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Effect of Notch Angle on the Fracture Toughness of Al7075 T6 Alloy- An Experimental Approach

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Abstract: *In this paper fracture toughness (k_{IC}) of Al7075 T6 alloy has been determined by using circumferentially cracked round bar (CCRB) specimen having three notch angles (α) namely 45^0,60^0,75^0 respectively. The purpose of the study was to determine the effect notch angle on the fracture toughness of the Al7075 T6 alloy. The obtained fracture toughness results for different notch are compared with ASTM standards. The result shows that the notch angle has significant effect on the value of fracture toughness (K_{IC}).*
Keywords: *Al7075 T6 alloy, CCRB specimen, Fracture toughness, notched specimen.*

I. Introduction

The need of high strength, low weight, and more corrosion resistant material is of current interest in the area of aerospace, marine etc. The Al 7075 T6 alloy material find wide applications in the different areas because of its excellent metallurgical properties. The Al 7075 T6 alloy is made more useful material with the characterization of material for fracture toughness. The determination of fracture toughness is based on the stress intensity factor (K_{IC}) at the crack tip with subscript I denotes the fracture toughness test is performed in tensile mode and C denotes the critical value of stress intensity factor. When K attains critical value then crack propagation becomes unstable and result in fracture of components [1].

Normally K_{IC} is determined by using compact-tension (CT) specimen or single edge notch bend (SENB) specimen or three point loaded bend specimens which are standardized by ASTM [14]. Also the standard test method for fracture toughness (K_{IC}) of metallic material is given by the American Society for Testing and Material (ASTM) (designation E99) [2]. The ASTM E99 standard test method is to be one of the most accurate ways of measuring K_{IC} of low ductility high strength alloys [3].These methods are difficult and also the preparation of specimen. Notched round bar specimens have widely used for finding mechanical properties of materials [4-5]. The advantages of using circumferentially notched bars for fracture toughness testing can be summarized as follows:

- The plane strain condition can be obtained because the circumferential crack has no end in the plane stress region compared with the standard specimen geometries [6].
- Because of radial symmetry microstructure of the material along the circumferential area is completely uniform [7].
- Preparation of CCRB specimen is easy.
- Fracture toughness test is easy to perform.

In the previous studies, Bayram et al. [8] measured fracture toughness K_{IC} of various steels and aluminum alloys with CCRB specimens and summarized that the experimentally measured fracture toughness values using CCRB specimens are accurate and reliable considering some correction factors.

Christopher D. Wilson and John D. Landes [9] used circumferentially notched round bars with finite notch root radii. They observed that the circumferential crack propagates radially inwards in tensile loading unlike unique crack propagation towards one direction in case of CT or SENB specimens.

Wang Chang [10] determined the plane strain fracture toughness (K_{IC}) by single cylindrical tensile small scale specimen with ring-shaped crack.

NeelakanthaV Londe [11] determined the fracture toughness of metallic material by using CCRB specimen having notch angle (45^0) and unchanged outer diameter (D) with different notch diameter (d) of Al6082-T6 alloy. They have found the value of K_{IC} closer to standard tests.

Ali Bayram [8] determine the fracture toughness of metallic material using CCRB specimen having notch angle (60^0) and unchanged outer diameter (D) with different notch diameter (d) tested for different metallic materials also find the fracture toughness by adding the correction factor. They have concluded that fracture toughness measurement of metallic material using CCRB specimen is to be an accurate and reliable procedure.

S K Nath [1] determine the fracture toughness of medium carbon steel using CCRB specimen having different notch angles i.e. 45^0,60^0,75^0 and unchanged specimen diameter(D) with different notch diameter(d). They have tested the material before heat treatment and after heat treatment and concluded that samples with lower notch diameter shows higher K_{IC} for same notch angle as compared to higher notch diameter.

The objective of the present work is to determine the effect of notch angle (α) on fracture toughness and to validate the results with the standards. For the present study the ratio of D/d kept as constant and the ratio is equal to 1.2 with varying notch angles. Also the effect of constant D/d ratio with different notch angles on fracture toughness value by using CCRB specimen is investigated.

II. Theoretical Determination Of K_{IC}

The determination of fracture toughness is based on the stress intensity factor (K_{IC}) at the crack tip, where I- denotes that the fracture toughness test is performed in tensile mode and C- denotes that the value of k is critical. Unstable crack propagation occurs when K attains a critical value and the component fails. In Linear Elastic Fracture Mechanics (LEFM) the critical Stress Intensity Factor (SIF) characterizes the fracture toughness [12]. Wang. C.H et al. [13] have given an equation for calculating K_{IC} of a CCRB specimen under tensile load and is given in equation (1). This relation is valid for $1.2 \leq D/d \leq 2.1$.

$$K_{IC}= [0.932\ P_f\sqrt{D}] / (d^2\sqrt{\pi}) \qquad \text{(Eq1)}$$

Where, P_f is the fracture load,
D is the diameter of the specimen, and d is the diameter of the notched section (Fig.1).
According to Dieter [14] for round notched tensile specimen, fracture toughness K_{IC} found using following Eq.

$$K_{IC} = P_f / (D)^{3/2}\ [1.72(D/d) -1.27] \qquad \text{(Eq 2)}$$

Where, P_f is the fracture load,
D is the diameter of the specimen, and d is the diameter of the notched section (Fig.1).
The assumption made while formulating above expression is that the specimen retains its elastic behavior until fracture occurs. This relation is valid for the D/d ratio between 1.00 and 1.25.

III. Materials And Methods

The material used for present work is Al7075 T-6 alloy whose chemical composition are given in Table. 1 and initially diameter of rod is 16mm.

Table: 1 Chemical composition of Al7075 T-6 alloy used, in wt%.

Al	Cr	Cu	Fe	Mg	Mn	Si	Ti	Zn
87.1-91.4	0.18-.28	1.2-2	Max 0.5	2.1-2.9	Max 0.3	Max 0.4	Max 0.2	5.1-6.1

The Mechanical properties 0f Al7075-T6 Alloy is given in Table. 2

Table: 2 Mechanical properties of Al7075 T-6 alloy

Property	Values
Ultimate Tensile Strength	572 Mpa
Fracture Toughness (K_{IC} in L-T direction)	29 Mpa√m
Fracture Toughness (K_{IC} in T-L direction)	25 Mpa√m

3.1 Specimen preparation

The test specimen geometry is as shown in Fig. 1. Nine testing specimens have been prepared as per standard specifications with following dimensions.

Specimen diameter (D): 10mm.
Gauge length (L_o): 5D.
Specimen length (L): 30D.
Notch diameter (d): 8.3mm.
Notch angle (α): 45^0,60^0,75^0 (Three notch angles have been used).

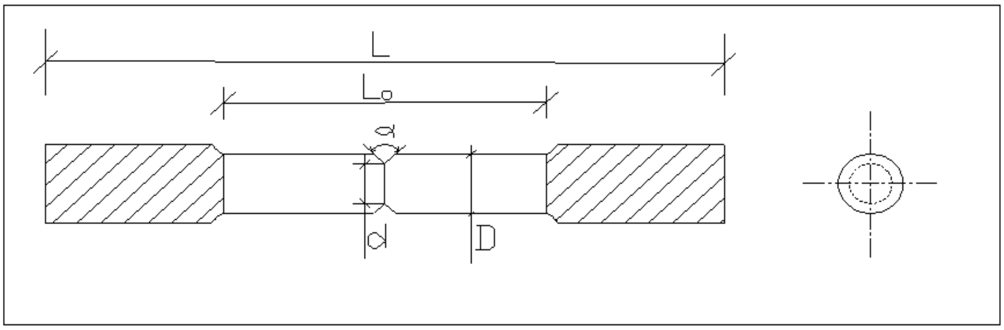

Fig. 1. Schematic representation of round notched tensile specimen

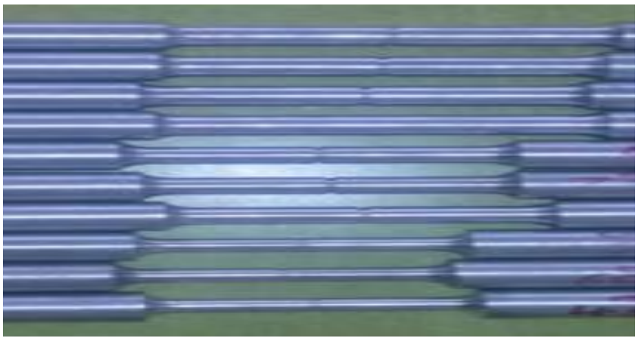

Fig. 2. Circumferentially crack round bar testing specimens

IV. Experimentation

The tensile test of each CCRB specimen was performed on 400KN Computerized Universal testing machine at room temperature. The specimen was loaded under tension and the detailed results are shown in table 3 and table 4.

V. Result And Discussions

The specimen having different notch angles loaded on UTM machine and results are recorded. Table 3 and 4 shows the experimental observations of maximum load and ultimate stress for each specimen respectively. The plane-strain fracture toughness of Al 7075-T6 alloy tested using CCRB specimen geometry was found to be in a range of 27.59 to 28.50 as per Eq. (1) and 29.00 to 29.95 as per Eq. (2) which is valid range of K_{IC} for Al7075-T6 alloy as available in literature obtained by standard tests. The average fracture toughness values calculated using Eq. (1) and Eq. (2) are 28.06, 29.49 $MPam^{1/2}$ respectively, it was observed that Eq. (1) results lower values of fracture toughness than Eq. (2) and are shown in figure (3) having notch angle 45^0,60^0,75^0 respectively. The measurement of fracture toughness is based on the critical stress intensity factor (K_{IC}) of the test specimen under Mode-I loading condition. These two equations give K_{IC} value in a valid range as available in the literature using standard CT (Compact Tension) specimens. The variation of Fracture toughness versus notch angle, was drawn for all the values of K_{IC} determined using Eq.1 and Eq.2 as shown in Figure (3).The tables 4 shows that the comparison between the ultimate tensile strength of unnotched specimen with the notched specimen and it is observed that if notch angle increases the value of tensile strength of material also increases.

Table 3: Details of Ultimate Stress, Fracture load, Fracture Toughness (K_{IC}) values of Notch Angle with variation in diameters.

Trial No.	Notch angle(α)	Specimen diameter(D)	Notch diameter(d)	Ultimate Stress (MPa)	Fracture load (P_F) in KN	Fracture Toughness $K_{IC}(MPa\sqrt{m})$	
						Eq 1	Eq 2
1	45^0	10	8.3	461	36.20	27.63	29.04
2	60^0	10	8.3	468	36.76	28.05	29.49
3	75^0	10	8.3	474	37.30	28.47	29.92
4	45^0	10	8.3	462	36.25	27.68	29.08
5	60^0	10	8.3	469	36.80	28.08	29.52
6	75^0	10	8.3	475	37.34	28.50	29.95
7	45^0	10	8.3	460	36.15	27.59	29.00
8	60^0	10	8.3	469	36.85	28.12	29.56
9	75^0	10	8.3	475	37.28	28.45	29.90

Table 4: Details of Ultimate stress of unnotched specimen and Notched specimen

Trial No.	Notch angle(α)	Specimen diameter(D)	Notch diameter(d)	Ultimate Stress (MPa)
1	0^0	10	-	**530**
2	45^0	10	8.3	461
3	60^0	10	8.3	468
4	75^0	10	8.3	474
5	45	10	8.3	462
6	60	10	8.3	469
7	75	10	8.3	475
8	45	10	8.3	460
9	60	10	8.3	469
10	75	10	8.3	475

5.1 Representation of K_{IC} values as per Eq 1 and Eq2 on Graph with Different Notch Angles

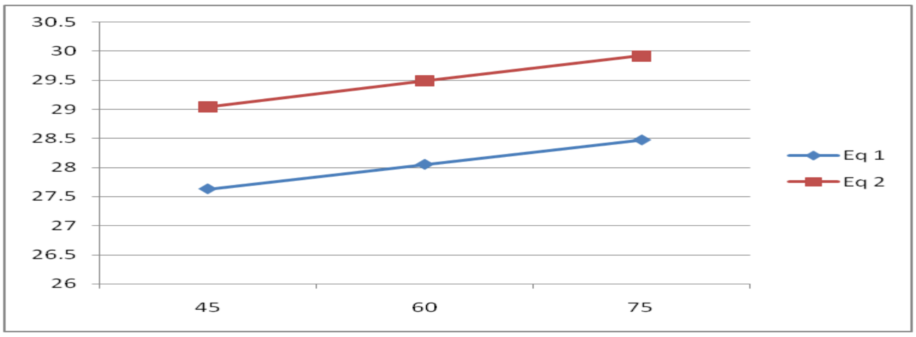

Fig. 3. Variation in Fracture Toughness with Notch angle

VI. Conclusions

It observed that by seeing the graph the value of notch angle changes then the value of K_{IC} also changes. It has been observed that as notch angle increases the value of fracture toughness get increases and in the literature survey it observed that decreasing notch angle decreases the fracture toughness value [1].

It has been observed that introducing notch to the test specimen the strength and % of elongation of the material decreases, results brittle failure occurs.

Based on above discussion final conclusions are as follows:

1. Fracture toughness (K_{IC}) of metallic material can be successfully determined by using round bar tensile specimen and the obtained values are comparable with other method like compression tension (CT) specimens.
2. The plane-strain fracture toughness of Al 7075-T6 alloy tested using CCRB specimen geometry was found to be in a range of 27.59 to 28.50 as per Eq. (1) and 29.00 to 29.95 as per Eq. (2) as per Eq. (2) which is valid range of K_{IC} for Al7075-T6 as available in literature obtained by standard tests
3. Introducing of notch in a tensile test specimen the % of elongation gets decreases.
4. Introduction of notch in tensile test specimen causes brittle failure although material will be ductile.
5. As a notch angle increases the value of K_{IC} also increases.

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