tension and compression. Compression hold was found to be more damaging than the tension hold. The fatigue failure in compression hold tests were marked by extensive crack branching and formation of secondary cracks. Oxidation assisted crack initiation and propagation contributed to life reduction at high temperatures in hold time tests. Additionally, the sub-structural changes of the starting microstructure were also found to be responsible for the reduction of the fatigue life.

OUTLINE

Modified 9 Cr-1 Mo steel, a modified version of plain 9 Cr-1Mo ferritic steel by the alloy addition of niobium and vanadium is used extensively as structural material for steam generator components of liquid metal cooled fast breeder reactor and fossil fired power plants. It is observed that even though the base material has superior creep rupture property compared to other low alloy steels, many in-service problems are associated with weld joints due to the mismatch in the creep behavior of the parent material, the weld metal and the heat affected zone (HAZ). The HAZ is made up of a number of relatively narrow sub-regions, which have different creep strengths. This leads to complex stress redistribution and complex states of stress is set up locally which have a great influence on the accumulation of creep damage and on the subsequent failure of the weldment. This mode of failure is known as type IV cracking and is associated with relatively large strains taking place within a very localised region of the HAZ known as the intercritical region. Apart from the strain localization in the fine grained HAZ, microstructural degradation such as coarsening of the carbide precipitates and substructural changes such as formation of cells/subgrains from the martensitic laths also occur.

Study on the evaluation of low cycle fatigue and creep-fatigue interaction behavior of modified 9 Cr-1 Mo ferritic steel weldments are relatively scanty compared to the vast data available on the creep behavior of this alloy. In view of this, an attempt has been made to further the current understanding on the low cycle fatigue and creep fatigue interaction behavior of weld joints and base material of modified 9 Cr-1 Mo ferritic steel. Low cycle fatigue tests were carried out on both base material and welded joints of the P91 material at 773, 823 and 873 K at strain rate 3 x 10^{-3} s^{-1}, employing various strain amplitudes. Post weld heat treatment was done on the weld joint at 1033 K for 3h followed by air cooling. Creep-fatigue interaction tests were conducted by introducing hold at peak tension and in peak compression for periods in the range 1 min to 10 min at 873K.

Fig. 1 shows continuous cyclic softening from first cycle onwards during all the tests in both weld joints and the base material. The overall stress response decreased with increase in temperature at all strain amplitudes employed during the test for both base and joint.

Fig. 2 shows the comparison of base and joint data on a strain-life plot. Both base metal and weld joint exhibited similar fatigue lives at 823 K.

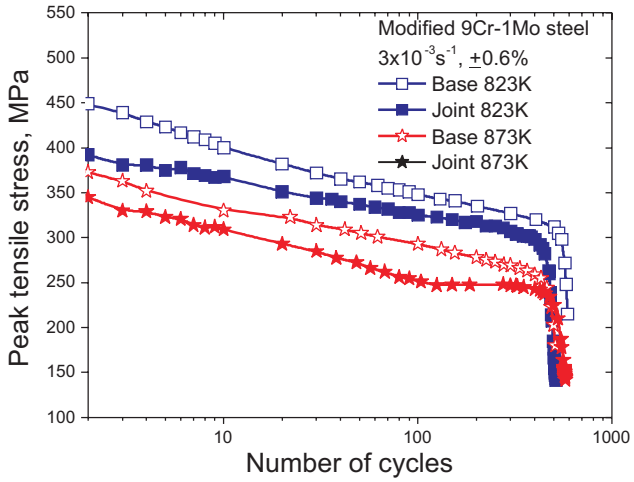

Fig. 1 : Comparison of cyclic stress response of base and weld joints

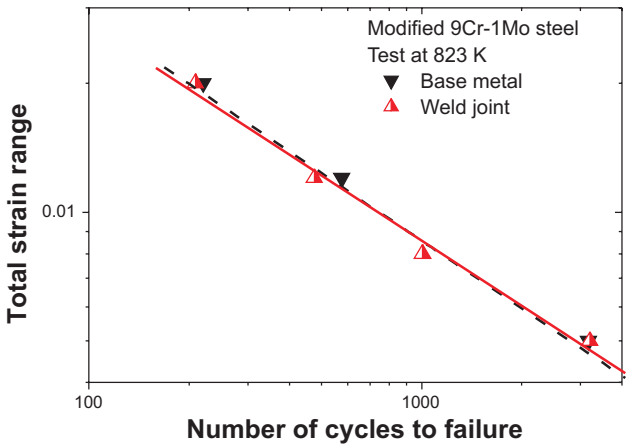

Fig. 2 : Comparison of fatigue lives of base and weld joints at 823 K

■ DEFORMATION SUBSTRUCTURE

The overall cyclic stress response is lower in hold time tests compared to continuous cycling. Detailed transmission electron microscopy of the samples tested to various fractions of fatigue life indicated that at room temperature the cyclic softening is attributed to annihilation of dislocations while at 873 K it is ascribed to the formation of cells and coarsening of the carbide precipitates. The substructure formed during continuous cycling without the introduction of hold is highly heterogeneous. The introduction of one minute tension hold during cycling resulted in a more well-defined cells. On increasing the tension hold time, dislocation substructure assumed configuration of well-defined equiaxed sub-grains.

■ GENERAL EXPLANATION RELATED TO DESCRIPTION

The fatigue life decreased with the introduction of hold and application of one minute compression hold period displayed a far more deleterious effect on the fatigue life than application of 1 minute hold under tension. Optical microscopy conducted on the longitudinal section of the tested samples, (1 minute tension and 1 minute compression) showed multiple crack initiation sites and oxidation assisted crack initiation and propagation (Fig. 3). It has been found that oxide layer spalls off during tension hold due to compressive stresses on them whereas the oxide layer cracks during compression hold due to tensile stresses. The data generated in IGCAR is compared with the best fit curve derived from the RCC-MR code for this steel at 823 K in Fig.4. All the data lie above the lower bound curve and thus it indicates RCC-MR curve can be safely used for design purposes.

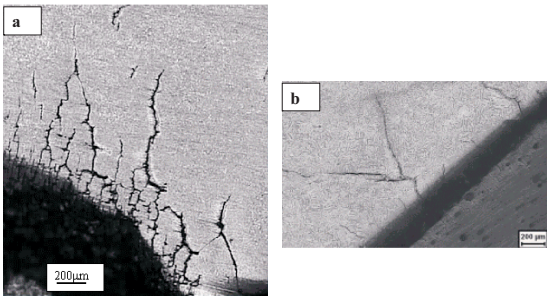

Fig. 3 : Optical Metallograph of fatigue tested sample, (a) 1 min. Compression hold and (b) 1 min. tension hold

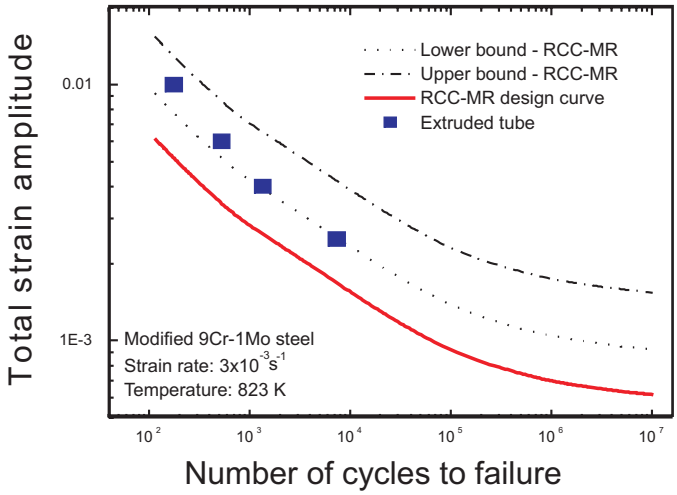

Fig. 4 : Comparison of data with RCC-MR

■ ACHIEVEMENT

This work has contributed to the data available on weldments of modified 9Cr-1Mo ferritic steel. The characterization of the deformation modes under fatigue, has added to the understanding of substructure evolution in this material.

■ PUBLICATIONS ARISING OUT OF THIS STUDY AND RELATED WORK

Vani Shankar, M. Valsan, K. Bhanu Sankara Rao, R. Kannan, S.L. Mannan and S.D. Pathak; *Mater. Sci. Eng. A*, **437** (2006) 413.

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