THE PROPAGATION OF SMALL TRANSGRANULAR SURFACE CRACKS IN HIGH-TEMPERATURE LOW-CYCLE FATIGUE

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INTRODUCTION

The propagation of small fatigue cracks has yet to be studied in any detail at high temperatures (Bressers et al (1), Ohtani (2)). The motivation for this study was the suggestion of Laanemäe et al (3), based on indirect evidence, that the dependence of the propagation of small transgranular cracks on cycle shape controls the cyclic lifetime of Alloy 617 in low-cycle fatigue (LCF) at 700°C.

EXPERIMENTS AND RESULTS

Details of the experiments are reported by Hurta (4). LCF tests were performed in air at 700°C on electropolished specimens of Alloy 617 (Ni-23%Cr-12%-Co-9%Mo-0.07%C). The mean grain diameter was 250 µm. Two types of cycles were applied: "S", at constant strain rate, and "H/T/C", where creep at constant stress alternates between tension and compression. The plastic strain range was held constant at 0.6%. Both cycle types produce transgranular fatigue crack propagation in Alloy 617 (3). The cycle times were about 65 s. Strain rates and stress levels were similar: For S, 10^{-4} s^{-1} and about 450 MPa; for H/T/C, 400 MPa and about $5 \cdot 10^{-5}$ s^{-1}.

The tests were interrupted at regular intervals. Lacquer replicas were made of the surfaces, sputtered with gold, and studied in the SEM, where surface crack lengths greater than 5 µm could be resolved. The cyclic lifetimes (S, about 1050 cycles; H/T/C, about 1200 cycles) were the same as in uninterrupted comparison tests.

Most cracks stopped once or several times at different stages of the test, some for hundreds of cycles, and then began to grow anew. The first arrest usually occurred at lengths much less than the mean grain diameter; these cracks were found to have stopped at twin boundaries. Often, especially in the H/T/C test, several arrested cracks would link up with a propagating crack, which produced sudden increases in the crack length and propagation rate. In the S test, the length of most cracks is less than the mean grain diameter, and only a few longer cracks develop. In the H/T/C specimen, many cracks attain a length of several grain diameters.

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The effect of cycle shape is best elucidated by considering, for a particular region of the specimen, the change in length of each crack throughout the test. The most convenient representation is a plot of the distribution of crack propagation rates observed for all cracks in a given range of crack lengths against the crack length (Fig. 1). The growth of cracks less than one grain diameter in length is not affected by the cycle shape. Longer cracks have higher maximum and mean propagation rates.

The cycle shape influences cracks longer than one grain diameter. All of these cracks propagate in an S test. In the H/T/C test, many of these cracks still stop, so that the minimum rate remains zero for all crack lengths. The maximum propagation rate remains the same for both tests, up to a crack length of about 1 mm. The mean value of the crack propagation rate at longer crack lengths rises much more rapidly in the S than in the H/T/C tests.

DISCUSSION

In the Alloy 617 at 700°C, only cracks smaller than one grain diameter show small crack behaviour, which is independent of cycle shape. Twin boundaries are an additional barrier to crack propagation, arresting cracks inside the first grain. However, cracks which succeed in breaking out of the first grain show a marked dependence on the cycle shape. The data suggest that, in the S tests, it is very difficult for a crack to break through one or perhaps two grain boundaries. However, once the crack becomes longer than this, it can no longer be arrested. In the H/T/C test, much longer cracks are still stopped. This suggests that it is actually more difficult for the H/T/C cracks to break through a barrier than for the S cracks. It has been suggested (3) that crack linking is the most important mechanism producing long cracks in an H/T/C test. The maximum propagation rates reveal that cracks can grow as fast in H/T/C tests as in S tests. Presumably this is because they are growing inside a grain. Once they reach the grain boundary, they are forced to wait until they link up with other cracks, hence the mean crack growth rate is lower in H/T/C tests.

CONCLUSIONS

In Alloy 617 at 700°C, cycle shape does not affect the propagation of cracks less than one grain diameter long, which can be arrested by twin boundaries. In S tests, the few cracks that can break out of the first grain always continue to grow. In H/T/C tests, cracks break out of grains by a linking process, but are stoped at subsequent grain boundaries and can only continue to grow further by linking, until their length exceeds several grain diameters.

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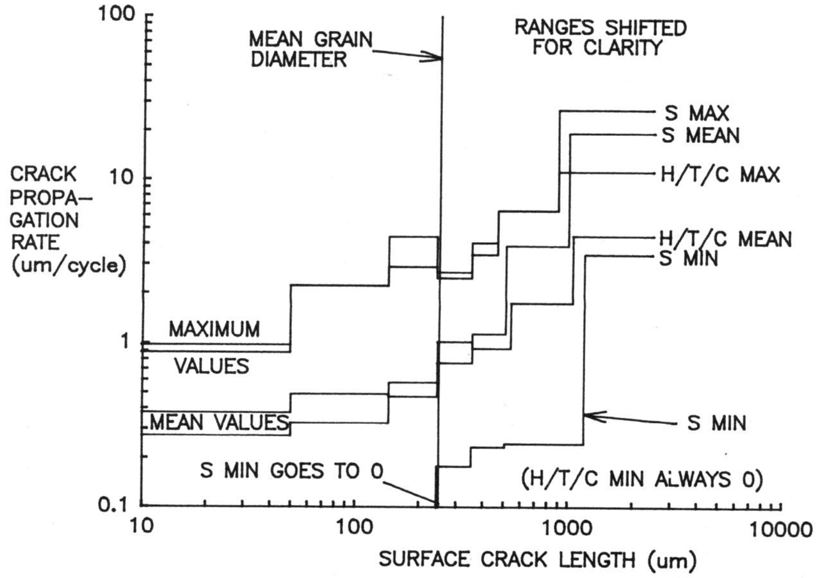

Fig. 1. Distribution of crack propagation rates for the indicated range of crack lengths, plotted against the crack length.