# ANALYSIS OF STRESS INTENSITY FACTOR OF AL7075 T651 PLATE WITH CRACKED HOLE -A CONSTANT CRACK LENGTH METHOD

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## ABSTRACT

The paper deals with analysis of Stress Intensity Factor (SIF) of Al7075-T651 plate modeled with two dimensional Through Crack. The crack is modeled in the plate with constant crack length and its stress intensity factor is studied under various loading conditions. In this method, the crack length is kept constant and the tensile load acting on the model is varied to study the effect of the load on the crack. The 2-Dimensional model is generated with crack length and they are subjected to different tensile load. The Stress Intensity factor is calculated for each tensile load. The change in stress intensity factor with change in tensile load is studied and the impacts in all crack models are studied. Also the single crack emanating from the hole and cracks from adjacent hole towards one another is studied.

**Keywords:** stress intensity factor, crack length, beta function, tensile load, Al 7075 T651.

## 1. INTRODUCTION

The technological advancement in the creation of new materials has enabled a wide scope for the material selection for different application, but the problem of fracture and susceptibility of the material towards crack propagation poses a serious threat in the usage of material in the long run. The material used for engineering application is considered as homogenous and flawless, but the material formed by manufacturing does have some flaws and defects. These materials when used fail before the estimated life cycle. Small defects such as scratch, blow holes and micro cracks have the major impact under a particular environment and loading condition. These defects under repeated loading and environmental change develop into cracks that pose serious problems while in service. The fracture mechanics deals with the crack analysis, the behaviour of the crack and the propagation of the crack in a particular environmental condition. Understanding of fracture mechanics is essential in dealing with the problems. This work deals with the study of the stress intensity factor along the crack. The stress intensity factor defines the stress field around the crack.

The aerospace industries faced a serious threat in the early years of aviation history as the sudden failures of the structures were unexplained [8]. The aircraft structures are made of material with high strength to weight ratio and the design safety factor close to unity. The sudden failure of the components or structure risks the life of many people travelling in the aircraft and billions of dollars spent to make the aircraft. The model described in the study is the plate made of Al7075-T651 with two holes at the centre and the crack formed around the hole. These plates are specifically used for aircraft structures with riveted holes. The environment in which the plates are going to be used is susceptible to temperature change and the loading effect.

The environment can transform the micro cracks into major cracks and cause sudden failure of the material. If the stress intensity factor is more compared to threshold stress intensity factor crack propagates [6-8].

The study of stress intensity factor helps define the stress field around the crack tip. The stress intensity factor provides the necessary details for failure of the material under tensile loading. When the stress intensity factor values increase beyond the critical value, the crack starts to open up, propagate and leads to failure of the plate.

## 2. MODELLING OF PLATE

The material used for the analysis is Al7075-T651 Aluminium Alloy [2]. Aluminium alloy has a high strength to weight ratio and finds its major application in the field of aerospace and missile engineering. This is a tempered Aluminium Alloy and corresponds to the series of 7075 Al alloys.

### 2.1 Chemical composition

**Table-1.** Chemical composition of AL7075-T651.

| Compounds | Weight percentage |
|---|---|
| Aluminium | 87 - 91.4 |
| Zinc | 5.1 - 6.1 |
| Magnesium | 2.1 - 2.9 |
| Copper | 1.2 - 2.0 |
| Iron | 0.5 Max |
| Silicon | 0.4 Max |
| Manganese | 0.3 Max |
| Chromium | 0.18 - 0.28 |
| Titanium | 0.2 Max |

**2.2 Properties**

The mechanical properties of Al7075 T651 are given below:

**Table-2.** Properties of AL7075-T651.

| Properties | Units | Value |
|---|---|---|
| Density | g/cc | 2.81 |
| Modulus of Elasticity | G Pa | 71.7 |
| Poisons Ratio | | 0.33 |
| Ultimate Tensile Strength | M Pa | 572 |
| Yield Strength | M Pa | 503 |
| Fatigue Strength | M Pa | 159 |
| Brinell Hardness | BHN | 150 |
| Shear Modulus | G Pa | 26.9 |

**3. PLATE MODEL**

The plate model as shown in Figures 2 and 3 is modelled using ANSYS with two holes at the centre of the place [1]. The plate is found to have symmetry along the centre of the hole and the crack is modelled in the horizontal plane at the ends of the hole [2]. The symmetry condition means that only one half of the plate is modelled to introduce the crack and find the stress intensity factor for the whole model [9]. The visibility of the crack at the centre of the model is more in the symmetric modelling of the plate. The plate shown in Figure-2 has two clamped portions on either ends of the model, these portions will not be modelled in ANSYS as it is used to clamp the plate while experimental analysis are carried out.

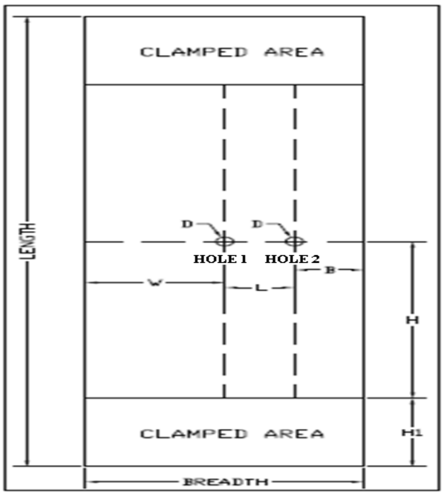


**Figure-1.** Plate model-front view.

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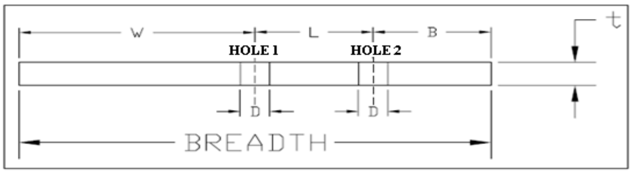


**Figure-2.** Plate model section along center.

### 3.1 Dimensions of the plate

**Table-3.** Dimension of the plate.

| t | | **6.350 mm** |
|---|---|---|
| r | 0.5t | 3.175 mm |
| $D_1$ | 1 $D_2$ | 6.350 mm |
| L | 4D | 25.40 mm |
| B | 4D | 25.40 mm |

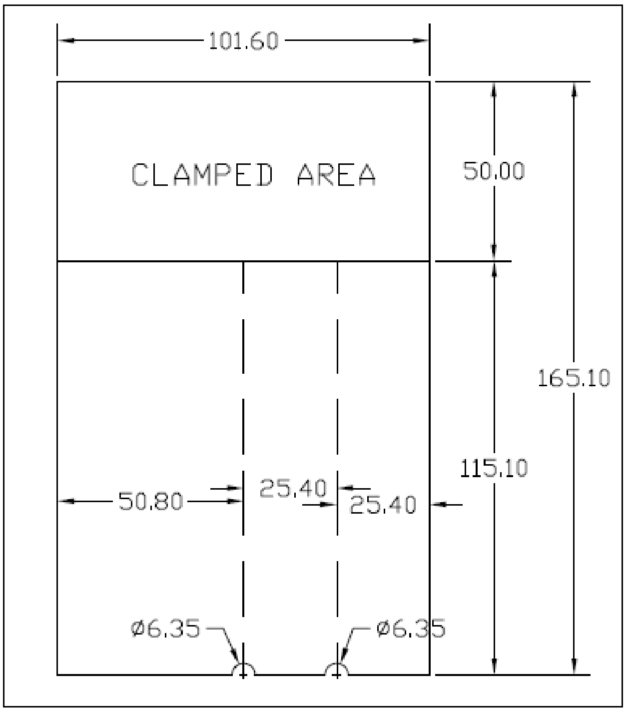


**Figure-3.** Plate dimension (Front view).

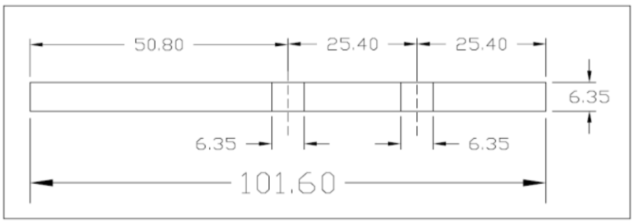


**Figure-4.** Plate dimension (Section along center).

## 4. CRACK MODEL

The major requirement in the crack analysis of the plate lies in defining the crack tip and the crack front of the model. The model is considered to be symmetric in nature along the crack face. In order to find the Stress Intensity Factor (SIF) for the crack model, the crack tip should be a singularity element. Singularity elements are defined as the quadratic elements with the mid-side nodes placed at the quarter point of the crack tip.

### 4.1 Through crack two dimensional model

The cracks that are parallel to the direction of thickness and runs throughout the thickness are known as Through Crack. These cracks are uniform throughout the model of uniform thickness. In this case, the plate has a uniform thickness and crack is parallel to the thickness of the model emanating from the hole, so the plate is modelled along with the crack in a two dimensional environment in ANSYS. Singularity elements are formed at the crack tip and the stress intensity factor is obtained.

### 4.2 Modeling

The through crack model is modelled with respect to the dimensions given in Figure 4 and 5. The key points in the global co-ordinate system are defined and this forms the edges of the model. The key point corresponding to the Crack tip is defined along with other key points. The lines are generated and area is formed using the lines. The holes are drilled using the Boolean Operation- Subtract in ANSYS command. The locations of the holes are based on the global co-ordinate system. The crack is perpendicular to the XY plane and parallel to Z direction. The element type used for the crack analysis is Plane 82[3]. This comes under the category of structural solid. These are 8 node 2 Dimensional elements and can have quadrilateral and triangular mesh.

## 5. BACKGROUND OF THE ANALYSIS

The fracture analysis is carried out to obtain the stress intensity factor at the crack tip of the model. The stress intensity factor values for Mode I [1] vary with the change in the beta function. The beta function describes the geometry and shape of the crack model [4].

### 5.1 Beta function, β

$$\boldsymbol{K = \beta\sigma\sqrt{\pi c}} \qquad [5]$$

| | |
|---|---|
| K | Stress intensity factor |
| β | Beta function |
| σ | Applied tensile load |
| c | Crack length |

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The Stress intensity factor obtained from the ANSYS FEM software is used to find the beta function. The beta function changes with respect to the change in the geometry and shape of the crack.

## 6. CONSTANT CRACK LENGTH METHOD

In this method, the crack length is kept constant and the tensile load acting on the model is varied to study the effect of the load on the crack. The 2-Dimensional model is generated with crack length and they are subjected to different tensile load. The Stress Intensity factor is calculated for each tensile load.

### 6.1 Case with single crack emanating from a hole

The model is generated with the crack formed on the side of the hole as shown in Figure 5, 6 and 7. The singularity points are generated around the crack tip and the Stress intensity factor is calculated. Individual cases are divided into numerous sub cases. Each sub cases are distinguished by the tensile load acting on the model.

**Table-4.** Subcases for different tensile load.

| **Case** | **Tensile load** (MPa) |
|---|---|
| 1.1 | 25 |
| 1.2 | 50 |
| 1.3 | 75 |
| 1.4 | 100 |
| 1.5 | 125 |
| 1.6 | 150 |

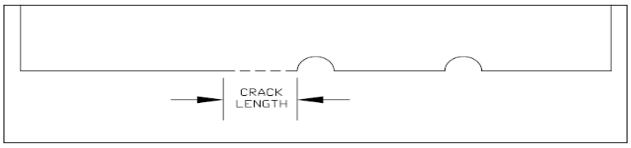


**Figure-5.** Crack Location for CASE A.

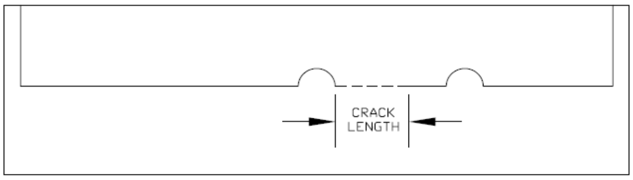


**Figure-6.** Crack Location For CASE B.

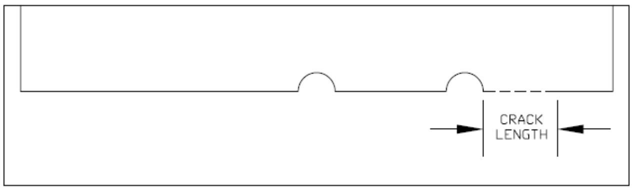


**Figure-7.** Crack Location for CASE C.

### 6.2 Results and discussions

**Table-5.** Stress intensity factor values for single crack from a hole.

| **Crack length** | **Stress intensity factor** | | |
|---|---|---|---|
| | **Case A** | **Case B** | **Case C** |
| 25 | 85.227 | 85.811 | 81.221 |
| 50 | 183.33 | 185.71 | 188.43 |
| 75 | 357.02 | 362.77 | 370.52 |
| 100 | 539.71 | 548.39 | 557.91 |
| 125 | 749.32 | 778.07 | 808.91 |
| 150 | 1023.8 | 1064.4 | 1115 |

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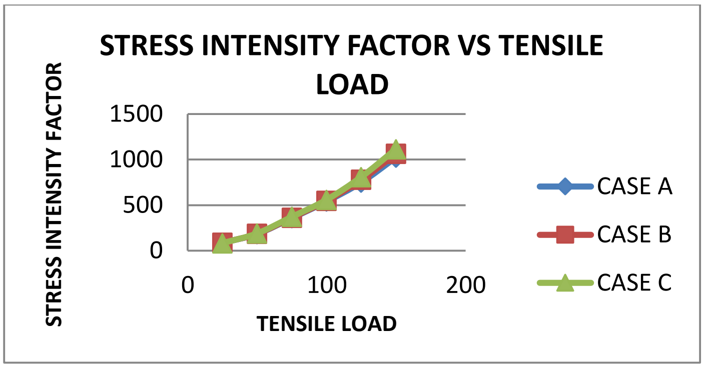


**Figure-8.** Plot of stress intensity factor vs tensile load.

**Table-6.** Beta function for single crack from a hole.

| Crack length | Beta function | | |
|---|---|---|---|
| | Case A | Case B | Case C |
| 25 | 0.727 | 0.7319 | 0.6928 |
| 50 | 0.7819 | 0.792 | 0.8036 |
| 75 | 1.0151 | 1.0314 | 1.0535 |
| 100 | 1.1509 | 1.1694 | 1.1897 |
| 125 | 1.2783 | 1.3273 | 1.38 |
| 150 | 1.4555 | 1.5132 | 1.5851 |

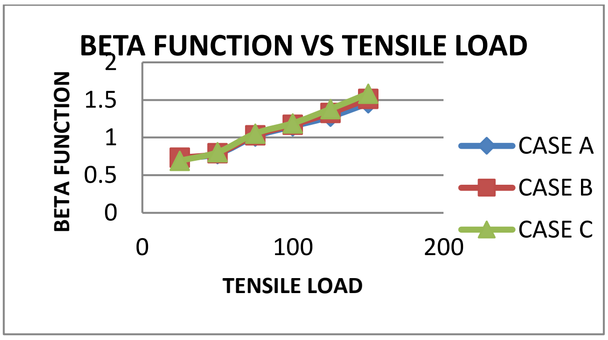


**Figure-9.** Plot of beta function vs tensile load.

The results show the impact of the change in the tensile load on the location of the crack. The stress intensity factor of the different cases is found to increase with the change in the tensile load applied to the model. The Figure-8 shows the change in the stress intensity factor remains constant for different cases under lower tensile load. As the tensile load increases, the stress intensity factor values for different load cases start to deviate. The same trend can be found in the Figure-9 showing the beta function plotted against tensile load.

## 7. CRACKS FROM ADJACENT HOLE TOWARDS ONE ANOTHER [10]

The model is generated with the crack at the both sides of the hole as shown in Figure-10. The cracks are formed between the holes. The singularity points are generated around the crack tip and the Stress intensity factor is calculated. Individual cases are divided into numerous sub cases. Each sub cases are distinguished by the tensile load acting on the model.

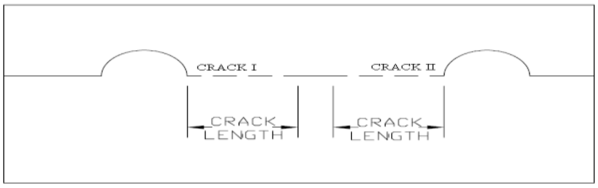


**Figure-10.** Crack locations for Case D.

**Table-7.** Subcases for different tensile load.

| Case | **Tensile load** (mpa) |
|---|---|
| 2.1 | 25 |
| 2.2 | 50 |
| 2.3 | 75 |
| 2.4 | 100 |
| 2.5 | 125 |
| 2.6 | 150 |

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### 7.1 Results and discussions

**Table-8.** Stress intensity factor values for Case D.

| Case | Tensile load (MPa) | Stress intensity factor k | BETA | Stress intensity factor K | Beta |
|---|---|---|---|---|---|
| | | Crack 1 | | Crack 2 | |
| 2.1 | 25 | 104.53 | 0.8916 | 95.03 | 0.8106 |
| 2.2 | 50 | 233.99 | 0.9979 | 209.72 | 0.8944 |
| 2.3 | 75 | 448.39 | 1.2749 | 405.11 | 1.1518 |
| 2.4 | 100 | 673.48 | 1.4361 | 609.06 | 1.2988 |
| 2.5 | 125 | 973.62 | 1.6609 | 875.71 | 1.4939 |
| 2.6 | 150 | 1340.2 | 1.9052 | 1192.6 | 1.6954 |

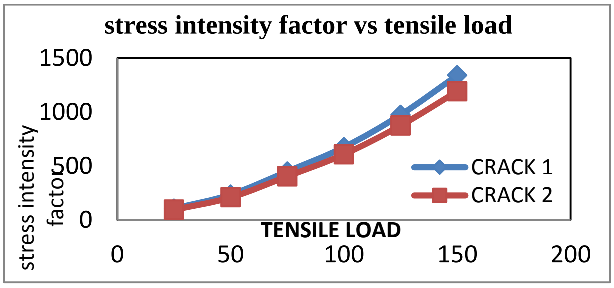


**Figure-11.** Plot of stress intensity factor vs tensile load for Case D.

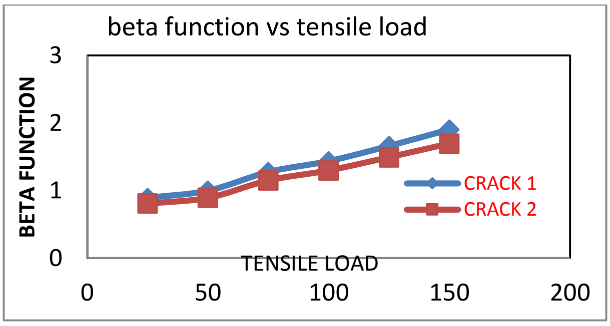


**Figure-12.** Plot of beta function vs tensile load for Case D.

The applied load on the model is changed and the stress intensity factor for each model is studied. The stress intensity factor shows a rise in the value with the change in the tensile load. The change in stress intensity factor is non linear with the change in the tensile load. The curve is similar in all the cases and the change in the load has similar impact on all the crack models shown above.

## CONCLUSIONS

The study clearly shows that stress intensity factor varies with respect to load applied when the crack length is kept constant under different location of crack. The impact of the change in the tensile load on the location of the crack can be seen. The stress intensity factor of the different cases is found to increase with the change in the tensile load applied to the model. The stress intensity factor shows a rise in the value with the change in the tensile load. The change in stress intensity factor is non linear with the change in the tensile load.

The study clearly defines the crack propagation is possible when numerical stress intensity factor increases with increase in load even the length of the crack defined for problem is same throughout the application of load. The location of crack also plays a vital role in propagation of crack. While looking closely at the cases considered the stress intensity factor increases predominantly with the position of crack in case C with increase in tensile load.

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