EFFECTS OF TEMPERATURE ON OVERLOAD RETARDATION IN 9%Cr 1%Mo STEEL

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INTRODUCTION

One of the main uses for 9Cr 1Mo is as piping steel in the steam generator of the Commercial Demonstration Fast Breeder Reactor. There, it is exposed to a temperature of 525°C and low stress, high frequency thermal fatigue, as well as occasional high load excursions on start-up and shut-down. This makes a study of the effect of such overloads in retarding fatigue crack growth of great interest.

There are several possible explanations of overload retardation. Christensen (1) proposed crack tip blunting followed by re-initiation as the cause, while Jones (2) thought it due to residual stress fields and strain hardening, reducing the plastic strain range at the crack tip, Elber (3) cited plasticity induced closure as a probable mechanism, and Suresh (4) suggested that it was a result of crack deflection, causing a decrease in mode I loading and enhanced roughness induced closure. The latter two explanations, involving closure, allow for delayed retardation, where the minimum growth rate does not occur immediately after overload (fig. 1).

EXPERIMENTAL

All tests were carried out on a 30KN servo-hydraulic machine equipped with an environmental chamber. The material, in the form of S.E.N. bend specimens, was tested in four-point bend under load control. A crack was grown through the specimen at a constant Kmax of 12MPa$\sqrt{m}$, a frequency of 20Hz and at R = 0.1. The crack length was monitored using a d.c. p.d. technique, allowing computer control of the loads. The programme was interrupted every 2 or 3mm for an overload (Kol) to be applied, after which, the baseline loading was recontinued. Data were collected at temperatures of 25°C, 225°C and 525°C, for a number of Kol/Kmax values.

RESULTS AND DISCUSSION

The two most common parameters used in interpreting overload data are Ar; the length of affected crack growth after the overload, and Nd; the number of cycles by which the overload extends the specimen life. The latter is misleading however when comparing overloads at different crack growth rate (e.g. 25°C and 525°C) and hence a new parameter Nol/Nbl has been defined. This is the ratio of the life of the specimen over the 2mm after

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overload to its life had there been no overload, and Nol/Nbl and aR are plotted against Kol/Kmax at each temperature in figures 2 and 3.

As expected, crack growth retardation at all three temperatures became more severe as the overload ratio was increased. All overloads resulted in delayed retardation, and curve fitting of the data shows that aR is proportional to $(Kol/Kmax)^2$ and hence, the plastic zone size. There was no obvious crack deflection and all these observations indicate that plasticity induced closure is the primary retardation mechanism operating.

The data also show that crack retardation is more severe at lower temperatures, most notably for greater overloads, where in some cases the crack was totally arrested (Kol/Kmax = 4 at 225°C and Kol/Kmax = 3 and 4 at 25°C). This cannot be explained by consideration of plastic zone sizes, which are smaller at lower temperatures, due to a higher yield stress. Stress relief or creep of the material at high temperature could account for the observations, but this is unlikely at such a high frequency. More likely is that softening of the material at high temperature results in smearing of fracture surface asperities at points of contact, which reduces closure. Evidence of this was observed in specimens tested at 525°C (fig. 4). Smearing mostly occurs in the plane stress region at the edge of the specimen, where the plastic zone size is greatest.

CONCLUSIONS

(1) Increasing overload ratio prolongs crack growth retardation.
(2) The length of affected crack growth, aR, has a linear dependency on plastic zone size.
(3) Retardation is reduced at higher temperatures.
These findings and the delayed character of the retardation suggests that the primary mechanism involved in this case is plasticity induced closure.

REFERENCES

(1) Christensen, R.H., "Metal Fatigue", McGraw-Hill, New York (1959).
(2) Jones, R.E., Eng.Fract.Mech. Vol 5 (1973) pp 585.
(3) Elber, W., ASTM STP 486, (1971), pp 230.
(4) Suresh, S., Eng.Fract.Mech. Vol 18 (1983) pp 577.

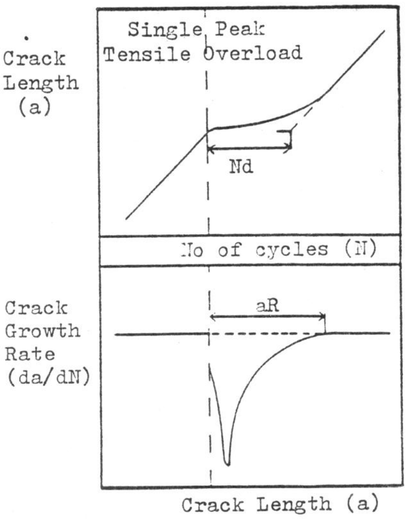

Figure 1 Growth of a Crack During a Delayed Retardation.

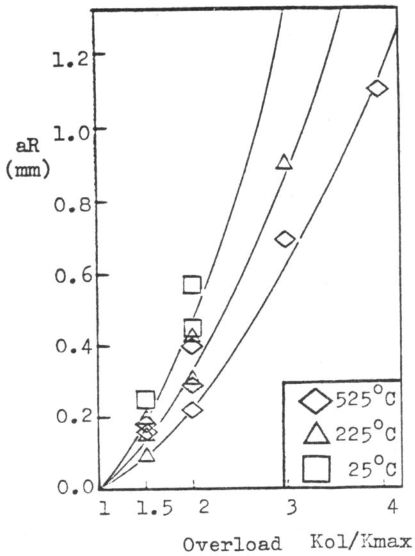

Figure 2 Variation of aR with Overload Ratio.

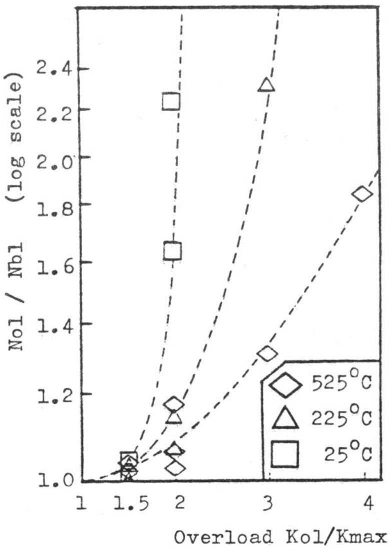

Figure 3 Variation of Nol/Nbl with Overload Ratio.

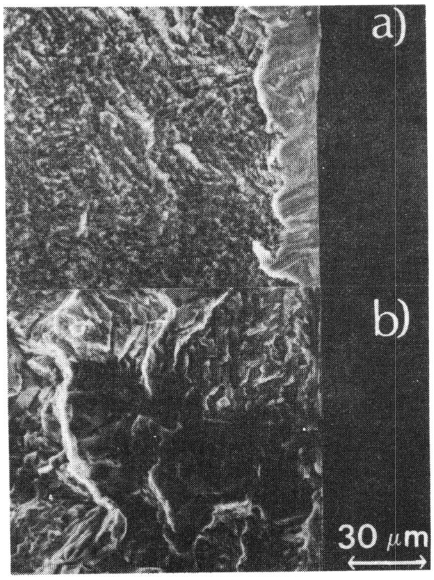

Figure 4 Fatigue after an Overload at a) 525°C & b) 25°C.