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Testing and assessment of cracking in P91 steels under creep-fatigue loading conditions

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ABSTRACT

Future green energy options dictate that renewable energy source must be utilized when available. This poses a challenge to conventional power plant, which has generally been designed for base-load conditions, as they now need to operate in a 'flexible' manner. This flexible operation, in high temperature power plant components, could lead to a combination of creep and fatigue crack growth failure. Thus a better characterization of interactive creep-fatigue crack growth behaviour is required especially for assessing long term failure in plant. The industrial codes, such as R5 or BS7910, treat this interaction using linear accumulation of damage. However, this does not consider the degradation of properties and reduction in creep ductility in long term operations and their effect on the subsequent creep/fatigue behaviour. In this work creep-fatigue crack growth (CFCG) tests were performed on compact tension specimen of P91 steel in the as received and ex-service conditions at temperatures ranging between 600 °C to 625 °C, with the hold-times ranging from static to 600 s. The experimental results in addition to appropriate data from the literature have been analysed using stress intensity factor range, ΔK appropriate under fatigue control and the creep fracture mechanics parameter C^* relevant under creep control. Scanning electron macroscopy (SEM) analysis confirms the influence of frequency on the mode of cracking. Within the scatter of experimental data for the present short term accelerated tests a linear cumulative damage rule can still predict the creep/fatigue interaction. However the effects due to low frequency cyclic loading as well as degraded the steel under ex-service conditions tending to reductions in creep ductility show factors of two or more faster cracking rates compared to as received static testing. Unavailability of long term tests at low stresses may pose additional problems under creep since creep is stress state controlled but fatigue in not. However using plane strain predictions of crack initiation and growth data using the NSW multiaxial ductility creep crack growth model suggest that conservative predictions of long term cracking can still be made under creep/fatigue and when there is a marked reduction creep failure ductility.

Abbreviations: a, crack length; a_0, a_f, initial crack length and final crack length measurements; Δa, amount of crack growth; $\dot{a}$, crack growth rate; A, creep constant; B, B_N, thickness and thickness with side groove; C^*, creep fracture mechanic parameter; da/dN, fatigue crack growth rate; da/dt, creep crack growth rate; D, ϕ, CCG power law coefficient and exponent; $\tilde{\varepsilon}_e(\theta, n)$, non dimensionless function of θ and n; ε_f, uniaxial creep failure strain; ε_f^*, multiaxial creep ductility; f, frequency; H, η, creep dimensionless coefficient; I_n, dimensionless integration constant; ΔK, stress intensity factor range; N, number of cycle; n, power law creep exponent; P, applied load; r_c, creep process zone size; T, temperature; t_i, creep initiation time; t_h, hold time; t_f, test duration; W, width; λ, p, fatigue material constant; $\dot{\Delta}$, Load line displacement rate

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