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Influence of Inner Surface Notch on Fatigue Crack Growth Characteristics of Aluminum Alloy

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Abstract— Effect of initial notch on the Fatigue crack growth of Aluminum 6061 specimen specified by ASTM is investigated. Growth rate obtained by experiment and numerical methods were compared. The values are in close agreement. The study shows the dependency of crack propagation on the stress intensity range of the Aluminum.

***Keywords*— Aluminum , ASTM, Fatigue crack growth, Numerical method.**

I. Introduction

The aluminum 6061 alloy have many applications such as structural parts of trucks, rail road cars, pressure vessels, etc as few of them. Its high strength to weight ratio makes it suitable for applications in different fields like, automotive, chemical and oil industries. Aluminum 6061 as fabricated can be easily heat treated to improve the mechanical properties of the material [i].Generally components are designed so as to avoid yielding of the critical loaded point. Safety against failure of a component is considered to be the basic requirement of any design. Although stress tensor is quite complex with six independent components, criteria like Von Mises or Tresca are adopted to obtain a scalar number, i.e. stress component. The scalar number is then compares with a limiting value which is determined through experiments.

Components fail, when a load applied is beyond the yield strength of the material. However it has been found that often structures fail , even when load is well within the yield stress. Thus we can note that design of a work component based completely upon avoiding yielding is not adequate in certain cases. Those cases are called as 'fatigue –cases'. Now the component may be susceptible to what one call as "crack- growth ". Fracture mechanics have become a perfect tool to deliver a useful methodology to compensate the inadequacies of conventional design concepts. The conventional design criteria are based on tensile strength , yield strength and buckling stress. These criteria are useful for several engineering applications , but they are insufficient when there is a crack in a structure. The crack that is likely to grow under given loading condition can be analyzed through several approaches. They are stress approach , displacement or energy methods[ii,iii]. Designer gave more importance to some design features such as , notches[vii], joints[viii], specimen geometry[iv] and groves[v, vi], to minimize the stresses.

In the present study, we followed a stress approach to analyze a crack growth on curved surface at room temperature under mechanical loading. In this approach , there is a need to account for the large amount of stresses that are developed in the vicinity of a crack tip . Thus it requires to descretize the structure and analyze for the stresses as close as possible to the crack tip i.e., Stress Intensity Factor (SIF).

II. Material and Methodology

Aluminum material is basically an extruded bar of 160 mm diameter and length 150 mm. An arc shaped tension specimen as shown in Fig. 1 is produced and the stages of manufacturing are as shown in Fig 2 (a-d). Specimen geometry suggested by ASTM E-399 is used for the present study. The notch geometry of 4 mm length with nose radius of 0.25 mm is fabricated by wire Electric Discharge Machining.

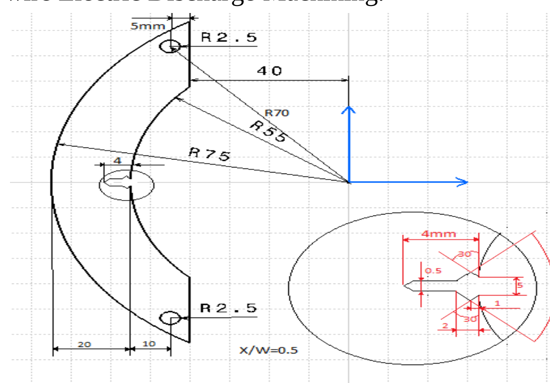

Fig. 1 Specimen geometry

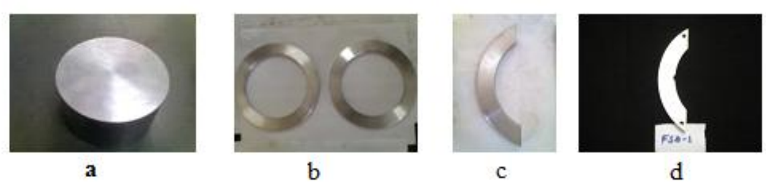

Fig. 2 (a –d) Raw material up to final specimen geometry

Fatigue Crack Growth (FCG) test has been carried out as per the procedure recommend by ASTM 647-08, using the hydraulic fatigue testing machine. A constant amplitude cyclic load at a frequency of 10 Hz, load ratio =0.3 and load range = 2.31 kN were applied at room temperature. Loading ratio, x/ w of 0.5 is used in the present study, where x is the distance from the point of loading to the crack face in the horizontal direction and w is the width of the specimen. The experimental setup is as shown in Fig. 3. The crack growth , **a** as a function of number of stress cycles N, is obtained as shown in Fig. 4. FCG

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rate as a function of stress intensity factor range is plotted using the experimental results as shown in Fig. 5.

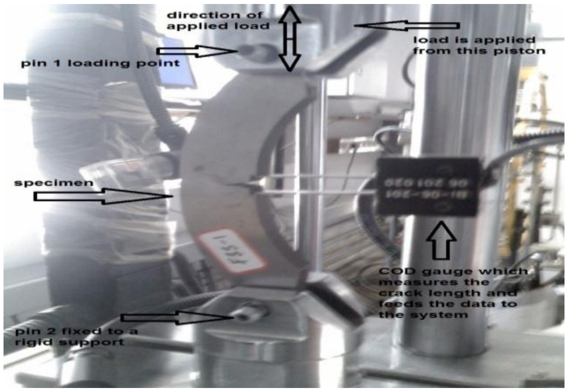


Fig. 3. Experimental setup

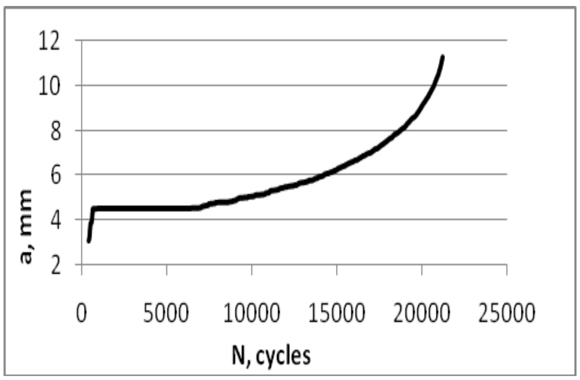


Fig. 4. Crack growth curve

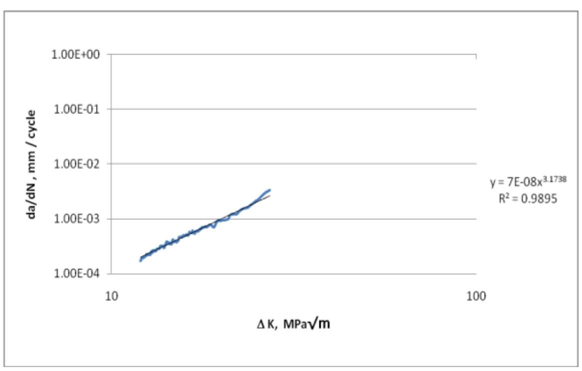
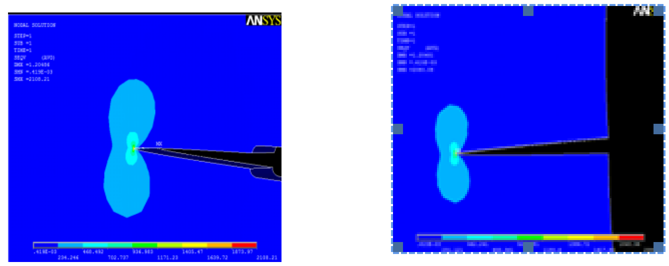


Fig. 5. Fatigue crack growth rate curve

These results were fitted according to the Paris law [xii]; $da/dN = C(\Delta K)^m$, where C and m are experimental constants obtained from fitting curve.

Finite Element Analysis;

A 3D, finite element analysis (FEA) is carried out using ANSYS software with plain strain assumptions. The geometries were meshed with two element types, namely quadratic element (2D) and Hexahedral element (3D) . Modulus of elasticity and Poisson's ratio of 68.9 GPa and 0.33 respectively are used as material properties. To resolve crack tip stress fields at the key point, a sufficiently fine mesh of 0.05 mm [ix, x] radius was incorporated and is as shown in Fig 6. The lower part of the specimen were constrained to zero, and the maximum tensile load is applied at the upper part of the specimen.



a b

Fig. 6 Finite element a) stress at the tip of crack with notch. b) stress at the tip of crack without notch.

The nodal solution so obtained provides maximum SIF, i.e. $(K_I)_{max}$ and the process is repeated for minimum load to obtain minimum SIF, (K_I)min. The process is continued up to the stage when $(K_I)_{max}$ researches (K_{IC}), the critical SIF. Using the Paris constants so obtained from the experiments, FCG rate is computed. The number of cycles up to the failure is calculated using the integral form[xi, xii], i.e., $\int_{ai}^{af} \frac{da}{C(\Delta K)^m}$. Note that the number of stress cycles for crack initiation is not included in the total life cycle of the specimen under consideration. The same procedure is repeated for the arc shaped tension specimen without any notch.

III. Results and Tables

FCG behaviour depends mainly on two fracture mechanics parameters, i.e. ΔK and K_{max}. Stress intensity range, ΔK explains fatigue damage ,whereas K_{max} for the crack tip widening.

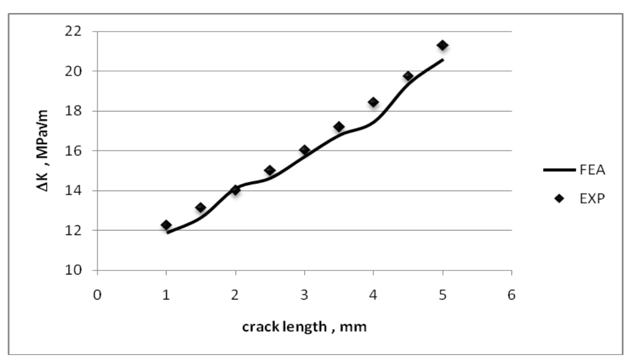


Fig. 7 Characteristic relation between crack length and stress intensity range.

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Fig .7 shows the dependency of the crack propagation on the stress intensity range of the aluminum material. It is been observed from the experiments that, there exist some ΔK that helps in the nucleation of crack and at K_{max} of 17.5 MPa√m, crack has grown by 1 mm. Thus from the initial notch of 4 mm ,total widening of the defect reach to 5 mm. But material is still safe as it can resist the further load on it. Further increase in load, leading to the fatigue damage of 21.28 MPa√m. By the time, stable crack resistance of the material have been reached, as crack grows to 5 mm. As a typical nature of Aluminum , ductile tearing prevails and material fails unstably. FEA prediction of crack growth due to fatigue damage shows the same trend, with variation of 3.1%.

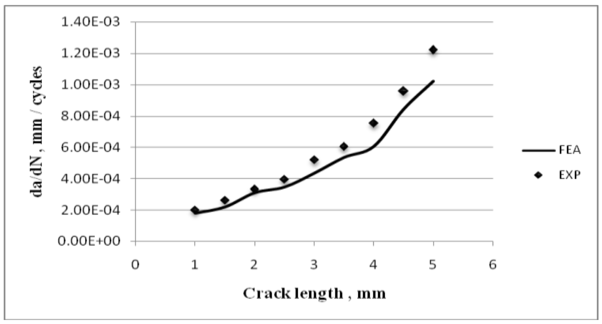

Fig. 8 crack growth rate curve.

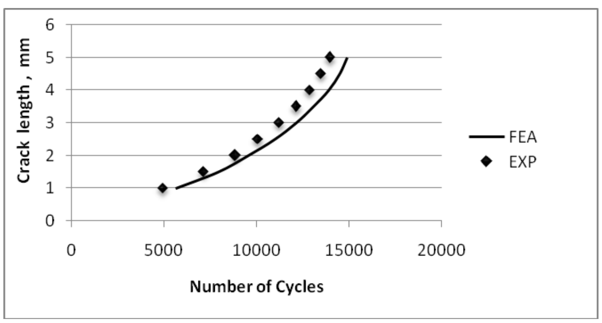

Fig. 9 crack growth curve.

Fig. 8 , shows that, crack grows at faster rate, as SIF starts reaching $K_{max,}$. The range of the stress cycles to grow the crack from 2 to 5 mm is of the order of 3.31×10^{-4} to 1×10^{-3}. Beyond this as SIF increases, the plastic zone size increases compared to the crack length and material fails with little stress cycles.

At the last stage, ΔK is maximum and growth rate is extremely high with little fatigue life cycles. Fig 9 shows, that the stress cycles required for the crack to propagate from the initial notch, up to the failure, is 13,989 cycles . Whereas FEA results shown the same trend, but failed to 14,888 cycles, with variation of 6%.

From Fig. 10, it is observed that , material resists as few stress cycles as 4937 as the crack starts propagating from the initial notch of 4 mm. Whereas material resists more stress cycles of 86957, as the crack starts propagating from the inner surface without any notch. Before failure, specimen with notch has resisted 13989 stress cycles as the crack propagated up to 5 mm in length. Specimen without notch can resist 154289 stress cycles as the crack has grown up to 8.5 mm, if it does not carry any notch with it.

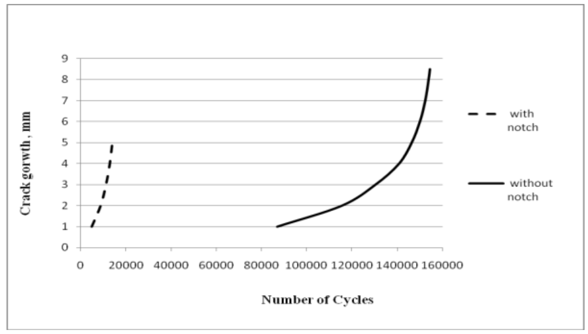

Fig. 10. FEA comparison of crack growth curve between with and without notched specimen.

IV. Conclusion

In this study, fatigue crack growth behaviour of Aluminum 6061-as fabricated in the presence and absence of notch is presented. The clear difference in the stress intensity range for the notch and without notch specimens acertain that, intensity of fatigue damage could be more if the material carries any flaws with it.

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