INFLUENCE OF WATER ENVIRONMENTS ON FRACTURE TOUGHNESS
OF AN A508 CLASS 3 FORGING

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INTRODUCTION

In the design of pressurised water reactors, use has
been made of J integral-crack growth resistance curves
(J-R curves) largely conducted in air at loading rates
faster than anticipated in service. In this study the
effect of water environments and loading rate on the
J-R of a pressure vessel steel is determined.

EXPERIMENTAL DETAILS

J-R curves were determined using DC potential drop on
50 mm thick sidegrooved compact specimen at 288 °C and
at one of four loading rates 5x10⁻¹, 5x10⁻², 5x10⁻³ and
5x10⁻⁴ mm/min. Tested were in air or one of three low
flow rate (20l/hr) water environments; simulated PWR
primary circuit water (0 < 5 ppb); simulated PWR water
plus 2 ppm sulphate; and Oxygenated (100 ppb) and
Sulphated (1 ppm) water. The final crack extensions were
predicted to within 8 %, except in PWR water at the
slowest loading rate where the technique was not success-
ful probably due to the formation of corrosion products.
Further details are given in Gibson and Druce (1).

RESULTS AND DISCUSSION

Figure 1 shows the effect of loading rate on the J-R
curves determined in air and the J-Δa points determined
in PWR water at the slowest loading rate. There is little
effect of loading rate except at the slowest rate.
Examination of the load-deflection curves revealed that
this latter effect was not due to a change of yield
properties, suggesting there is no effect of dynamic
strain aging. Examination of the fracture surfaces
revealed no effect of loading rate, with the average
dimple size the same at the fastest and slowest loading
rates (280 ± 20 and 270 ± 20 μm² respectively). However,
the Vickers hardness near the crack surface and thus the
fracture strain was higher for the slowest compared to
the fastest loading rate (258 and 223 VPN respectively).

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The effect of loading rate could be due to thermally activated plastic flow reducing the crack tip constraint at the slowest loading rate and thus increasing the strain for void growth.

Figure 2 shows the J-R curves determined in air and various water environments at a loading rate of 5x10^{-2} mm/min. It can be seen from figures 1 and 2, that there is little effect on toughness of PWR water environments, with or without additions of sulphate. Examinations of the fracture surfaces revealed that fracture was by microvoid coalescence in all cases. The effect of Oxygenated and Sulphated water was to lower the J-R curve, see figure 2. Examination of the fracture surfaces revealed that the crack growth occurred by a combination of quasi-cleavage and microvoid coalescence. The occurrence of quasi-cleavage explains the audible clicks and associated rapid changes in load and PD during these tests. The quasi-cleavage is probably due to hydrogen embrittlement.

CONCLUSIONS

Fracture toughness of an ASTM A508 class 3 steel at 288 °C was unaffected by the presence of simulated PWR primary circuit water, with or without additions of 2 ppm sulphate. However, in Oxygenated (100 ppb) and Sulphated (1 ppm) water the toughness was lowered and there were bursts of quasi-cleavage fracture augmenting microvoid coalescence. Loading rates over the range 5x10^{-1} to 5x10^{-3} mm/min had little effect on fracture toughness, but he toughness was higher at a loading rate of 5x10^{-4} mm/min.

ACKNOWLEDGEMENT

This work was part funded by the CEBG.

REFERENCE

Figure 1 Effect of loading rate on J-R curves

Figure 2 J-R curves determined at a loading rate of 5x10^{-2} mm/min