

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: [www.ijirset.com](http://www.ijirset.com)

Vol. 6, Issue 4, April 2017

# Evaluation of Stress Intensity Factor and Initial Crack Path in Cracked GI Sheet

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**ABSTRACT:** Structures are subjected to unfavourable changes in their structural properties which are mainly due to errors in design and construction, heavy loads, fatigue or other degradation. Plate structures are very much sensitive to the formation of cracks and its growth which adversely affects its performance. Induced or self occurring defects, notches, holes acts as stress concentration zone which initiates the crack formation. Understanding the severity of cracks is important to predict the life of component. According to linear elastic fracture mechanics, stress intensity factor is a key parameter in determining the severity of crack. Higher factor of safety was chosen for unforeseen factors years ago. Development of fracture mechanics enables a designer to use a lower factor of safety, thereby reducing the cost of such structural components. The weight of these components is also reduced and their reliability is enhanced. In this work, experimental and analytical determination of combination of stress intensity factors for rectangular plates with various inclined through crack subjected to uniaxial load at failure and direction of initial crack path are determined.

**KEYWORDS:** stress concentration zone, stress intensity factor, inclined through crack, initial crack path.

### I. INTRODUCTION

Cracks are obvious in any structure. Especially plates are highly prone to crack. But all cracks are not dangerous. It depends upon the potency of a crack. There are various methods to determine the potency of a crack such as Displacement related approach which includes Crack tip opening displacement method or Stress related approach in which stress intensity factor is a key term.

Stress intensity factor is nothing but a parameter which describes the severity of a crack. At the tip of crack where radius is zero, stress becomes infinity. Thus it becomes difficult to determine the severity of crack. In such cases, Stress intensity factor gives a value at the crack tip. Greater the value of stress intensity factor, greater will be the crack severity.

The work in this paper is divided in two stages. 1) Evaluation of combination of stress intensity factors in GI sheet at which failure occurs 2) Determination of initial crack path in GI sheet. Stress intensity factor is determined using experimental and numerical studies whereas initial crack path is determined using experimental and theoretical studies.

### II. RELATED WORK

Investigation about the optimal pre-cracked length in order to eliminate the effect of the SIF and the fracture toughness was done in [1]. Effort to present various techniques developed for stress analysis and stress intensity factor was studied in [4]. Four parameters have been well accepted to measure the potency of a crack. Investigation on the SIF near crack tip under different loading modes in a finite plate of araldite with four geometric configurations under three loads

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for varying a/w ratio was conducted in [10]. The results were compared with those obtained from photoelasticity method and observed that the stress intensity factor is greater in case of crack approaching a circular and triangular hole.

### III. EXPERIMENTAL WORK

Experimental study was conducted to determine the stress intensity factor of GI sheet with inclined through crack. The size of specimens for GI sheet were 250mm x 60mm x 1mm with an inclined through crack of 20mm size with various inclination angles ranging from 15,30,45,60 and 75 degrees. The specimens were tested in Universal testing machine having a capacity of 1000 kN for tension test. The stress intensity factor for inclined through crack under uniaxial loading is

$$K_I = \sigma(\sqrt{\pi a})\sin^2\beta f(a/w) \text{ and } K_{II} = \sigma(\sqrt{\pi a})\sin\beta\cos\beta f(a/w)$$

Figure 1(a) shows specimens with various inclination angles and 1 (b) to (f) shows the cracked specimens with  $\beta$  varying from 15 to 75 degrees where  $\beta$  is the angle between vertical and induced crack. These specimens were used for conducting the experimental work.

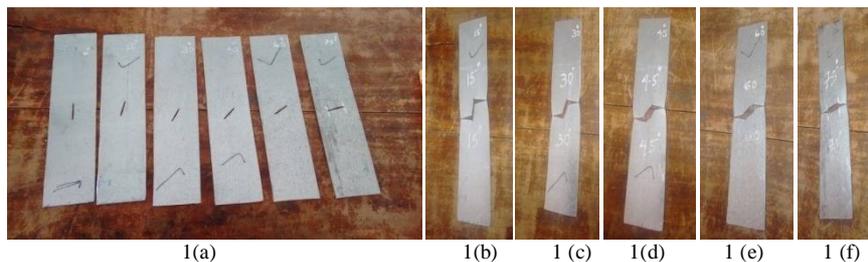


Table 1 shows the ultimate tensile stress values of GI specimens obtained from the experiment and Table 2 gives  $K_I/f(a/w)$  values obtained by substituting to the equation for stress intensity factors mentioned in experimental work.

$\beta$	15 <sup>0</sup>	30 <sup>0</sup>	45 <sup>0</sup>	60 <sup>0</sup>	75 <sup>0</sup>
Ultimate tensile stress (KN/mm <sup>2</sup> )	0.361	0.318	0.268	0.254	0.242

Table 1 Ultimate tensile stress of specimens

$\beta$	15 <sup>0</sup>	30 <sup>0</sup>	45 <sup>0</sup>	60 <sup>0</sup>	75 <sup>0</sup>
$K_I/f(a/w)$ (MPa√mm)	135.54	445.596	751.068	1067.75	1265.54
$K_{II}/f(a/w)$ (MPa√mm)	505.85	771.79	751.068	616.46	339.1

Table 2 Experimental result of Stress intensity factor

### IV. FINITE ELEMENT ANALYSIS OF GI SPECIMENS

A numerical study was done to determine the stress intensity factor for GI sheet. Ansys Workbench 15.0 software package is used for the modelling, analysis and post processing of crack. Modeling of cracked plate is done using

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ANSYS design modeller. Cracks are developed by using Fracture tab available in the model window. The specimens were loaded using appropriate boundary conditions. The solution for SIF is obtained by using Fracture tool available in the solution window. For the analysis, five rectangular plates with crack of varying inclinations as in experiment were used.

Figures 2 (a) to (d) represents the cracked model, meshed crack model, loading diagram and results for 15 degree inclined crack respectively. These are obtained on conducting analysis in ANSYS workbench.

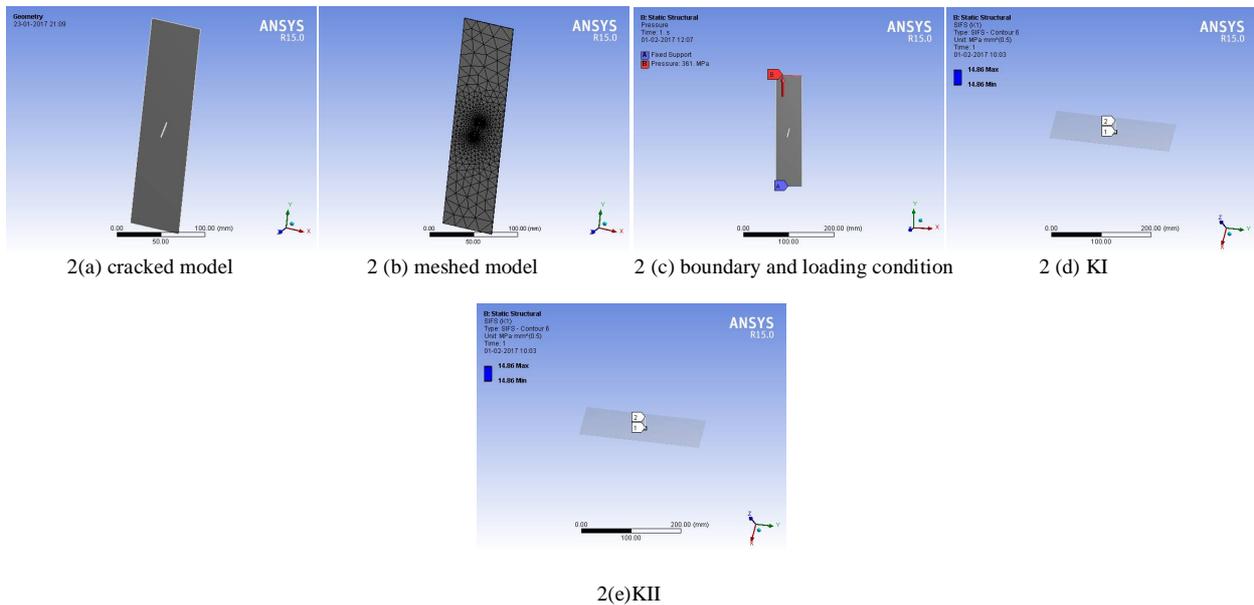


Table 3 gives ANSYS output of stress intensity factor for GI specimens.

$\beta$	$15^0$	$30^0$	$45^0$	$60^0$	$75^0$
$K_I$	14.86	119.48	263	451.22	619.29
$K_{II}$	63.924	206.98	250.11	256.92	178.11
$f(a/w)$	0.12	0.27	0.32	0.42	0.5

Table 3 Ansys output for GI specimen

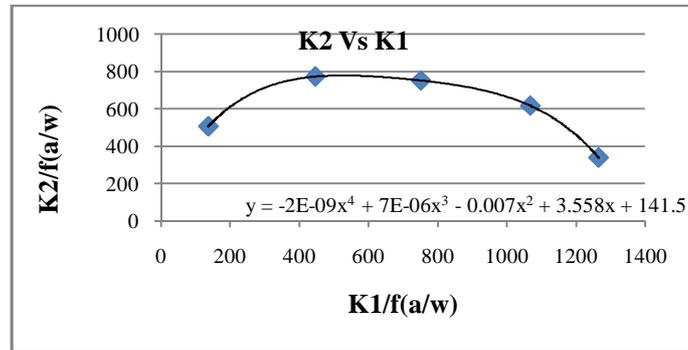
Figure 3 (a) shows combination of stress intensity factor of GI sheet at which failure occurs. This is obtained from experimental result of stress intensity factor (Table 2). This combination gives an idea about the occurrence of failure in advance.

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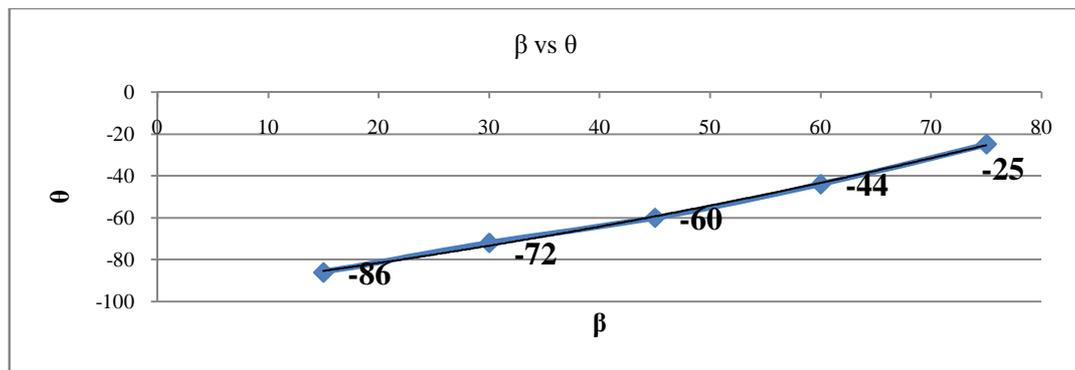
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3(a) combination of stress intensity factor of GI sheet at which failure occurs

## V. DETERMINATION OF INITIAL CRACK PROPAGATION PATH

From the tension tests done on GI sheet, the initial crack propagation angles ( $\theta$ ) were obtained and plotted for each  $\beta$  as in figure 4(a).



4(a)

Theoretically, procedure for determination of initial crack propagation angle for elasto-plastic material under plane stress condition subjected to combined state of stress and small scale yielding is described below. We know that,

$$\sigma_x = \frac{K_I}{(\sqrt{2\pi r})} f_x, \sigma_y = \frac{K_I}{(\sqrt{2\pi r})} f_y, \sigma_{xy} = \frac{K_I}{(\sqrt{2\pi r})} f_{xy} \quad (1)$$

$$\text{Where, } f_x = \cos\alpha - 0.5(\sin 2\alpha \sin 3\alpha) - \mu[2\sin\alpha + 0.5(\sin 2\alpha \sin 3\alpha)]$$

$$f_y = \cos\alpha + 0.5(\sin 2\alpha \sin 3\alpha) + 0.5\mu(\sin 2\alpha \cos 3\alpha)$$

$$f_{xy} = 0.5(\sin 2\alpha \cos 3\alpha) + \mu[\cos\alpha - 0.5(\sin 2\alpha \sin 3\alpha)]$$

$$\alpha = \frac{\theta}{2} \text{ and } \mu = \frac{K_{II}}{K_I}$$

$$\text{Equation for principal stress is } \sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2} \quad (2)$$

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On substituting equation (1) in (2), we get

$$\sigma_{1,2} = \frac{K_I}{(\sqrt{2\pi r})} \left( \frac{f_x + f_y}{2} \right) \pm \sqrt{\left[ \left( \frac{f_x - f_y}{2} \right)^2 + f_{xy}^2 \right]} \quad (3)$$

Crack propagates from the crack tip to the direction where strain energy density is maximum. The strain energy is composed of two distinct forms – volume changes and distortion. Normal strains cause a change in volume, shear strain cause distortions. The total strain energy is the sum of distortion energy and volume energy.

$$w_t = w_v + w_d$$

Where,  $w_t$  = total strain energy,  $w_v$  = dilatational strain energy and  $w_d$  = distortional strain energy.

For uniaxial loading,  $w_t = 0.5(\sigma_1 \varepsilon_1 + \sigma_2 \varepsilon_2 + \sigma_3 \varepsilon_3)$

$$= \frac{1}{2E}(\sigma_1^2 + \sigma_2^2 + \sigma_3^2) - \frac{\nu}{E}(\sigma_1 \sigma_2 + \sigma_2 \sigma_3 + \sigma_3 \sigma_1)$$

Hydrostatic stress causes volume change and that it is invariant. The hydrostatic stress can be determined from the average magnitudes of the three principal stresses.

$$\sigma_{avg} = (\sigma_1 + \sigma_2 + \sigma_3)/3$$

$$w_v = \frac{3(1-2\nu)}{2E} * \sigma_{avg}^2 = \frac{(1-2\nu)}{6E} * (\sigma_1 + \sigma_2 + \sigma_3)^2$$

$$w_d = w_t - w_v = \frac{\sigma_1^2 - \sigma_1 \sigma_2 + \sigma_2^2}{6G}$$

Therefore,

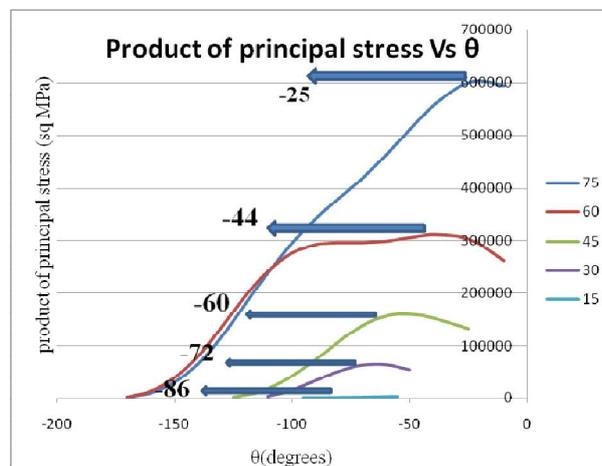
$$w_v = \frac{(1-2\nu)}{2E} * \left[ \frac{E w_d}{1+\nu} + \sigma_1 \sigma_2 \right]$$

$$w_t = w_d \left[ 1 + \frac{1-2\nu}{2(1+\nu)} \right] + \frac{1-2\nu}{2E} * \sigma_1 \sigma_2 \quad (4)$$

According to Von Mises failure theory, Yielding occurs when distortion energy in a part is equal to the distortion energy in a simple tension test.

Therefore from equation (4), maximum strain energy coincides with the point of maximum dilatational energy which in turn is proportional to the product of principal stresses.

For GI specimens, principal stresses were determined using equation (3) and the initial crack propagation angle was found out when product of principal stress was maximum as in figure 5(a).



5(a) Product of principal stress Vs θ

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## VI. CONCLUSION

In day to day life, GI sheets may be used as roofing material. Experimental and finite element analysis of rectangular specimens with inclined cracks was conducted to determine the stress intensity factor and the equation for the combination of stress intensity factors at failure for uniaxial loading were obtained.

Initial crack propagation angles for specimens with inclined crack subjected to uniaxial loading have been studied by applying mixed mode criterions. From study conducted on basis of strain energy density criterion, it was observed that crack initiates in the direction where product of principal stress was maximum.

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