研究課題：高機能表面改質処理による高疲労強度材料の開発

The Effect of the R Ratio on the Number of Delay Cycles Following an Overload

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Introduction

That an overload can lead to a reduction in the rate of fatigue crack propagation at an R ratio of 0-0.1 has been known for almost fifty years. Only recently has it been shown that a 100% overload at higher R values ranging up to 0.7 can result in a similar effect on fatigue crack growth behavior (1). Crack closure measurements showed that the rate of fatigue crack propagation following an overload was related to the extent of crack closure resulting from the overload. The present study extends this recent work to higher R values, i.e., 0.9, and also extends the range of overload values studied up to 300%. In addition a 3-D finite element program (MARC) was used to complement the experimental program. In view of its significance in past studies, the role of crack closure on the delay phenomenon was investigated in detail.

Number of delay cycles

The number of delay cycles for several overload levels were investigated as a function of the R value. For a given % overload, N_D was clarified as a function of the R value. For R values of less than 0.6, N_D is independent of the R value. However for an R value of 0.7, for 100 and 200 % overloads, there is decrease in N_d. For R values of 0.8 and higher this decreasing trend is reversed and N_d increases to the point where complete crack arrest can occur. An increase of the % overload level to 300% also results in complete crack arrest.

3D FEM analysis

The 3D FEM analysis was used to determine the crack opening procedure in the overload plastic zone. In all cases the analysis indicated that the loading point was the last to open.

A relatively good match was achieved in both cases, and that the variations in da/dN in the overload zone were directly related to variation in K_{op}, i.e., crack closure is responsible for the observed behavior. The number of delay cycles, N_D' was determined in the FEM program by integration the rate equation between the limits of 0 and the OLPZS. The FEM results for N_D at overload levels of 100 and 200% agreed well with the experimental results.

Discussion

Crack opening point.

The 3D finite element program indicated that or all overload test conditions the last portion of the crack to open was at the point of the overload. That the crack tip always opened before the overload point did, and the crack tip did not become the last point to open until the crack emerged from the overload affected zone. The view that emerged from Bao's work was that at short distances up to approximately 25% of the overload affected zone the last point to open was at the overload point. For larger crack penetrations, where the retardation in crack growth was still pronounced, into the zone the last point to open was at the crack tip. However a 3D FEM analysis carried out by which considered Bao's test conditions found that the crack always opened last at the point of the overload.

SEM studies

There is disagreement between FEM studies and experimental findings with respect to the crack opening process as the fatigue crack passes though the overload zone. The FEM results often indicate that the last point to open when the crack is within the overload zone is located at the point of the overload. On the other hand, Bao has observed using a SEM that for 0.3 mm thick specimens of 9Cr-1Mo steel that when the crack had penetrated 30 % through a 1 mm wide overload zone created by a 100% overload, and the specimen was loaded to the crack opening level, the crack at the point of the overload was clearly open, whereas the crack at the tip was still closed.

Conclusions

The effect of an overload on the rate of fatigue crack propagation has been extensively studied at R ratios of the order of 0-0.1, but relatively little is known about the effect an overload at much higher R ratios, i.e. up to 0.9. To provide information on the effect of the R value on delay behavior, the present experimental and FEM study has been carried out. The following results were obtained.

(1) Both the experimental and the analytical results show that the delay phenomenon is found at all R values, and perhaps surprisingly, for a given overload ratio, the number of delay cycles in a compact specimen is greater at R = 0.9 than at 0.1.

(2) Over the complete range of R values the delay phenomenon is shown to be caused by overload-induced crack closure.