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Fatigue analysis of crack growth rate and path in aluminium alloy 2024-t3 under mix mode loading

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***Abstract* - These paper methods for estimating fatigue crack growth (FCG) under mode I, mixed mode I/II loading. The experimental part of the study consists of fatigue crack growth on thin plate. For the above specimen types, both Mode I and mixed mode FCG tests are first performed. To find fatigue crack growth path in aluminium alloy 2024-T3 plates under constant amplitude loading (CA). The tests were performed on a standard servo hydraulic fatigue testing machine (MTS810).Find fatigue crack growth path. Further FEA analysis is done by XFEM based algorithm available in the finite element code ABAQUS is explored with respect to its performance in estimating crack growth paths. FEA software version (ABAQUS/CAE 6.13.1) is used and the results suggest that using mode I, mode I/II experimental data, both experimentally and FEA analysis estimation of pure mode & mixed mode fatigue crack growth is possible.**

***Key words* - mix mode crack growth, crack path, XFEM**

I. INTRODUCTION

Cracks initiated in structural components subjected to multiaxial stress state, in welds, or flaws originated at manufacturing defects in forged or cast members, which are originally randomly oriented, can reveal some amount of mixed mode growth prior to become aligned with one of the principal stress planes. The assessment of such defects, including fatigue crack propagation stage, may follow rules established in fracture mechanics guidelines,[1-2].

An experimental investigation is carried out to study the influence of compressive loading cycles on the crack propagation response of AM60B magnesium alloy. The relation between the residual plastic zone size and crack propagation rate is critically examined, in this experiment different load ratio condition crack growth and length are measured. [14]

This paper fatigue crack growth under variable amplitude loading in a real structure is modelled using an elastic–plastic finite element analysis It can be shown that due to an overload depending on the overload ratio R and the mode I/mode II ratio plastic deformations occur, Richard equation is used to find stress concentration factor to CTS specimen It can be concluded that due to a mode I overload plastic deformations along the crack surfaces occur.[5]Whereas subsequent calculation procedures essentially rely on material data derived from Mode I crack tests. Comprehensive surveys of theoretical approaches, experimental techniques and examples of fatigue crack growth (FCG) evaluation under mixed mode conditions can be found elsewhere[5'6]. In particular, numerous investigations have been devoted to establish criteria and solutions for determining the crack propagation angle in mixed mode, as well as to develop numerical techniques for simulating crack growth in complex structural components and stress fields Inherently or by definition, most of the calculation models for mixed mode cracks incorporate Mode I FCG curves along with an equivalent stress intensity factor as the crack driving force parameter. Validation of such a procedure requires experimental data for both Mode I and mixed mode loading conditions, [12]In this paper, FCG tests are performed tension specimens subjected to Mode I and mixed mode I/II loading conditions. Based on the experimental results and finite element analyses FCG for mixed mode loading and the Mode I achieved .To explore the performance of alternative analysis methods, the XFEM algorithm implemented in ABAQUS [13] is applied for calculating crack growth paths.

Test description and experimental crack paths

The material considered in this study is 2024 t3 aluminium alloy. Table 1 shows chemical composition and table 2 mechanical property of the material.

Table 1: Chemical composition of Al 2024-T3

Element	Al	Cu	Mg	Zn	Si	Ti	Cr
Weight (%)Balance	3.8–4.9	1.2–1.8	0.25	0.50	0.50	0.15	0.10

Table 2: Mechanical properties of AL 2024-T3

Property	Value
Yield strength (MPa)	345
Modulus of elasticity (GPa)	73.11
Poisson's ratio	0.33
Shear strength(MPa)	283
Tensile strength(MPa)	345

The geometries of the test specimens are shown in Fig. 1. All specimens are 160 mm long, with a test cross-section of W=40, B= 6mm, e=10, for SE (T) geometries. Altogether three SE (T) specimens were tested.

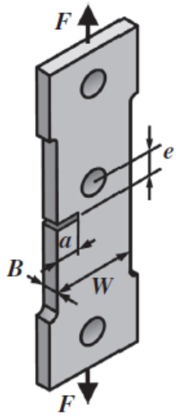

Fig 1: Schematic of specimen geometries adopted in this study

When preparing the specimen for experiment wire cut EDM is used. For archiving exact dimension of the specimen .Notch length of all specimens is 6mm. SE (T) specimens were tested in servo hydraulic fatigue testing machine (MTS810). Frequency at 20 Hz, Both fatigue crack growth tests were performed at the load ratio of R = 0.1 and room temperature.

Mixed mode loading standard SE(T) ones for the specimens was achieved by machining a hole of 10 mm diameter in the central part of the specimens after pre-cracking, similar to the approach described in Ref. [12]. The hole was centred with respect to the specimen width but shifted with respect to the original crack plane. The eccentricity parameter the distance from the hole centre to the pre-crack plane (Fig. 1), was equal to e = 10 mm for the specimens SET1 and SET2,or SET3 was tested under pure Mode I conditions. Geometrical parameters and loading conditions for the tension specimens considered in this study are summarized in Tables 1.fig 2 shows the experimental set up.

Table 3: Geometrical parameters and test conditions for SE (T) specimens

Loading mode	Specimen	a…min (mm)	Frequency (Hz)	Hole parameters (mm)		load (kN)
				Ø	e	
I	SET1	6	20	-		10
I+II	SET2	6	20	10	10	10
I+II	SET3	6	20	10	10	12

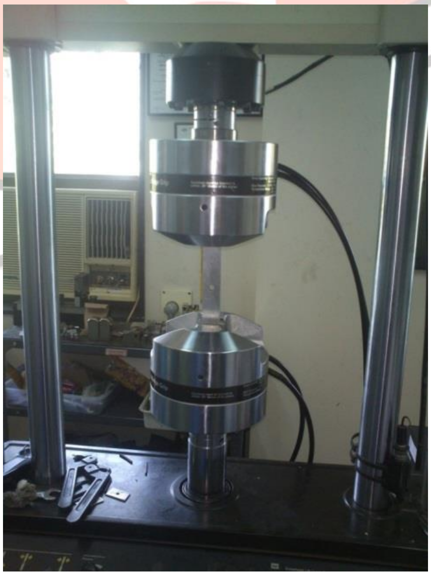

Fig 2: Experimental setup

Experimentally fatigue crack growth in SET1, SET2, SET3

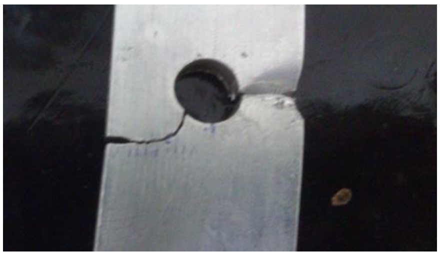

Fig. 3: Experimental fatigue crack growth path for mix mode loading condition

Fig.4: crack paths for mode I loading

II. FEA ANALYSIS

Algorithm available in a number of commercial finite-element codes, ABAQUS [13], is applied below to simulate FCG paths for the SE (T) configurations denoted by SET1and SET3. For the SE (T) models two mesh types, both having the element size below 1 mm around the crack growth path, are generated. Model with randomly shaped and sized finite elements, referred to as ‘‘irregular’’ mesh. Fig 4 shows mesh view for mix mode fig 5 for mode I.

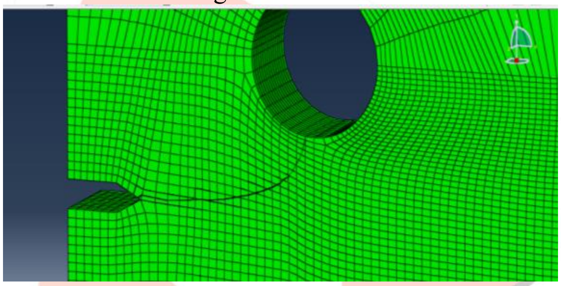

Fig 5: Mashing view for mix mode loading XFEM algorithm

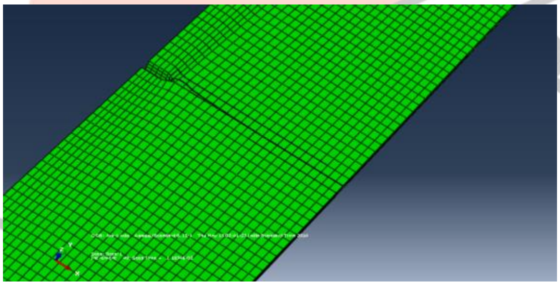

Fig 6: Mashing view for mode I loading XFEM algorithm

III. RESULT AND DISCUSSION

For load (10,-10) for mix mode

For table no. 4 is shows experimental result for mix mode loading condition ,load ratio is -1 ,when experiment start minimum notch is 6 mm than minimum crack length is 6, for increase no of cycle for above pare crack start at 12500 cycle, increase no of cycle crack growth is increase.

Table no 4

Crack length (mm) a..min=6mm	No of cycles
6	12500
8	13760
10	15630
12	17500
14	18430
16	19430
18	20380
20	20380
Failure	23430

For SET2 load (12,-12) for mix mode

Table 5 shows experiment result for loading (12,-12) for mix mode condition.

For lower loading condition crack start at higher no of cycle

Table no.: 5

Crack length (mm) a..min=6mm	No of cycles
8	14300
10	15780
12	17010
14	18020
16	18810
18	19650
20	19930
Failure	21700

For SET1 load (10,-10) for pure mode

Table no. 6 shows the experimental result for mode 1 loading condition

Table no.: 6

Crack length (mm) a..min=4mm	No of cycles
6	11330
8	8210
10	8270
12	9160
14	9850
16	10110
18	10300
20	10450
22	10550
24	10670
Failure	11300

IV. COMPARING RESULT

Experiment Vs. FEA analysis fatigue crack growth SET2

When comparing the result for experimental crack path an FEA analysis fig 7 shows the graph for measured crack path for experimental and FEA analysis on X and y direction.

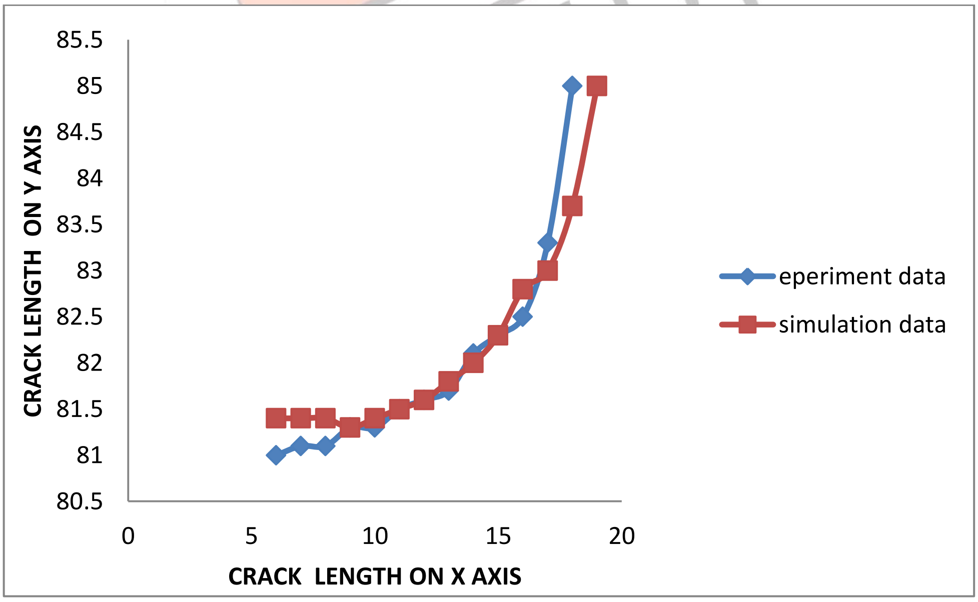

Fig 7: Crack path for SET1 Vs. Simulation

Experimental Vs. FEA analysis fatigue crack growth SET1

Below graph shows the fatigue crack growth obtain by experimentally or by simulation bred line indicates experiment fatigue crack growth path or blue line indicate simulation crack growth path both path are almost similar for minor error,

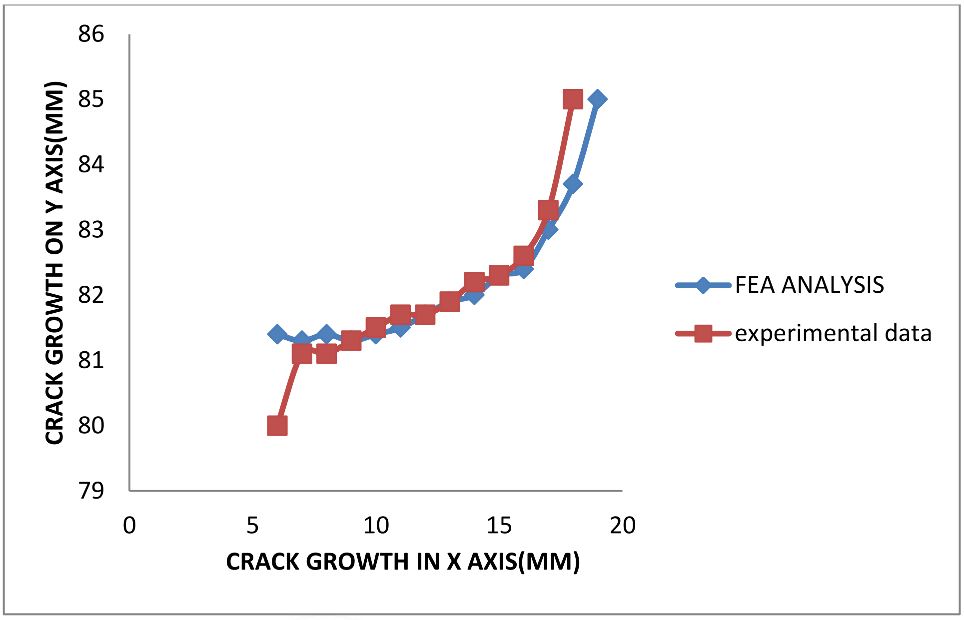

Fig 8: Crack path for SET2 Vs. Simulation

Experimental vs. FEA analysis fatigue crack growth mode I

This graph shows mode I fatigue crack growth path blue line indicate simulation crack growth path or red line data is the average data for two faces of the plate,

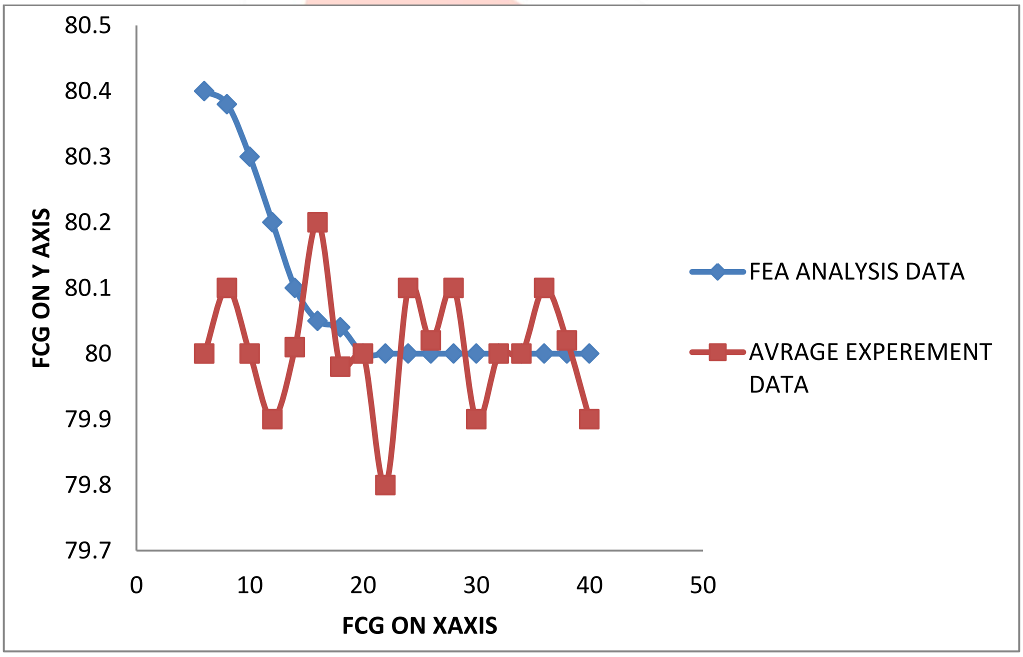

Fig 9: Crack path for SET3 Vs. Simulation

No of cycle vs. Crack length

This graph shows what is the changes for changing load ratio, buy this graph we are suggest that where changing load no changing fatigue crack growth path but load is increased then no of cycle is decreased.

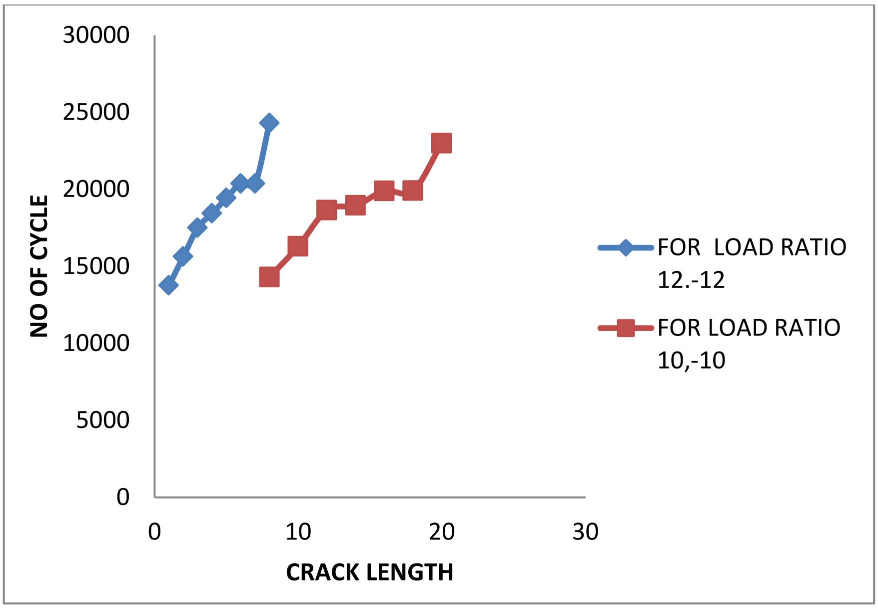

Fig 10: No of cycle Vs. Crack length

V. CONCLUSION

In this paper, our objective is to estimate fatigue crack growth (FCG) on thin plate. For the above specimen types, both Mode I and mixed mode FCG tests are first performed. To find fatigue crack growth path in aluminium alloy 2024-T3 plates under constant amplitude loading (CA). The tests were performed on a standard servo hydraulic fatigue testing machine (MTS810). Further FEA analysis is done by XFEM based algorithm available in the finite element code ABAQUS is explored with respect to its performance in estimating crack growth paths. FEA software version (ABAQUS/CAE 6.13.1) is used and the results suggest that using mode I, mode I/II experimental data, both experimentally and FEA analysis estimation of pure mode & mixed mode fatigue crack growth is possible. By comparing experiment analysis and result of FEA analysis, it is found that, results of both methods are almost similar with minor difference. It is found through experiment that fatigue crack growth rate increases when loads are increased. Number of cycles decrease when load increases.

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