© 2017 IJEDR | Volume 5, Issue 4 | ISSN: 2321-9939

Determination of Fracture Toughness (KIC) For Al-Alloy A384

[1]Avinash Patil, [2]Ambadas, [3]Babu Reddy
[1]M -Tech Student, [2]Assistant Professor, [3]Assistant Professor
[1] Department of Machine Design, Visvesvaraya Technological University, Centre for PG Studies, Regional Office, Kalaburagi, Karnataka, India

---

Abstract- Determination of fracture toughness and fatigue crack growth behavior are important parameters of structural materials. These parameters can be used to predict their life, service reliability and operational safety in different conditions. This experiment is design to illustrate how strength in the presence of cracks-termed fracture toughness-is characterized and measured. In the present work, The Plain strain fracture toughness of Al-alloy A384 is determined. Tests were carried out on universal testing machine (Axial Fatigue Testing Machine) using compact tension specimens under mode I loading condition according to ASTM E399. The experiment results from fracture toughness test are then validated with analytical calculations and it is observed that, For Al-alloy A384 material a moderate fracture toughness value is obtained.

Key Words: **Fracture toughness, Fatigue crack growth, Mode I loading, Al-alloy A384, Plain strain condition**

I. INTRODUCTION

In today's generation ships, aircraft and rockets are extremely complex engineering systems with many thousands of components. In the construction of such systems it is impossible to complete avoid the presence of flaws such as cracks. Understanding the strength of materials in the presence of cracks is thus key to developing reliable aerospace and ocean engineering hardware. This experiment is designed to illustrate how strength in the presence of cracks - termed Fracture Toughness - is characterized and measured. Here, the fracture toughness of one of the aluminium alloy (A384) is measured, aluminium being the dominant material used to build aircraft and spacecraft.

Most of engineering machine parts and structures are failed by fatigue and fracture causes problem. Our aim to understand how materials fail and how crack start and propagate, how we control it and our ability to prevent such failures. Aluminium alloys have more advantages in aircraft, spacecraft and submarine mainly due to excellent combination of properties such as, Excellent cast-ability, Good surface finish, Lightweight, Fewer tendencies to oxidation, Lending to modification, Low coefficient of thermal expansion, High strength-to-weight ratio, Excellent corrosion resistance and Acceptable strength.

These properties lead to their increased application in many automotive, aerospace and engineering Sectors where wear, tear and fracture are the major problems in addition to the weight saving. One of these components is a piston, which plays a vital role in automotive engines.

In the aluminium industry, significant progress has been achieved in providing "improved" alloys with good combinations of strength, fracture toughness, and resistance to stress-corrosion cracking. Optimum selection and use of fatigue resistant aluminium alloys also has become more of a factor for designers and materials engineers for extending fatigue life and/or structural efficiency. Characteristics of a wide variety of commercial aluminium alloys and tempers provide specific combinations of strength, toughness, corrosion resistance, weld ability, and fabric ability. The relatively high Strength-to-weight ratios and availability in a variety of forms make aluminium alloys the best choice for many engineering applications. Therefore, aluminium is an ideal material for structural applications in a wide range of operating temperatures and loading rates. The objective of this project work is to study the fracture toughness behavior of aluminium alloy. This project focus on how much resistant offered by the material to the crack growth at room temperature using fracture toughness testing machine under mode 1 loading.

II. MATERIALS USED

Material selected for research was Al-alloy A384 and this material has got good structural property because of that it will be used in aerospace, aircraft and engine applications. lot of research is been done to know its mechanical properties so for no one has done fracture toughness study because of that toughness study is done. The material composition research procedure is explained in details as follow.

Chemical Composition of the Al-alloy (A384)

The table 1 shows Chemical Composition of Aluminium alloy A384. And its properties are shown in table 2. Aluminium and along with Silicon (Si), Ferrous (Fe), Zinc (Zi) and Copper (Cu) has been explained in details below.

Table 1: Chemical compositions of Al –alloy A384

Mechanical properties	**Values**
Young's Modulus	71 GPa
Ultimate Tensile Strength	331 MPa
Yield Strength	165 MPa

Density	$2.82 \times 10^{-0.06}$ kg/mm^3
Poisson's Ratio	0.33

Table 2: Mechanical properties of Al – alloy A384

Composition	Wt %
Silicon (Si)	10.5-12.
Ferrous (Fe)	1.3
Copper (Cu)	3-4.5
Magnesium (Mg)	0.1
Manganese (Mn)	0.5
Nickel (Ni)	0.5
Zinc (Zn)	3
Tin (Sn)	0.35
Other	0.05
Aluminium	Balance

$= \frac{PL}{bd^2}$ N/mm^2

III. METHODOLOGY

- Selection of Material for manufacturing Al-alloy A384
- Casting of Al-alloy A384 material by using Stir cast Method
- Removal of impurities from raw Al-alloy A384 material by Machining process
- Preparation of Specimen According to ASTM Standard
- Determination of Fatigue precrack Load
- Testing the Specimen in UTM (axial fatigue testing machine) under load
- Analytical Calculation for All-alloy A384
- Comparative Study between Experimentally and Analytically
- Result and Discussion
- Conclusion

IV. EXPERIMENTAL DETAILS

CASTING PROCESS:

The stir casting method has been used to make aluminium alloys A-384, Because of easy processing, cost efficiency and economical point of view fabrication of any kind of aluminium alloy will be done by stir casting method. Aluminium Alloy A384 is melted in a crucible by heating it in a muffle furnace at 800$^{\circ C}$ for some time. Alloys were preheated at 1000$^{\circ C}$ and 900$^{\circ C}$ respectively for onto three hours. The temperature was first raised about 750$^{\circ C}$ above the liquids temperature of aluminium alloy, to melt it completely and was then cooled down just below the liquids to keep the slurry in semi solid state. Stirrer was carried out for about 10 minutes at stirring rate of 290 RPM. At this stage, the preheated Aluminium particles were added manually to the vortex. In the final mixing processes the furnace temperature was controlled within 700 ±10$^{\circ C}$. After stirring process the mixture was pour in the mould to get desired shape of specimen. Fallowings are the equipments used in the casting process.

Electrical muffle Furnace: In electrical muffle furnace the electrical energy is converted into the heat.

Stirring Unit: The stirring is carried out in electrical muffle furnace to perform the homogeneous and uniform distribution of alloys the stirrer is inserted in the muffle furnace and the stirring is started slowly like it is mechanical impeller. The stirrer material is mild steel and speed of the stirrer is 200-300 rpm.

Casting Die: A die is a hollow container that will hold the liquid material until it turns solid. The liquid hardens adopting its shape. The prepared molten form of Al-alloy A384 is poured into die to form its shape and material used for die is EN-8 because its improved strength over the mild steel and dimension used for manufacturing is 50×50×10 mm.

SPECIMEN PREPARATION: In the Present work specimen used was compact tension (CT) because the compact geometry consumes less material, but this specimen requires extra material in the lateral direction, due to presence of holes in specimen. The specimens is prepared as per ASTM standard E399 in L-T direction and its details are given in figure 1.

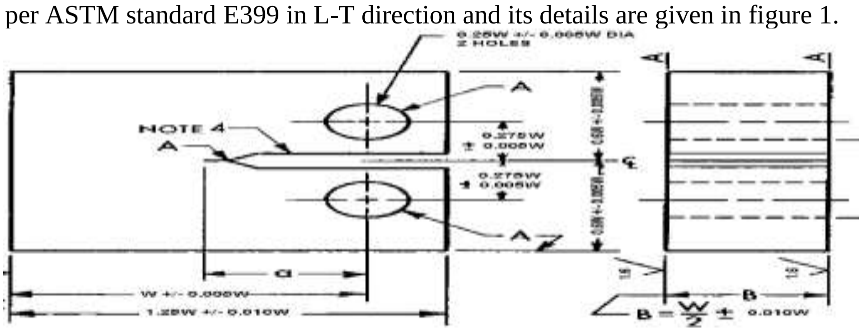


Figure: 1 Compact tension specimen configuration

MACHINING: Machine used for preparation of compact tension specimen is carried out which is prepared on CNC wire cut Electronic Discharge Machine (EDM), Which is prepared according to ASTM E399. In this wire material used is molybdenum and wire diameter is 0.18mm and standard prepared compact tension specimen shown in figure 2.

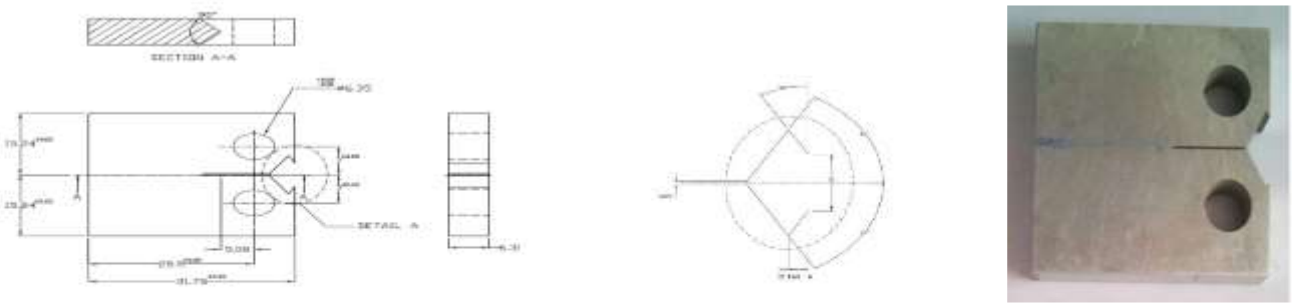


Figure: 2 Standard prepared compact tension specimen

General Information and Requirements for Fracture toughness test

Specimen Size:

In order to consider results to be valid, the sample ligament size (W-a) must be not less than 2.5 × (KIc / σ_{ys}) ^{2}, In the environment and orientation, and the temperature and load rate test**.** For sample sizes to meet the maximum constraint and size requirements associated with sample size, the following dependencies must be followed. Once the fracture toughness value K_Q is known and specimen dimensions .the test is valid only if K_Q becomes KIC and it should satisfy fallowing inequalities.

$$a = \text{crack depth} > 2.5 \times (KIc/\sigma_{ys})^2$$
$$B = \text{specimen thickness} > 2.5 \times (KIc/\sigma_{ys})^2$$
$$W = \text{specimen depth} > 5.0 \times (KIc/\sigma_{ys})^2$$

Specimen Configuration:

Standard configuration for general proportions is shown in figure 16. The configuration may also have $2 \leq W / B \leq 4$, but the other proportions will not change.

Specimen Proportions:

Crack size a, nominal width of 0.45 ~ 0.55 times.

Specimen Orientation:

Orientation is such a important variable for fracture toughness measurements. ASTM fracture testing standards require that the orientation be reported along with the measured toughness; ASTM has adopted a notation for this purpose. The letters L is longitudinal; T is lateral and S short transverse directions, with respect to the rolling direction or the forging axis. Two letters are required to determine the orientation of the fracture mechanics sample; the first letter indicates the direction of the main tensile stress that is always the plane of perpendicular to mode 1 crack test and the second letter indicates the direction of the crack propagation.

Fatigue precracking: Fatigue precracking produced on same machine as on fracture toughness test machine. The objective of fatigue pre crack is to produce a sharp crack. It is required because to simulate a straight crack in test specimen. Fatigue cycling is continued until a sharp crack is produce and it satisfies the fallowing requirements.

- Crack size that is total size of the crack starter plus fatigue crack shall be between 0.45 W and 0.55 W.
- Fatigue crack size on each face of specimen shall not less than the larger of 0.025 W or 1.3 mm. Its needs only emerge.

For producing sharp crack fatigue pecracking load is required which is calculated from below formula:

$$\boldsymbol{Pf} = \frac{0.4Bbo^2\sigma y}{(2W+ao)} = \frac{0.4\times6.35\times(13.97)^2\times247.5}{2\times25.5+11.43} = \mathbf{1.97\ K}$$

Figure: 3 Exp. Setup Machine

Figure: 4 Fatigue precrack Specimen

Figure: 5 Fracture CT specimen

V. EXPERIMENTAL PROCEDURE: The Standard mechanically worked environment condition state of compact tension specimen kept in fixture in universal testing machine(Axial fatigue testing machine) and all standard dimension, properties are input through monitor and fatigue precracking load is applied to the specimen when it is precrack is produce on specimen after that a tension load is applied till it reaches the fracture and all the autographic results are formed and results are tabulated and same procedure is repeated for different specimen.

VI. EXPERIMENTAL RESULT

Specification for specimens 1, 2 and 3

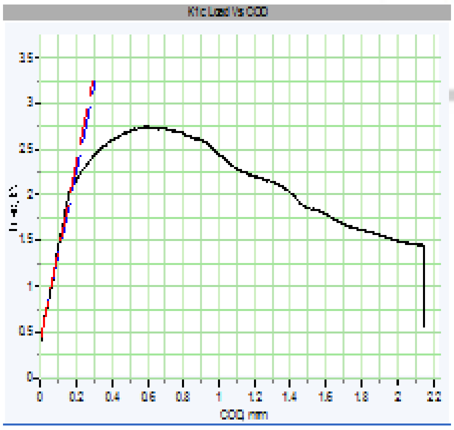
Experimental results for specimen 1, 2 and 3

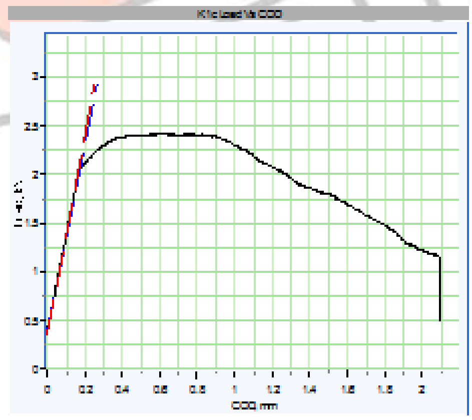
Table 3: Specification for specimen 1, 2 and 3

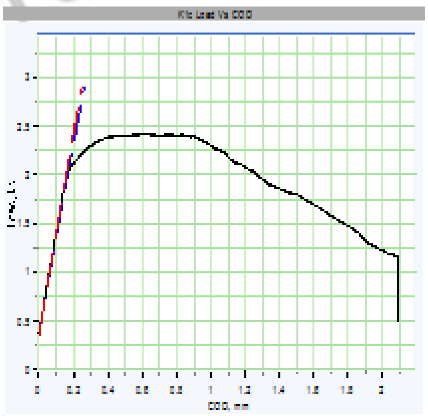
INPUTS	VALUES		
	SPECIMEN-1	SPECIMEN-2	SPECIMEN-3
Geometry	CT Specimen	CT Specimen	CT Specimen
Test Control	Stroke	Stroke	Stroke
Displacement	5 mm	5 mm	5 mm
Rate	0.01 mm/sec	0.01 mm/sec	0.01 mm/sec
Thickness	6.35 mm	6.35 mm	6.35 mm
Poisson's Ratio	0.33	0.33	0.33
Width	25.5 mm	25.5 mm	25.5 mm
Net Thickness	6.35 mm	6.35 mm	6.35 mm
Modulus	71 GPa	71 GPa	71 GPa
Yield Stress	165 MPa	165 MPa	165 MPa
Tensile Strength	331 MPa	331 MPa	331 MPa
Initial a/w	0.4693967	0.4799417	0.4752941

Table 4: Experimental result for specimen 1, 2 and 3

SPECIMENS	EXPERIMENTAL RESULT				
	a/w	P_{max} (KN)	P_Q (KN)	K_{max} (MPA)	K_Q (MPA)
1	0.4693	2.75	2.127	23.861	18.492
2	0.4799	2.424	2.046	21.731	18.343
3	0.4752	2.836	2.031	23.146	18.784







Graph: 1 Load vs COD for specimen 1 Al – alloy A384

Graph: 2 Load vs COD for specimen 2 Al – alloy A384

Graph: 3 Load vs COD for specimen 3 Al – alloy A384

The resulting graphs that is graph 1-graph 3 shown for all three specimen, From this graphs and output results, It is observed that 5% of secant offset line is drawn and it is intersection with P-COD curve .The 5% of secant line is drawing by having its slope 5% less than P-COD curve .Where in the intersection point fracture load P_Q is found to be 2.068 MPa till that load the P-COD curve curve is linear and the maximum load(P_{max}) for material is observed around 2.67 MPa at COD 0.7 mm then after there will be shows complete 'pop in' instability where initial crack movement propagate rapidly to complete fracture and the P-COD curve is suddenly drops.

VII. ANALYTICAL CALCULATION FOR SPECIMEN 1, 2 AND 3

SPECIMEN-1	SPECIMEN-2	SPECIMEN-3
$K_Q = \frac{PQ}{B\sqrt{W}} f(a/w)$ $K_Q = \frac{2127\times 8.704}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$	$K_Q = \frac{PQ}{B\sqrt{W}} f(a/w)$ $K_Q = \frac{2042\times 9.512}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$	$K_Q = \frac{PQ}{B\sqrt{W}} f(a/w)$ $K_Q = \frac{2031\times 8.960}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$
K_Q = 18.25 Mpa	**K_Q = 19.15 Mpa**	**K_Q = 17.94 Mpa**
$K_{max} = \frac{Pmax}{B\sqrt{W}} f(a/w)$ $K_{max} = \frac{2745\times 8.704}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$	$K_{max} = \frac{Pmax}{B\sqrt{W}} f(a/w)$ $K_{max} = \frac{2424\times 9.512}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$	$K_{max} = \frac{Pmax}{B\sqrt{W}} f(a/w)$ $K_{max} = \frac{2836\times 8.960}{6.35\times 10^{-3}\times\sqrt{25.5\times 10^{-3}}}$
K_{max} = 23.562 Mpa	**K_{max} = 22.73 Mpa**	**K_{max} = 25.05 Mpa**

Table 5: ANALYTICAL CALCULATION FOR SPECIMEN 1, 2 AND 3

Comparison of experimental and analytical calculation results:

SPECIMENS	EXPERIMENTAL					ANALYTICAL				
	a/w	P_{max} (KN)	P_Q (KN)	K_{max} (MPA)	K_Q (MPA)	a/w	P_{max} (KN)	P_Q (KN)	K_{max} (MPA)	K_Q (MPA)
1	0.4693	2.75	2.127	23.861	18.492	0.4693	2.75	2.127	23.562	18.25
2	0.4799	2.424	2.046	21.731	18.343	0.4799	2.424	2.046	22.73	19.15
3	0.4752	2.836	2.031	23.146	18.784	0.4752	2.836	2.031	25.05	17.94

Table 6: Comparison of experimental and analytical calculation

VIII. CONCLUSION

For given a / w ratio or crack length to width fallowing experimental observations are made:

- It is observed that the moderate fracture toughness value around 22.91 MPa is obtained for Al-alloy A384.
- The fatigue pre cracking load is obtained for Al-alloy A384 material is 1.97 KN which is required produce sharp crack near the crack tip.
- The maximum load (P_{max}) obtained before complete fracture of specimen is around 2.67 KN.
- For Al-alloy A384 the fracture load (P_Q) is obtained is about 2.068 KN.
- The provisional fracture toughness of Al-alloy A384 was observed around 18.53 MPa.
- Analytical calculation like provisional fracture toughness and fracture toughness for Al-alloy A384, were calculated is 18.44 MPa and 23.78 MPa respectively.
- Comparative study between experiment and analytical value of fracture toughness is made and it is observed that, there is only 3% error between them.

ACKNOWLEDGEMENT

I wish to express my sincere thanks & gratitude to thank my parents, teachers & all people who have helped me directly or indirectly for the completion of this project work. I hereby acknowledge with deep sense of gratitude the valuable guidance, encouragement and suggestions given by my M-Tech project guide and course coordinator Prof. Ambadas kadam & I also thank Prof. Babu Reddy, who had been a constant source of inspiration and entails the the theoretical knowledge of this subject throughout this project.

REFERENCES

[1] Anderson, T. L. 2005. Fracture mechanics: Fundamentals and applications. 3rd ed. Florida, USA: CRC Press.

[2] Pehrson, Brandon Paul, "Fracture Toughness: Evaluation of Testing Procedure To Simplify JIc Calculations. Master's Thesis, University of Tennessee, 2005.

[3] Elastic plastic fracture behaviour and effect of band-overload on fatigue crack growth rate of an HSLA steel by omrakash National Institute of Technology Rourkela, Odessa.
[4] Zhu, Xian-Kui and Joyce, James ., "Review of fracture toughness (G, K, J, CTOD, CTOA) testing and standardization" (2012). U.S. Navy Research. 49.
[5] SaleemsabDoddamani, Mohamed Kaleemulla,FratturaedIntegritàStrutturale, 41 (2017) 484-490; DOI: 10.3221/IGF-ESIS.41.60.
[6] Evaluation of Fracture Toughness and Mechanical Properties of Aluminium Alloy 7075, T6 with Nickel Coating, 97 (2014) 178 – 185 AT ELSVAIR.
[7] Sumod Daniel, Dr .G.Harish , IOSR Journal of Engineering (IOSRJEN),ISSN (e): 2250-3021, ISSN (p): 2278-8719 Vol. 04, Issue 02 (February. 2014).
[8] Puneeth.N, Satheesh.J, G. Anil Kumar Review on Evaluation of Fracture Toughness of Al 6082/AL2O3/AL2SiO5 Metal Matrix Composites , Emerging Research in Management &Technology ISSN: 2278-9359 (Volume-6, Issue-2).
[09] Ajit Bhandakkar1, R C Prasad1, Shankar M L Sastry, Fracture Toughness of AA2024 Aluminum Fly Ash Metal Matrix Composites, International Journal of Composite Materials 2014, 4(2): 108-124 DOI: 10.5923/j.cmaterials.20140402.10.

[10] Elements of fracture mechanics by prashantkumar published by tatamchgrawhil education private limited,7estpatelnagar,Newdelhi.