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Fracture Analysis of FRP Composites Subjected to Static and Dynamic Loading

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Abstract: **The utility of stress intensity factors (SIF's) within the analysis of the issues of residual strength, fracture and fissure rate has resulted in effort being enlarged on the determination of Norse deity. The objective of this work is to analyze the strain Intensity issue (SIF) for benchmark issues for static and dynamic loading in composite plates having center, edge. Any the analysis is extended to CT specimen, plate with 3-point bend, v-notch and double edge notch. In the static associate degree analysis SIF's area unit found for an identical material mistreatment singular and j-integral approach and it's inferred that the deviation is nominal. For the orthotropic material Norse deity is seen for the higher than specimens with Carbon UD/Epoxy, R Glass UD/epoxy, S2 glass fabric/epoxy material properties. The Transient Dynamic analysis on the higher than specimens is applied. Full methodology is utilized to perform loading and therefore the J-integral approach is employed to search out the SIF's. The detail analysis mistreatment FEA is applied for hard Norse deity for the higher than specimens.**

Keywords: Strain Intensity Factor, Static And Dynamic Loading, Composite Materials, FEA.

1. INTRODUCTION

Composite material is defined as macroscopic combination of two or more materials. Macroscopic combinations are specified to exclude alloys that consist of material on microscopic scale. The need for high performance to weight ratio structure coming from the most advanced engineering fields is the main driver of the increasing usage of composite materials for crucial application. Both isotropic and orthotropic materials are used for plates and steels. Unlike conventional isotropic materials of steel and concrete. There are no readily available design charts and guidelines to help the structural engineer when it comes to working with composites. Analytical solutions for cracked plates are very limited. Aim of the present work is to provide the structural engineer with data regarding SIF and variation of stress at the crack tip using Finite Element Analysis. FEA addressing plate problem fall under two categories-one involving singularity formulations and other involving paths independent integrals approach. ANSYS allows us to model orthotropic materials with specialize elements called Layered Elements. After building a model with a layered element structural analysis can be carried out. Steel and glass polymer are taken as an orthotropic materials in our present study.

2. FRACTURE MECHANICS

Fracture mechanics is that the sphere of mechanics involved the study of the propagation of cracks in materials**.** It uses methods of analytical solid mechanics to calculate the feat on a crack and folks of experimental solid mechanics to characterize the material's resistance to fracture. The designing field if break mechanics is built up to build up an essential comprehension of split engendering, which can bring about lethal impacts. There are three fundamental methods of break: Mode I crack – Opening mode Mode II fracture – Sliding mode
Mode III fracture – Tearing mode

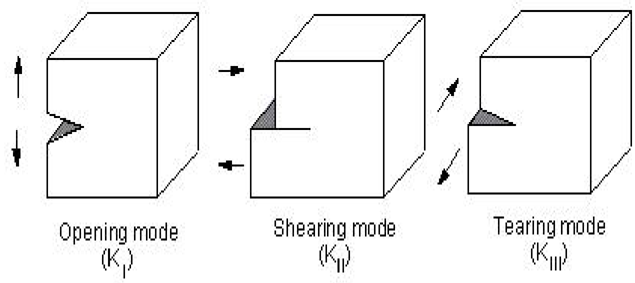

Fig 2.1: Modes of fracture

Some typical fracture parameters are:
1) Stress Intensity Factor (KI): Stress intensity factor is associated with the basic modes of fracture. It is proportional to type of load, material of the specimen and shape and size of the crack.
2) J-Integral: It is defined as a path independent line integral that measures the strength of singular stresses and strains near a crack tip.
3) Energy release rate (G): It represents the amount of work associated with the crack opening or closing.
G=KI2/2E per unit volume

2.1 CALCULATING FRACTURE PARAMETERS:

A) Stress intensity Factor: Calculate K_I, $K_{II,}$ and K_{III}.
Except for the analysis of thin plates, the asymptotic or

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near-crack-tip behavior of stress is usually thought to be that of plane strain. For half crack model,

$K_I=\sqrt{2\Pi}$ [2G/ (1+k) |v| / $\sqrt{r}$

$K_{II}=\sqrt{2\Pi}$ [2G/ (1+k) |v| / $\sqrt{r}K_{III}==\sqrt{2\Pi}$ 2G |w| / $\sqrt{r}$

The stress intensity factors at a split for a direct flexible break mechanics examination could likewise be registered (utilizing the KCALC command). The examination utilizes a work of the nodal relocation inside the territory of the break. the specific relocation at and near a split for straight versatile materials are:

$$u=\frac{K_I}{4G}\sqrt{\frac{r}{2\pi}}\left((2\kappa-1)\cos\frac{\theta}{2}-\cos\frac{3\theta}{2}\right)-\frac{K_{II}}{4G}\sqrt{\frac{r}{2\pi}}\left((2\kappa+3)\sin\frac{\theta}{2}+\sin\frac{3\theta}{2}\right)+0(r)$$

$$v=\frac{K_I}{4G}\sqrt{\frac{r}{2\pi}}\left((2\kappa-1)\sin\frac{\theta}{2}-\sin\frac{3\theta}{2}\right)-\frac{K_{II}}{4G}\sqrt{\frac{r}{2\pi}}\left((2\kappa+3)\cos\frac{\theta}{2}+\cos\frac{3\theta}{2}\right)+0(r)$$

$$w=\frac{2K_{III}}{G}\sqrt{\frac{r}{2\pi}}\sin\frac{\theta}{2}+0(r)$$

Where,

u, v, w = displacements in a local Cartesian coordinate system

r, θ =coordinates in a local cylindrical coordinate system
G= shear modulus

K_I, K_{II}, K_{III} = stress intensity factors relating to deformation shapes shown in fig 3.1

V=Poisson's ratio

0(r)=terms of order or higher

$$\kappa=\begin{cases}3-4\nu & \text{if plane strain or axisymmetric}\\ \dfrac{3\nu}{1+\nu} & \text{if plane stress}\end{cases}$$

B) J-Integral

J-Integral is one of the most widely accepted parameters for elastic-plastic fracture mechanics. The J-Integral is defined as follows:

$$J=\lim_{\Gamma\to 0}\int_{\Gamma_o}\left[(w+T)\delta_{1i}-\sigma_{ij}\frac{\partial u_j}{\partial x_1}\right]n_i d\Gamma$$

3. FRACTURE ANALYSIS OF ISOTROPIC AND ORTHOTROPIC PLATES WITH CRACKS USING FEA:

ANSYS is a finite element package used for determining the SIF and J-integral. For case study-I, Plane 82 element is used for modeling of plate under plane stress conditions as per given dimensions. For case study –II, SHELL 99 element is used varying the number of layers. The element near crack tip were meshed with crack tip elements by shifting mid side node to 1/4th distance. The meshed models are solved by applying tensile load and symmetric boundary conditions. Then the J-integrals are completed.

A) Case study-I: Isotropic plates with Centre crack

Isotropic steel plate of dimensions 10mm x 10mm x 5mm having a centre crack of 2mm and with material properties, E=48.3 GPa, υ=0.3, subjected to a tensile load=1KN has been considered to determine SIF.

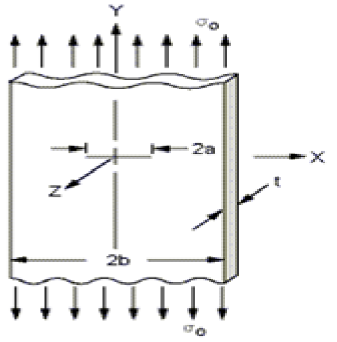

Fig 3.1: Model of plate with center crack

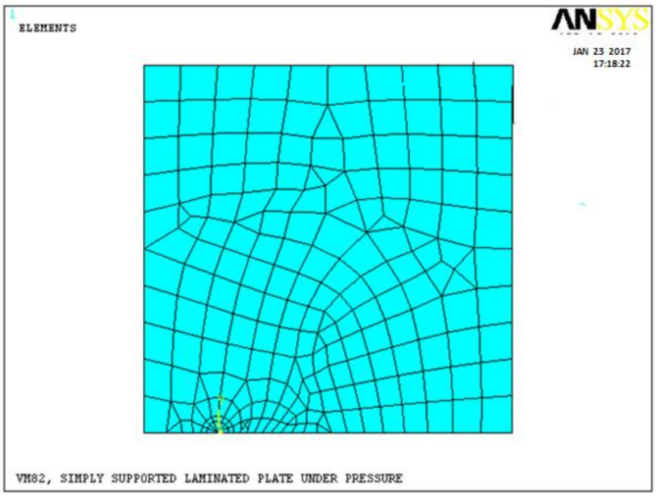

Fig 3.2: FE Model of center crack

B) Case study-II Composite plates Material properties

1) *R-glass roving UD/Epoxy*

E_x	= 48.3 GPa
E_y=E_z	= 12.4 GPa
NUXY	= 0.16
NUYZ=NUZX	= 0.28
G_{xy}	= 6.6 GPa
G_{yz}=G_{zx}	= 4.14 GPa
Density	= 2 gm/cc

2) *S_2-glass fabric/Epoxy*

E_x =E_y	= 22.925 GPa
E_z	= 12.4 GPa
NUXY	= 0.12
NUYZ=NUZX	= 0.2
G_{xy}	= 4.7 GPa
G_{yz}=G_{zx}	= 4.2 GPa
Density	= 1.8 gm/cc

3) *Carbon UD/Epoxy*

E_x	= 25 GPa
E_y=E_z	= 10 GPa
NUXY	= 0.16
NUYZ=NUZX	= 0.16
G_{xy}	= 5.2 GPa
G_{yz}	= 3.8 GPa
G_{zx}	= 6 GPa
Density	= 2 gm/cc

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C) Dynamic loading with Center crack:

Orthotropic plate of dimensions 10mm x 10mm x 5mm having a centre crack of 2mm and with the above materials, subjected to a static pressure (tensile load =1KN) and transient dynamic loading has been considered to determine SIF by varying the number of layers and a/b ratio.

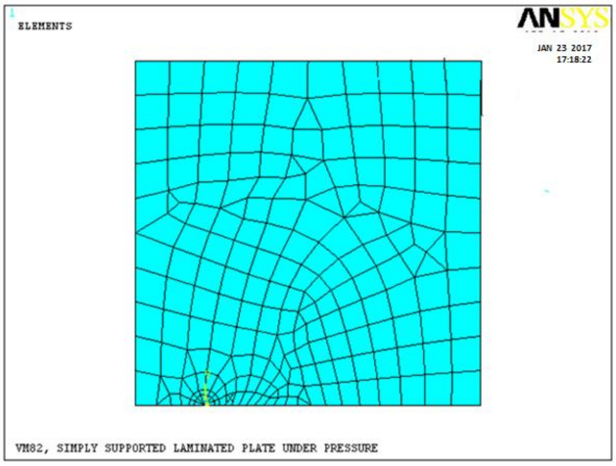

Fig 3.3: FE Model of center crack

D) Compact Tension (CT) specimen

CT specimen with the above materials, subjected to a tensile load =1KN and transient dynamic loading has been considered to determine SIF by varying the number of layers.

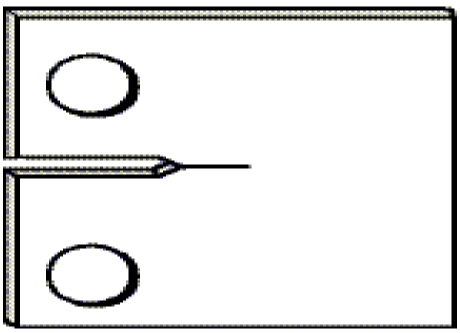

Fig 2.5: CT Specimen

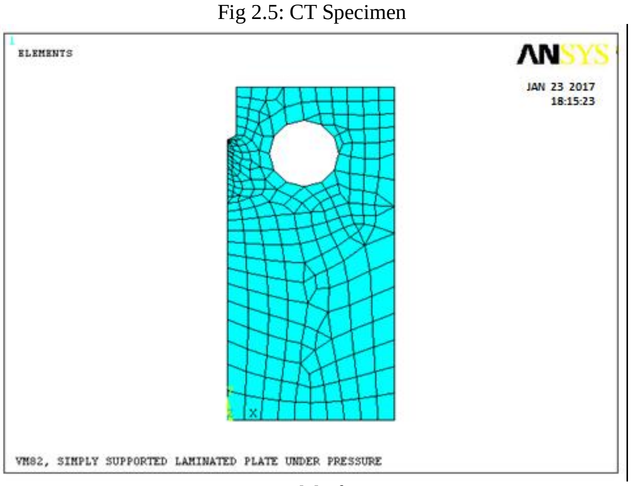

Fig 3.4: FE Model of CT specimen

Plate with 3-point bend

Orthotropic plate of dimensions 80mm x 20mm x 10mm having a 3-point bend with the above materials, subjected to a static pressure (tensile load =1KN) and transient dynamic loading has been considered to determine SIF by varying the number of layers.

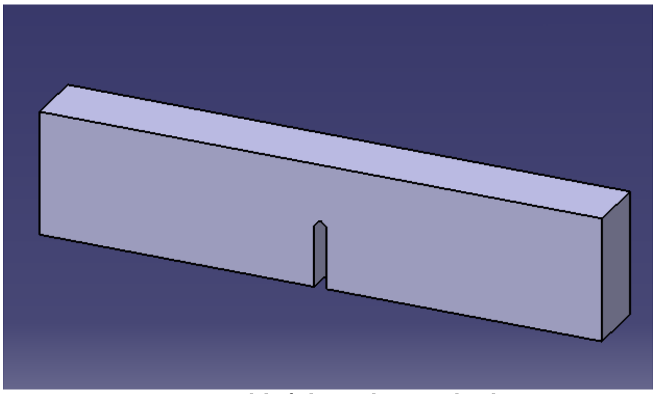

Fig.3.5 Model of plate with 3-point bend

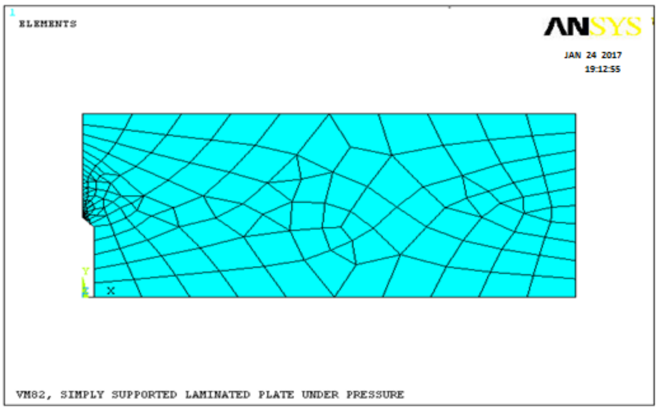

Fig. 3.6 FE Model of plate with 3-point bend

V-Notch

Orthotropic plate of dimensions 65mm x 12.7mm x 12.7mm having a v-notch with enclosed angle of 22.5° with the above materials, subjected to a static pressure (tensile load =1KN) and transient dynamic loading has been considered to determine SIF by varying the number of layers.

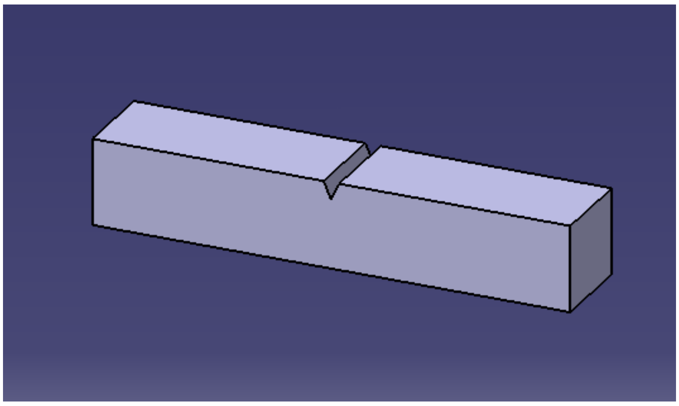

Fig. 3.7 Model of plate with V-notch

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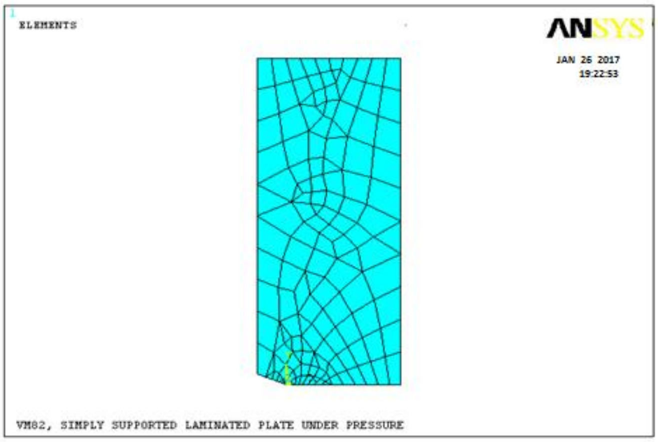

Fig 3.8 FE Model of plate with v-notch

Double Notch

Orthotropic plate of dimensions 30mm x 15mm x 2mm having two notches at a distance of 3mm from the centre with the above materials, subjected to a static pressure (tensile load =1KN) and transient dynamic loading has been considered to determine SIF by varying the number of layers.

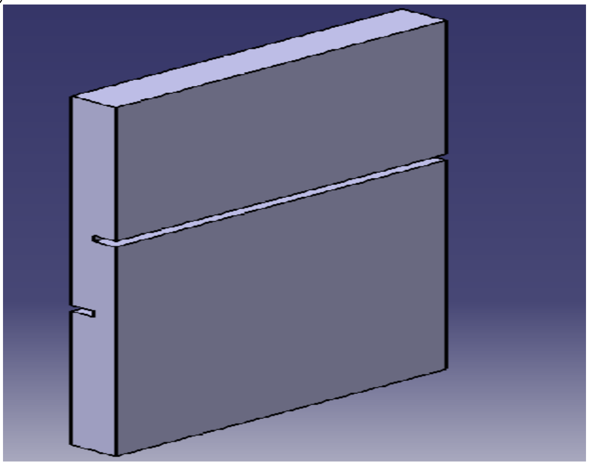

Fig. 3.9 Model of the plate with a double notch

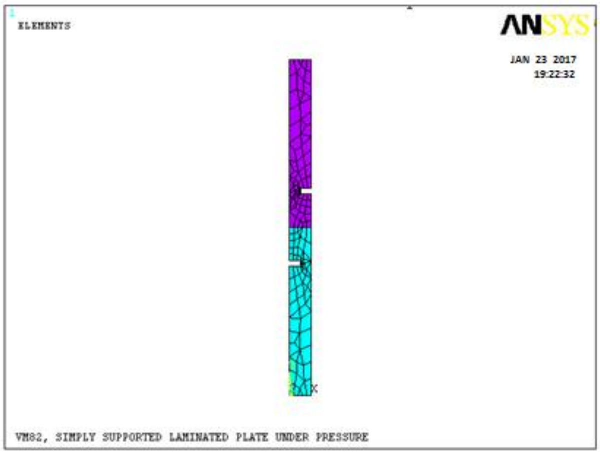

Fig. 3.10 FE Model of plate with double notch

4. RESULTS & DISCUSSIONS

A) Case-1 Table1: Isotropic Material

Approach	J -Integral	Singular	Deviation (%)
SIF	15.68854	16.659	5.8

B) Case-2 Composite Material

Static Loading Evaluation of stress intensity factor (SIF) in composite plate with center line crack

Table 2: SIF's for different layers by varying a/b ratios of R-glass UD/Epoxy material:

a/b	SIF N-mm$^{3/2}$			
layers	0.2	0.4	0.6	0.8
2	4.6631	9.1237	13.4741	14.9767
4	2.8707	5.2743	8.042	8.3692
6	3.2728	6.2711	9.5644	10.0853
8	2.8707	5.2743	8.042	8.3692

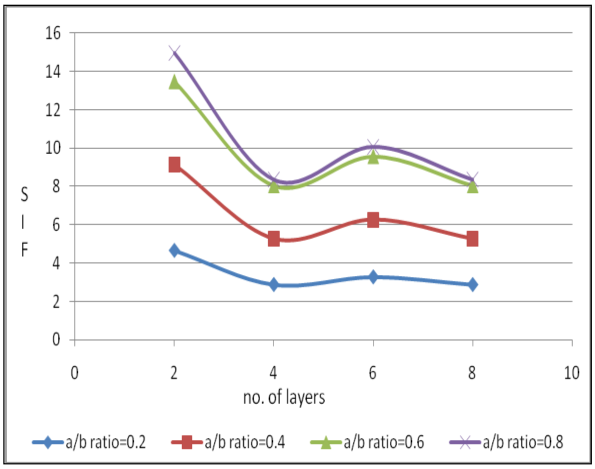

Fig 4.1: Variation of Stress Intensity Factor (SIF) with increasing number of layers

From table 1 It is observed that by increasing the a/b ratio, the SIF is increasing. This is due to the crack propagation; material separation and energy release rate is high as the crack grows. However the variation of SIF with respect to number of layers is not linear. It is observed that the SIF for the plate with 4 and 8 layers is same and for plate with 2 layers SIF is very high as compared to all other layers. Due to symmetry lay-up and when the crack is parallel to fiber direction the SIF is more and when it is in transverse direction the SIF is less.

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C) Dynamic Analysis

Table 3: Evaluation of stress intensity factor (SIF) in composite plate with center crack at the center

a/b	SIF N-mm$^{3/2}$			
layers	0.2	0.4	0.6	0.8
2	9.32633	18.2474	26.94835	43.47777
4	5.741464	10.54879	16.08412	24.29596
6	6.545719	12.5423	19.12885	29.27762
8	5.742147	10.54879	16.08412	24.29596

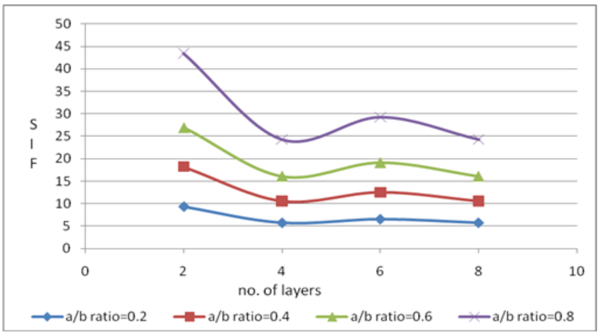

Fig. 4.2: Variation of Stress Intensity Factor (SIF) with increasing number of layers

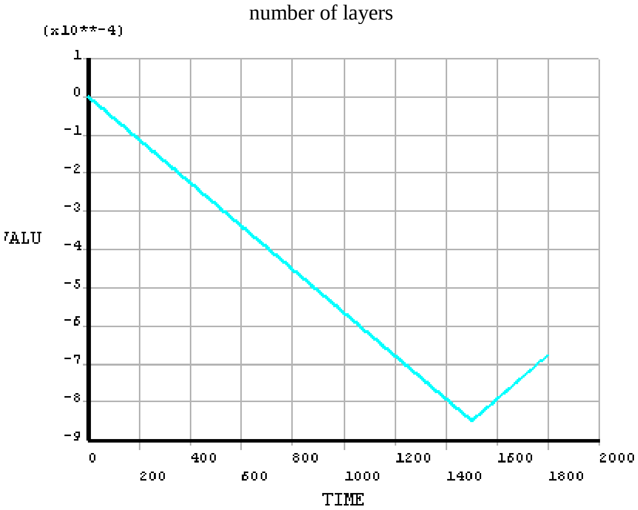

Fig 4.3: Sample response to the applied dynamic load for R-glass epoxy

From table 3 it is observed that by increasing the a/b ratio, the SIF is increasing. This is due to the crack propagation, material separation and energy release rate is high as the crack grows

Table 4: Evaluation of stress intensity factor (SIF) in CT specimen

a/b	SIF N-mm$^{3/2}$		
Layers	R-Glass	S-Glass	Carbon
2	44.5	22.222	36.9684
4	25.4088	22.222	26.4941
6	27.7692	22.225	28.4275
8	25.4088	22.222	26.4941

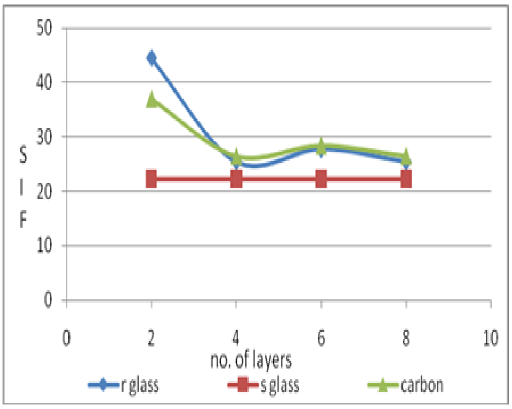

Fig. 4.4 Variation of Stress Intensity Factor (SIF) with increasing number of layers

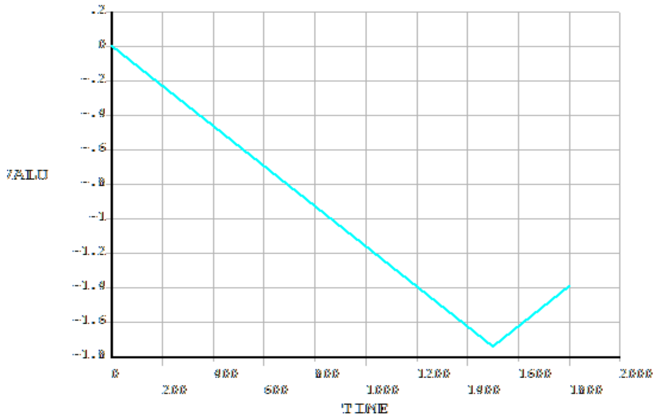

Fig 4.5: Sample response to the applied dynamic load for carbon UD epoxy

From table it is observed that the variation of SIF with respect to number of layers is not linear for the plates with R-glass UD/Epoxy and Carbon UD/Epoxy materials. It is also observed that the SIF for this plate with 4 and 8 layers is same. The variation of SIF with respect to the number of layers for the S-Glass UD/Epoxy plate is almost minimal.

5. CONCLUSIONS

Stress induced in the composite material plates are found to be much lesser than isotropic material plates due to fibre reinforcements at different angles. Further the crack growth is obstructed by the fibre orientation. The SIF in R-glass roving UD/epoxy plates is high as compared to S-glass fabric/epoxy and Carbon UD/epoxy is due to longitudinal and transverse modulus influence. The SIF in S-glass is almost constant because the transverse modulus effect is being neglected. The SIF for all specimens subjected to static loading is found to be less when compared to dynamic loading. Present approach is generic one, where the design tables are produced and being used as when required for the safety of the structures.

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