STUDIES ON MIXED MODE CRACK PROPAGATION

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Mixed mode crack propagation studies were carried out on D16AT Al alloy. A compact tension specimen and a Richard's type loading device were used in order to obtain Mode I and Mixed Mode loading. Specimen and loading device were subjected to uniaxial tensile stress. The experiments were carried out in both Static and Fatigue loading. The angle of crack propagation(θ) was found in both the cases. Critical load to failure in Static loading and crack propagation rate in Fatigue were studied. These findings were compared with the results of SED and MTPS criterion.

INTRODUCTION

The experimental investigations of the mixed mode crack problems which have been carried out till now have not been sufficient to obtain greater clarity. Additional experimental verifications will therefore be required to bridge the gap between experimental and theoretical predictions.

The criteria available up to now for mixed mode fracture has been divided into two groups. One is based on the stress field existing just before unstable crack propagation of crack would occur and other is energy release rate theory based on energy equilibrium. For example, Maximum Tangential Stress Criterion(MTS)(1), Maximum Tangential Strain Criterion(MTSN)(2), Maximum Tangential Principal Stress Criterion(MTPS)(3), Strain Energy Density Criterion(SED)(4) and T Criterion(5) belong to the former, Griffith-Irwin Energy Criterion(6) belongs to the latter. Good amount of literature is available in the case of static loading. In the case of fatigue loading, only few

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papers are available. The growth of Fatigue cracks under mixed mode loading at different conditions were studied by Iida and Kobayashi(7), Roberts and Kilber(8), Tanaka(9), Toor(10); Sih(11) extended the SED theory for mixed mode Fatigue loading. By using SED approach Hills and Ashleby(12), Badaliance(13), Au(14), Patel and Pandey(15) predicted the propagation rate for different conditions.

Good amount of experimental data is available in the case of static loading but few findings are available in the case of Fatigue loading. Erdogan(1), Roberts(8), Pustejovosky(16), Chinadurai et al(17), Richard(18), Henn et al(19) conducted experiments on mixed mode Fatigue loading. The present investigation has been carried out with Compact Tension Shear(CTS) specimen of D16AT Al alloy with the help of Richard's type loading device to study the effects of fracture angle, critical load, crack propagation rate in the mixed mode loading. These results have been compared with MTS, SED and also with the experimental results of Richard(18), Henn et al(19).

MATERIAL

D16AT Al alloy which is an aircraft material was used for this purpose. The material properties have been found by performing the tension test as per ASTM Std E8(19).

0.2% proof stress	=	294.3 MPa,
Young' modulus	=	65255.14 MPa,
Fracture toughness	=	31.022 MPa $m^{1/2}$

Composition

Al main constituent
Cu 4.3%, Mg 1.5%, Mn 0.6%
Traces of Si, Fe, Zn were found.

Specimen and Loading Device

In the present work a Richard's type loading device, along with a CTS specimen was used. Different angles (0°-90°) can be obtained by changing the position of loading device(18). The specimen was held in position in the loading device with the help of 6 studs. The specimens were prepared from the sheet in such a way that the crack was perpendicular to the rolling direction.

Pre-cracking was done by Fatigue cycling at a frequency of 8 cycles/sec and at a load level of R = 0.1 under mode I as per the ASTM Std E399(20).

EXPERIMENTS

After generation of mode I pre crack the specimens were subjected to pure mode I and mixed mode in both Static and Fatigue loading. The Static and Fatigue tests were performed on MTS testing machine. The Fatigue tests were performed at R = 0.25, under the frequency of 3 cycles/sec. In all the Fatigue tests the maximum load was kept as 8.829 N. In the Static loading the instant at which crack initiates and crack initiation angle were noted. In the case of Fatigue loading the crack was monitored with the help of a travelling microscope at a regular interval.

RESULTS

The angle of crack propagation(θ) as a function of crack angle (β)was measured experimentally in both Static and Fatigue loading. In Fig.2 both the experimental results of Static and Fatigue were compared. The fracture angle measured under Static loading is slightly less than that of Fatigue loading.

In Figs.3 and 4 the predictions made by MTPS and SED were compared with the experimental results of Static and Fatigue loading respectively. In the case of Static loading experimental results matched well, whereas in Fatigue case at smaller angles the results of SED and experimental results differed. In the same figure the experimental results of Richard's also are shown.

The critical load needed for crack propagation, reduced to its value for β = 90° are shown in Fig.5 along with the theoretical predictions of SED and MTPS criterion. For angles up to 60° no deviation was observed. But for smaller angles the experimental results deviated considerably.

In the Fatigue loading the crack propagates in a zig zag manner whereas in Static loading it is curved and smooth. In mixed mode loading in no case the crack followed the self similar path but after some amount of growth in the mixed mode direction it approached the mode I direction. The same thing was noticed even in the case of theoretical prediction.

Fig.6 gives the variation of number of cycles to failure to crack angle at load ratio R = 0.25. It has been observed that the number of cycles required for failure found to increase as the crack angle decreases from 90°-30°. The increase is considerable at angle 30°. Fig.7 shows the variation of crack growth rate with crack angle. The crack growth rate is found to decrease as the crack angle increases from 30°-90°.

Fig.8 gives the variation of crack growth rate da/dn with the strain energy density factor range. It has been found that the predictions made by SED theory(15) is over-estimating the experimental results.

CONCLUSIONS

The angle of crack propagation was compared for both Static and Fatigue loading. It has been noticed that the fracture angle's of Static loading were slightly less than that of Fatigue loading. These were lying in the close range when compared to the predictions made by MTPS and SED theory except small deviation in the case of Fatigue loading with SED theory.

Critical load required for propagation was found to be matching well at higher crack angles but deviation was observed at smaller crack angles.

The number of cycles required for failure was found to decrease as crack angle increased and da/dn increased as the crack angle increased.

The comparison of theoretical predictions with experimental results for da/dn with ΔS shows that the theoretical predictions is overestimating the experimental results. So some modification is needed in this case.

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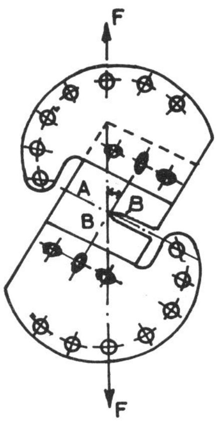

Figure 1 Specimen and loading device

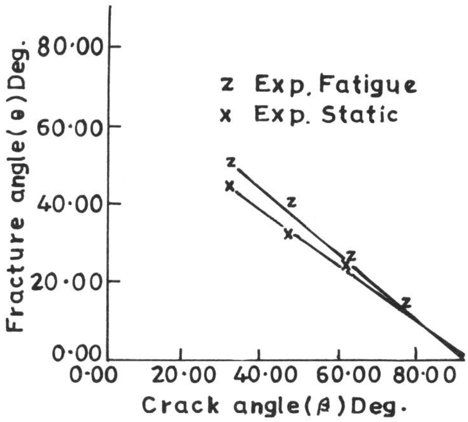

Figure 2 Comparison of Static and Fatigue results

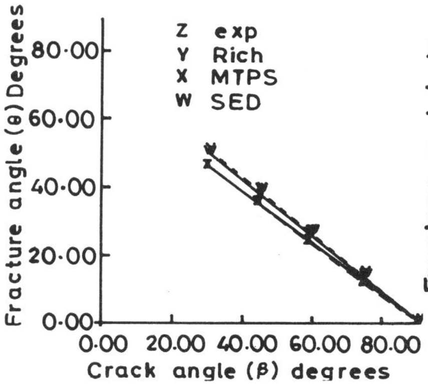

Figure 3 Comparison of Static with MTPS and SED theory

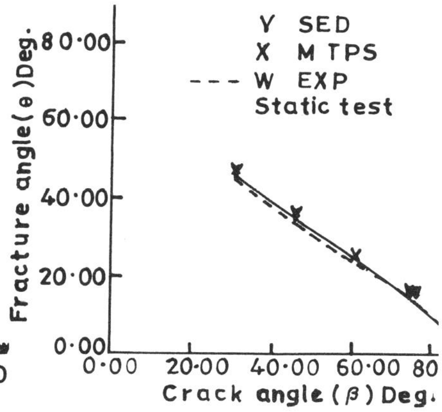

Figure 4 Comparison of Fatigue with MTPS and SED theory

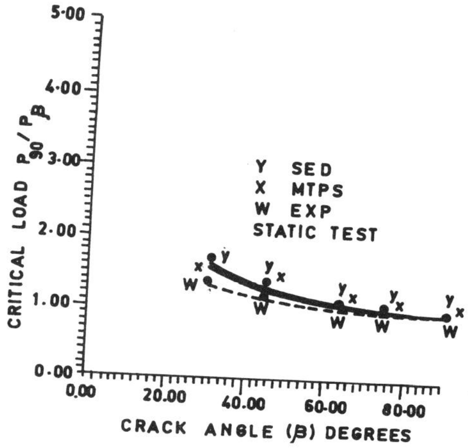

Figure 5 Comparison of Experimental PCR with MTPS and SED

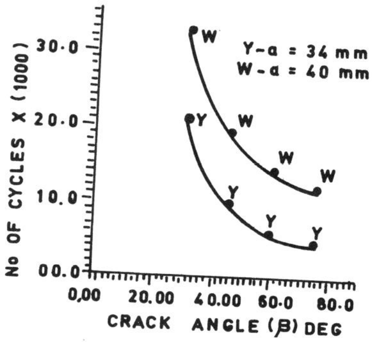

Figure 6 Variation of no. of cycles to failure with β

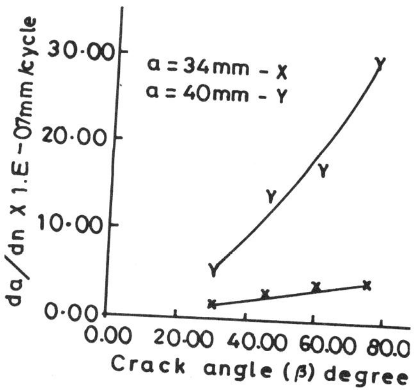

Figure 7 Variation of da/dn with crack angle β

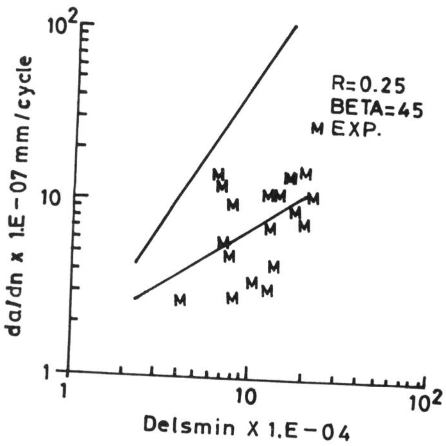

Figure 8 Variation of da/dn vs ΔS