INFLUENCE OF TIME DEPENDENT MECHANISMS ON FATIGUE CRACK GROWTH IN A SINGLE CRYSTAL NICKEL-BASE SUPERALLOY

G.Onofrio, S.H.Ai, V.Lupinc, G.Vimercati*

The influence of microstructure, hold time and environment on the fatigue crack initiation and propagation behaviour of CMSX-2 single crystal superalloy has been studied at ambient and elevated temperature (750 and 950°C), respectively. At 750°C microstructure had no discernible influence on fatigue crack propagation behaviour while at 950°C crack growth was faster in the rafted material. The inclusion of a hold time at peak load produced significant decrease of crack growth rate in air.

INTRODUCTION

The main damaging mechanisms to take into account in designing single crystal turbine blades are creep and low cycle fatigue, but fatigue crack initiation and propagation processes may also be of interest, in particular during thermal transients.

In single crystal specimens, fatigue crack propagation can be influenced by crystal orientation (1), temperature and cycling frequency (2,3) as well as microstructure (4). Howland and Brown (1) and Anton (4) reported that {111} planes fatigue fractures were favoured at room temperature, while fatigue crack growth at high temperature occurred mainly on (001) planes. Studies of high temperature thermomecanically treated, i.e. rafted γ', specimens showed a decrease in mechanical resistance if compared with the non rafted material. In particular flow stress (5) and creep strength (6) resulted reduced in rafted single crystals, while no effect of microstructure was

* CNR-ITM, Via Induno 10, 20092 Cinisello B., Italy

observed on life under strain controlled fatigue conditions (3).

In this work the fatigue crack propagation at 750 and 950°C was studied in CMSX-2 superalloy for two different microstructures, i.e. cuboidal and rafted γ'. The influence of time dependent mechanisms has been investigated at 950°C using different wave shapes and environments. The time dependent behaviour has been explored adding a hold time period to the triangular fatigue cycle while the oxidation effect has been studied comparing air and vacuum tests.

MATERIAL AND EXPERIMENTAL PROCEDURE

The single crystal bars of CMSX-2 cast and solution treated by Thyssen, had the following chemical composition (wt. %):

Cr	M	Ti	Ta	W	Co	Al	Ni
7.9	0.6	0.99	6.0	7.9	4.6	5.58	balance

Ageing of 1080°C/4 h + 870°C/20 h (ST) led to a dispersion of coherent cuboidal precipitates of 0.5 m average size. The rafted γ' structure was obtained adopting a thermomechanical treatment (TMT)of 24 h at 1050°C under a tensile stress of 120 MPa.

Single edge notch specimens with 11.7 x 4.4 mm^2 cross section, supplied by Alfa Romeo Avio, were machined within 10° off the [001] orientation. A 1 mm deep notch with 0.05 mm radius at the crack tip was then machined. Fatigue crack propagation tests were performed on a servohydraulic testing machine, in load control at 750 and 950°C with triangular waveshape at frequency of 4 Hz (R = 0.05). Some tests have been performed adding a 5 s hold time at maximum load to the triangular wave at 950°C both in air and vacuum (10^{-3} Pa). Crack length was measured using the d.c. potential drop technique and the crack growth rates were calculated adopting the incremental polynomial procedure. The fractured specimens have been sectioned parallel to the applied stress and crack propagation directions and prepared by standard metallographic techniques in order to observe the relatonship between fracture and microstructure.

EXPERIMENTAL RESULTS AND DISCUSSION

Fatigue crack propagation (FCP) rates at 750 and 950°C as a function of ΔK are reported in Fig. 1 for the different microstructures at a frequency of 4 Hz. At the higher temperature the rafted γ' material shows less FCP resistance than the standard one, whereas negligible influence of the thermomechanical treatment was found at 750°C. These results are consistent with the fractographic observations that show similar fatigue propagation mechanisms in both materials at 750°C. At 950°C different fracture morphologies are apparent depending on the microstructure. In the standard material at low ΔK the crack grows along (001) planes (Fig. 2). When ΔK increases some crystallographic facets appear on {111} planes specially at the near-surface region and this type of fracture prevails at high ΔK (Fig. 2).

The FCP of the thermomechanically treated material does not show any cristallographic features. At low stress intensity range the fracture surface is flat (Fig. 3) while at high ΔK values some asperities, but without any cristallographic features, can be found on the fracture surface.

The difference in crack growth rates measured for the two materials at 950°C can be explained in terms of roughness induced closure at the crack tip. The presence of significant roughness in the fracture surface of standard material, associated with secondary cracks (Fig. 4) could explain its lower crack growth rate if compared with rafted material. Results of air and vacuum hold time tests are reported in Fig. 5 for standard and Fig. 6 for thermomechanically treated material. In these figures the data obtained at high frequency are also reported for comparison. In both microstructures the addition of a hold time period at maximum stress during air tests causes a marked decrease of the fatigue crack propagation rates that become very similar for both standard and rafted γ' materials.

This results can be explained in terms of oxide induced closure. In the air tests oxide layers form on crack faces enhancing crack closure (Fig. 7,8). In these conditions FCP mechanism is completly controlled by the oxidation behaviour of the alloy and therefore it does not depend on microstructure. Hold time tests in vacuum have shown only slightly higher crack propagation rates than those measured in air with triangular wave shape; supposing no oxidation effect is operative in air tests the influence of creep on fatigue crack propagation rates seems to be negligible in the explored experimental conditions. Comparing air and vacuum tests a ratio between ΔK_{eff},operating in presence of closure mechanisms, and ΔK of about 0.5-0.6

can be estimated.

CONCLUSIONS

The influence of microstructure and time dependent damaging mechanisms on fatigue crack propagation resistance of CMSX-2 single crystal have been evaluated at 750 and 950°C. The main results obtained employing different test conditions are:

- At 4 Hz triangular wave the FCP rate of rafted γ' material increases and the threshold stress intensity decreases when raising the temperature from 750 to 950°C. Nearly no effect of temperature has been found in standard material.
- In air hold time tests, the FCP rate is about one to two orders of magnitude lower than in the triangular tests, depending on microstructure. This effect has been attributed to oxide closure at crack tip.
- In vacuum hold time tests the FCP rates are very close to those obtained in air with triangular wave shape.

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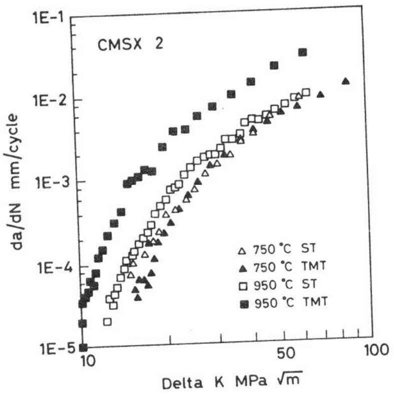

Figure 1 Effect of heat treatment and test temperature on FCP rate.

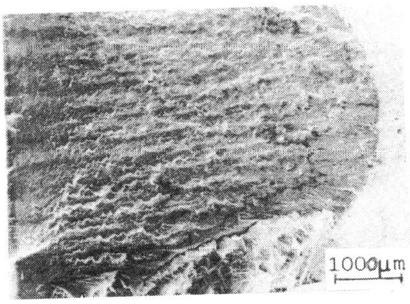

Figure 2 Fracture surface in the ST material tested at 950°C.

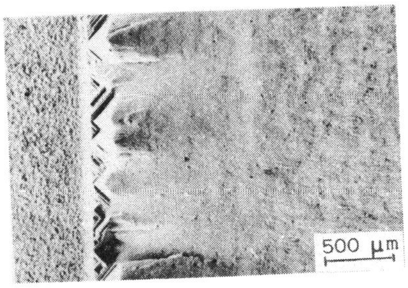

Figure 3 Fracture surface in the TMT material tested at 950°C.

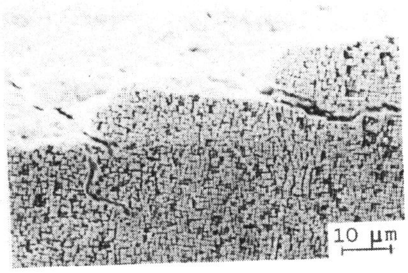

Figure 4 Fracture surface at 950°C with secondary cracks in ST material.

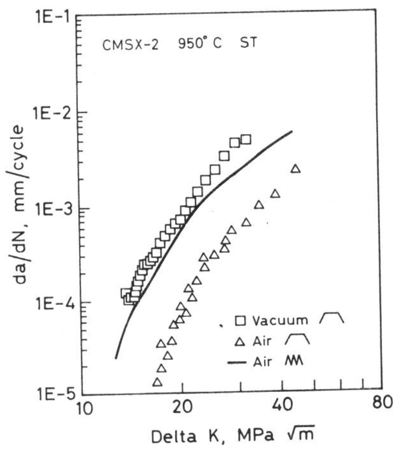

Figure 5 Effect of hold time on FCP rate in the ST material.

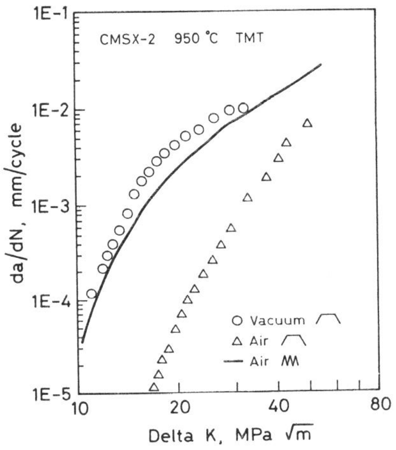

Figure 6 Effect of hold time on FCP rate in the TMT material.

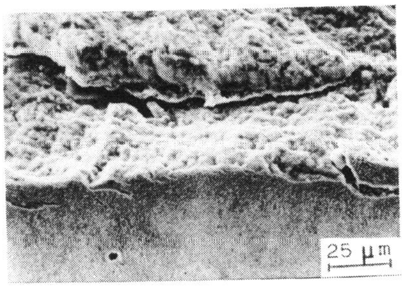

Figure 7 Oxide layer on fracture surface of ST material tested at 950°C.

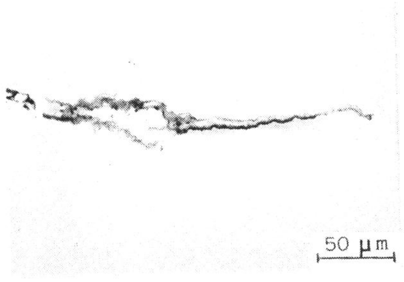

Figure 8 Oxidized secondary crack in ST material tested at 950°C and hold time.