Experimental and Analytical Fracture Analysis of Thin Aluminum Sheet by J-integer and Crack Tip Opening Displacement (CTOD) method

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***Abstract*—A J integer and CTOD test are usually done on materials undergoes plastic deformation prior to failure. The testing material more or less resembles the original one, although dimensions can be reduced proportionally. More than 3 tests are done to minimize any experimental deviations. The specimen is placed on the work table and a notch is created exactly at the center. The crack should be generated such that the defect length is about half the depth. The load applied on the specimen is generally a three point bending load. A strain gauge is used to measure the crack opening. Crack tip plastically deforms until a critical point after which a crack is initiated that may lead to either partial or complete failure.**

Keywords :stress intensity factor,J integral, FEA.

I. INTRODUCTION

Fracture is a problem that society has faced for as long as there have been man-made structures. The problem may actually be worse today than in previous centuries, because more can go wrong in our complex technological society. Major airline crashes, for instance, would not be possible without modern aerospace technology. Fortunately, advances in the field of fracture mechanics have helped to offset some of the potential dangers posed by increasing technological complexity. Our understandings of how materials fail and our ability to prevent such failures have increased considerably since World War II. Much remains to be learned, however, and existing knowledge of fracture mechanics is not always applied when appropriate. While catastrophic failures provide income for attorneys and consulting engineers, such events are detrimental to the economy as a whole. An economic study estimated the annual cost of fracture in the U.S. in 1978 at 119 billion (in 1982 dollars), about 4percent of the gross national product. Furthermore, this study estimated that the annual cost could be reduced by 35 billion if current technology were applied, and that further fracture mechanics research could reduce this figure by an additional 28 billion.

Date of submission 21 may 2016.

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The finite element method (FEM) has been widely used in various problems of fracture mechanics. FEM was originally used as a simple analytical tool for obtaining the continuum based displacement and stress fields. Sophisticated singular elements were proposed by Barsoum and Henshell and Shaw and efficiently implemented by Fawkes and Owen and Fawkes to simulate the singularity condition at crack tips. Then, it was extensively adopted as a major improvement to already available numerical techniques in LEFM.

II. LITERATURE REVIEW

The insufficient attention on studies related to fracture behavior of sheet metals originates from the fact that engineering materials with thinner sections are not considered as load bearing structural parts. Only Liu and his co-workers have suggested some guidelines to assess fracture criteria for thin and tough plates of structural materials D M kulkarni et al 2004 has found the experimental technique for fracture criteria of sheet metals and he has examined the effect of the variation of thickness of such steel sheets on their fracture criteria. A new approach is suggested in his research for determining fracture criterion of thin sheets using load drop technique, which assists in detecting the physical event of crack initiation. [1] Garca et al gives experimental analysis of two structural steels, one with a ductile behavior and the other one with brittle behavior, this paper compares the results obtained by means of small punch test (SPT) performed on notched samples with those obtained in standard fracture toughness tests, in order to obtain a relationship between them and to analyze the suitability of the SPT for estimating the fracture toughness. [2] S Yoshizu et al has to explain this scatter, by using Beremin proposed model called Weibull stress or Beremin model. These models cannot completely describe experiments, nor did they calculate the scatter of fracture initiation points. S Yoshizu et al of the present paper is to propose a new model which more precisely predict fracture toughness as well as fracture initiation points.[3]

III. METHODOLOGY

1) In this research, comparative study of experimental and simulation data will be carried out for following materials

- Aluminum Sheet (Shell, Pressure vessel, Aircrafts)

These materials are selected for the study because their susceptibility of Fracture failure in particular application

2) First objective of the study is to find out mechanical properties by using standard tensile test for above materials.
3) Then finite element model will be prepared as per literature and ASTM standard to find of crack tip opening displacement for each material.
4) The tensile test results (stress VS strain graph readings) will be used as material property for respective material model.
5) FEA will give us J integral and K1.
6) The crack tip opening displacement can be found from the relationship of J integral or K1 with CTOD which is given literature. These readings can be achieved.

IV. EXPERIMENTAL SETUP

Experimental tests were performed on the modified compact tension (CT) specimen, by pulling the specimen in a 400KN Universal Testing Machine at the very slow speed of 0.1 mm/min as shown in Fig. The detection of crack initiation was done by closely observing the crack-tip with the help of magnifying glass and simultaneously monitoring the run-time load-displacement curve. It was found that the crack grew suddenly and the load started dropping at the same time. Thus, the load-displacement curve yields the critical load. The critical load obtained from experiments was used as loading boundary conditions in a nonlinear numerical analysis to obtain stress-strain fields.the Fig 1 shows UTM machine and Fig 2 shows Experimental setup

Fig. 1: Universal tensile Machine

Fig. 2: Experimental setup with Anti-buckle plate

V. FEA ANALYSIS

The CTOD test specimens were modeled by Two-dimensional elastic-plastic finite element (FE) analysis, using ANSYS 15.0. Because of the symmetry, 1/2 of the specimen was modeled. Crack tip of the fatigue crack was modelled by 5m radius semicircle. Minimum element size was 0.1 mm. The element was defined by using 20 nodes having 2 degrees of freedom per node and translations in x, y directions as shown in fig. Meshing was graded from fine at the crack tip to coarse at the solid boundary. The most important region in a fracture model is the region around the edge of the crack. Element size that ranges from 0.035 to 0.060 percentage of the absolute crack length is considered around the crack tip. A triangular wedge-shaped element is formed by collapsing the top plane of a Quad element along the surface diagonal. The elements with multiple nodes are arranged along different radial lines around the crack tip. These elements are quadratic in behavior. The mid nodes of the elements in the first radial line are placed at the quarter positions to produce the appropriate 1/*gama* singularity as the limit of the plasticity is approach. Elastic plastic finite element analysis can be considered as an extension of elastic by incorporating extra conditions pertaining to nonlinear plasticity conditions due to Gdouts and Papkalitakis (1987). Nonlinear material behavior is modelled by using the incremental theory of plasticity. The Von Mises yield criterion is considered to be valid for these materials. The isoparametric six-node triangular elements, with mid-side nodes displaced from their nominal position to quarter points at the crack tip, were employed to form a circular zone surrounding the tip in order to better capture the stress field. The stress intensity factors (SIFs) were predicted by using the displacement extrapolation method for plane stress and plane strain in pure Mode I (plane tensile).

The elastic-plastic process requires continuous assessment of stress and plastic strain at all points of the structure, as the applied load increases. Hence the load is applied in a sequence of relatively small increments, and within each step a check on stress and equilibrium is made. As loading starts, the program starts to iterate the stress above the yield stress to consider the plastic effects. The whole non-linear curve is considered to consist of a number of straight lines, each being designated as a load step.

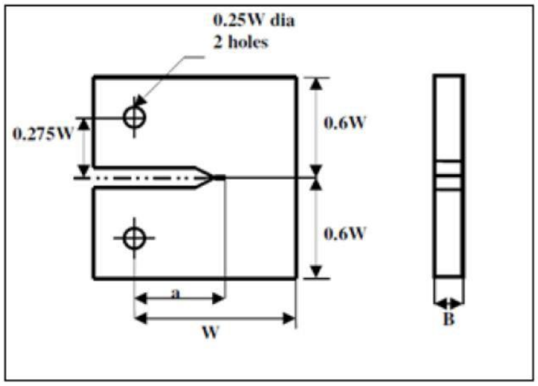

Fig. 3: CT Specimen for J-Integer and CTOD Analysis

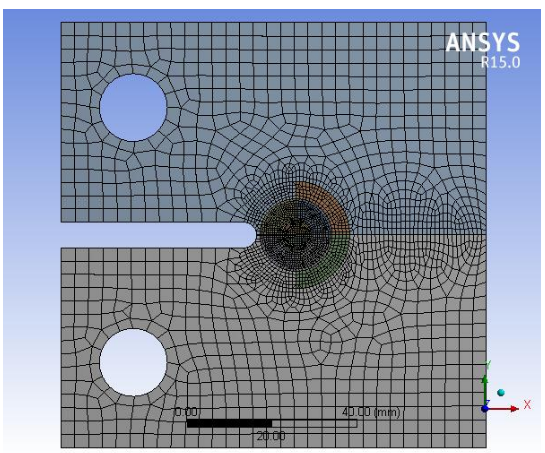

Fig. 4: Meshing of CT Specimen

With the help of this analysis, the value of plastic CTODpl and crack tip necking is determined at the same node considered in linear analysis. The results of plastic CTOD and crack tip necking are shown in Fig 3 respectively for S1 specimen. The values of elastic CTOD and plastic CTOD are used to find equivalent fracture toughness similar to experimental method.

FEA analysis gives the results of J integral for different 3 no of contours .The average J integral for a particular time steps is calculated. The relationship between J integral and CTOD Values are as follows.

VI. RESULTS

Three specimens were tested for each thickness of three different thickness like 1mm 1.1mm and 1.2mm. It was found that in the thin plate of aluminum alloy 6061-T6, significant plastic deformation took place before the crack growth at the region near to the crack-tip. A dimple was formed before to the crack growth on each face of the specimen The V formed by the tangents to the two edges of the dimple at the crack-tip had an included angle of 65o. At the critical load the crack grew suddenly along one of the two edges of the dimple, and

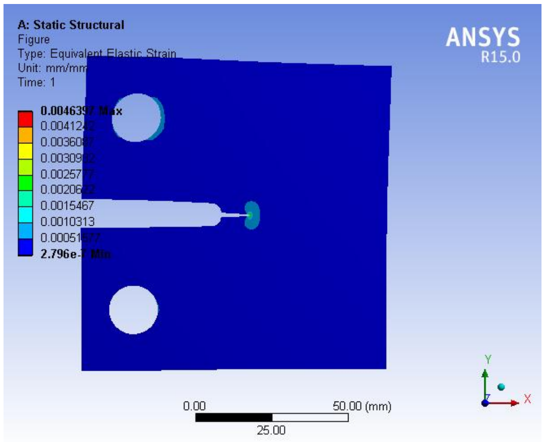

Fig. 5: Distribution of Von Mises Stress in A CT Specimen

the load on the specimen started dropping. If the crack initiated along the upper edge of the dimple on the front surface, the crack moved inside the material at an angle in such a way that it comes out along the lower edge of the dimple on the rear surface

TABLE I: Stress intensity factors obtained by FEA

SIFS (K1) Contour 1 [MPa·mm^(0.5)]	SIFS (K1) Contour 2 [MPa·mm^(0.5)]	SIFS (K1) Contour 3 [MPa·mm^(0.5)]	SIFS (K1) Contour 4 [MPa·mm^(0.5)]	SIFS (K1) Contour 5 [MPa·mm^(0.5)]
174.9	185.84	185.9	185.91	185.91
SIFS (K1) Contour 6 [MPa·mm^(0.5)]	SIFS (K1) Contour 7 [MPa·mm^(0.5)]	SIFS (K1) Contour 8 [MPa·mm^(0.5)]	SIFS (K1) Contour 9 [MPa·mm^(0.5)]	SIFS (K1) Contour 10 [MPa·mm^(0.5)]
185.92	185.92	185.92	185.92	185.92

TABLE II: J-Integer values by FEA

J-Integral (JINT) Contour 1 [mJ/mm²]	J-Integral (JINT) Contour 2 [mJ/mm²]	J-Integral (JINT) Contour 3 [mJ/mm²]	J-Integral (JINT) Contour 4 [mJ/mm²]	J-Integral (JINT) Contour 5 [mJ/mm²]
0.477	0.48772	0.48761	0.48759	0.48759
J-Integral (JINT) Contour 6 [mJ/mm²]	J-Integral (JINT) Contour 7 [mJ/mm²]	J-Integral (JINT) Contour 8 [mJ/mm²]	J-Integral (JINT) Contour 9 [mJ/mm²]	J-Integral (JINT) Contour 10 [mJ/mm²]
0.48759	0.48759	0.48759	0.48759	0.48759

VII. CONCLUSION

1) One of the key observations in this study is the de- tection of the crack initiation in thin Sheets from the phenomenon of load-drop. The detection of this event eliminates the elaborate effort required.

TABLE III: Comparison Of Analytical and FEA values of Fracture Properties

	Exprimental			FEA		
Thickness	K1[MPa·mm ^(0.5)]	J1 [mJ/mm^2]	CTOD (mm)	K1[MPa·mm ^(0.5)]	J1 [mJ/mm^2]	CTOD (mm)
1	187.32	0.51	0.85	185.92	0.48759	0.6572
1.1	174.57	0.52	0.93	181.53	0.47	0.7831
1.2	171.37	0.53	1.07	172	0.49	0.983

Fig. 6: Cracked Specimen After Testing

2) The plastic zone size for all the tested sheets extends up to the ligament boundary of the specimens.
3) The amount of crack-tip necking could be determined by FE analysis, which otherwise a difficult task to measure

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