FATIGUE CRACK PROPAGATION IN A SINGLE CRYSTAL SUPERALLOY AT ELEVATED TEMPERATURES

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INTRODUCTION

The safe utilization of single crystal turbine blades requires the development of new life-prediction procedures. These must take account of the possible growth of cracks during the service life of the blade, and detailed studies of the micromechanisms of deformation at crack tips are important in this context.

A comparison has been made of fatigue crack propagation mechanisms in SRR99 single crystals in the form of Compact Tension (CT) specimens and in Corner Crack Tension (CCT) specimens. Micromechanisms of crack propagation have been compared in tests at room temperature, 650°C and 850°C, including a study of the crack tip plastic zones at known stress intensities by means of Selected Area Channelling Patterns (SACPs) (1).

EXPERIMENTAL MATERIAL & METHODS

CT and CCT specimens (fig.1) of SRR99 have been prepared, with nominal composition (wt %) 5.5 Al, 2.2 Ti, 8.5 Cr, 5.0 Co, 2.8 Ta, 9.5 W, 0.015 C, balance Ni. All crystals were of 100 axial orientation and were solution-treated for 4 hr at 1300°C, then aged 1 hr at 1100°C and 16 Hr at 870°C. This produces a homogeneous microstructure of 80% of fine cuboidal γ' with edge lengths of 250 nm.

All fatigue tests were conducted under constant load amplitude using a triangular waveform at $R = 0.1$ with crack growth monitored by a DC potential drop technique. Tests on CT specimens were interrupted at $\Delta K = 22$ MPa$\sqrt{}$m, sectioned on their mid-plane, examined in the SEM and the size of the crack-tip plastic zones measured (1).

RESULTS AND DISCUSSION

Fig.2 shows two FCGR curves obtained at 850°C, 0.1 Hz with a CT and a CCT specimen. It is seen that the CT specimen exhibits a higher threshold and lower FCGR at low ΔKs. At intermediate ΔKs the two curves merge, and a similar effect is observed at a test frequency of 10 Hz. It is considered that this difference arises from the differences in crack lengths, which was 0.25-0.5mm in the CCT and 1.5-2.5 mm in the CT specimens. This will lead to differences in roughness- and oxide-induced closure, and this is in agreement with fractographic evidence.

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Figs.3 and 4 compare FCGRs at 0.1Hz and 10Hz of CT and CCT specimens respectively at 850°C. In both cases FCGR decreases with decrease in frequency at low ΔKs due to oxide-induced closure. At intermediate ΔKs the effect is reversed, and a similar effect has been reported in MAR M002 by Crompton and Martin (1) who suggest that material ahead of the crack tip is embrittled by environmental exposure, leading to accelerated growth at low frequencies.

At room temperature Stage I crystallographic failure occurs. Fatigue at 650°C 10 Hz leads to Stage II cracking in CT specimens but in CCT specimens a sudden change to Stage I occurs after initial growth in Stage II. If this frequency is close to the critical frequency for the change from Stage I to Stage II cracking, the model of Leverant and Gell (2) would suggest that at short crack lengths (low ΔK) the dislocations recover from the slip bands faster than the crack can grow along them, so Stage II cracking occurs. At longer crack lengths da/dN (and da/dt) are faster in the CCT specimens, so the switch to Stage I cracking becomes possible because the crack propagates at a rate which exceeds the rate of dislocation recovery out of the band.

The measured crack tip plastic zone sizes (+/- 2 μm) at a ΔK of 22 MPa √m were 13 μm at 25°C and 650°C(10 Hz and 0.1 Hz) suggesting that little time-dependent deformation is occurring. At 850°C the size was 21 μm at each frequency, and the change in dimension is fully accounted for by the change in yield stress with temperature.

CONCLUSIONS

1. Lower thresholds occur in CCT than in CT specimens, and this is due to reduced closure in the former.

2. At 650°C CT specimens show Stage II and CCT show mixtures of Stage II and Stage I cracking. The latter operates when the crack propagates at a rate exceeding the rate of dislocation recovery out of the slip band.

3. At 850°C the intermediate FCGR increases with decreasing frequency, possibly due to oxide embrittlement ahead of the crack tip.

REFERENCES

(1) Crompton, J.S. and Martin, J.W., Mat.Sci.Eng.,Vol.64, 1984, pp 37-43.

(2) Leverant, G.R., and Gell, M., Met.Trans. Vol.6A, 1975,pp.367 - 371.

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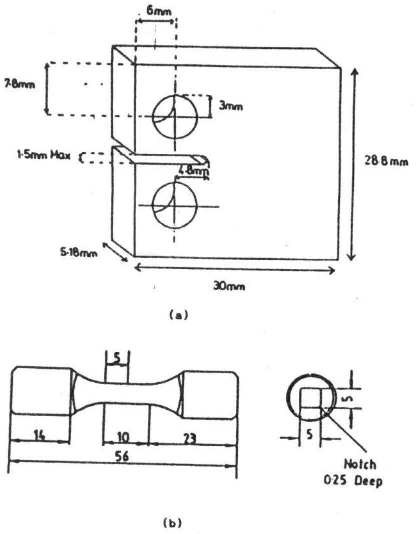

Fig.1 (a) CT specimen, (b) CCT specimen. Dimensions in mm.

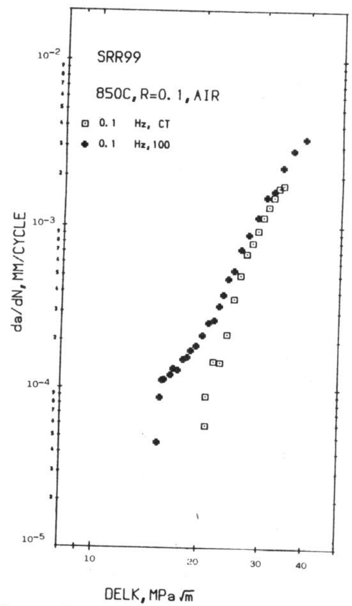

Fig.2. FCGR curves for CT and CCT specimens at 850°C, 0.1 Hz.

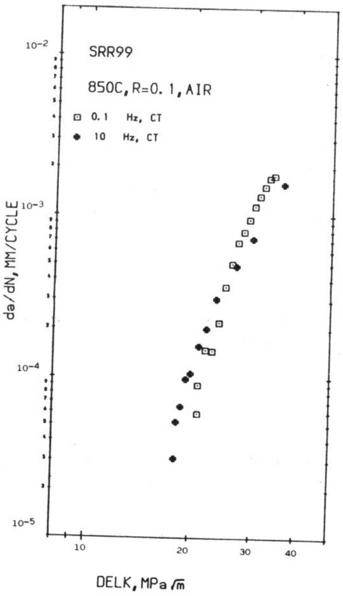

Fig.3. FCGR curves at 850°C, 0.1 Hz and 10 Hz for CT specimens.

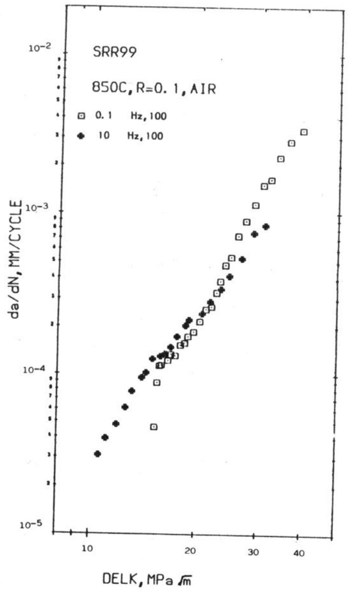

Fig.4. FCGR curves at 850°C, 0.1 and 10 Hz for CCT specimens.