# Fracture Analysis Of FRP Composites Subjected To Static and Dynamic Loading

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*Abstract*— **Analytical solution exists for relatively simple cases. Due to complicated boundary conditions associated with the governing equations analytical approaches are used. Over the last decade or so finite element method has been firmly established as a standard procedure for the solution of practical fracture problems. The usefulness of stress intensity factors (SIF's) in the analysis of the problems of residual strength, fracture and fatigue crack growth rate has resulted in effort being expanded on the determination of SIF. A number of techniques have been suggested for the validation of SIF from the finite element results but adequate representation of crack tip singularity remains a common problem to most of these method.**

**The objective of the present work is to investigate the Stress Intensity Factor (SIF) for benchmark problems for static and dynamic loading in composite plates having center, edge. Further the analysis is extended to CT specimen, plate with 3-point bend, v-notch and double edge notch. In the static analysis SIF's is to be found for an isotropic material using singular and j-integral approach. For the orthotropic material SIF is to be found out for the above specimens with Carbon UD/Epoxy, R Glass roving UD/epoxy, S2 glass fabric/epoxy material properties. The Transient Dynamic analysis on the above specimens is to be carried out.**

***Keywords— SIF, UD/Epoxy, V-Notch, Double edge Notch***

## I. INTRODUCTION

The fundamental goal in production and application of composite materials is to achieve a performance from the composite that is not available from the separate constituents or from other materials. 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.

Recent developments in industries such as aerospace industry require lightweight and stiff materials fit the bill perfectly. The materials such as fiber-reinforced plastics are widely being used as a replacement for steel in the oil and gas industry. Also the automotive industry uses laminated glass composite in the car windshields to increase their strength. Nano-aluminum is now used as a solid rocket propellant.

Ceramic composites reinforced with fibers are replacing other conventional engineering materials due to their excellent high temperature properties. Plates and shells are three-dimensional bodies characterized by the fact that one of the dimensions is much smaller than the other two [1]. 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 [2].

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.

## II. LITERATURE REVIEW

Ahmad and Loo [1] developed a singular element based on classical plate theory. This analysis appears flawed as mode II SIF was detected for loadings symmetric with respect to the line crack.The work of Barna A Szabo [2] studies the formulation of FEA models foe beams, plates and shells, based on the principles of virtual work. The focus of implementation is to make the models suitable for numerical solutions. Ang and Williams [3] presented a closed formed solution for an orthotropic, infinite plate having finite crack within the context of the Kirchoff theory.

Sih and Chen [4] extended the same using similar concept to anisotropic plate using the Lekhnitski formalism.Yuan and Yang [5] (2000) studied the same problem by applying the Reissner plate theory and Stroh formalism.

Among the available methods for calculating fracture parameters, the interaction energy integral method Yau et al

[6] has emerged as a useful technique for the extraction of mixed-mode stress intensity factors. The contour integrals where derived directly from the J-integral by considering an additive composition of the existing fields with a judicious choice of known auxiliary fields.
For the purpose of post processing finite element solutions, the contour integrals were typically recast as equivalent domain integrals over a finite region surrounding the crack tip. Nakamura [7] (1991) employed this method to determine mixed mode stress intensity factors along straight, three-dimensional biomaterial interface cracks.
Reddy et al [8] investigated SIF in a rectangular orthotropic composite annular disc with a circular hole with the use of iso-parametric finite elements. These elements are used because they meet the necessary requirements for convergence. It was concluded that variations of stress depended on the orthotropic constants. The procedure could be extended for any material, geometry of crack type and type of load.

Further, Reddy.P.R [9] has studied the fracture behavior of ceramic matrix composites using singular and higher order elements. The following conclusions are drawn: as the notch depth is increasing, corresponding fracture load, fracture toughness and work of fracture values are decreasing for a particular orientation of fibers The inverse is true when the results of another orientation composite were studied. It was also observed from the load displacement curve that fibers offer resistance to crack propagation. But all fibers do not participate in strengthening the composite because of poor bonding.

## III. 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*

- 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.

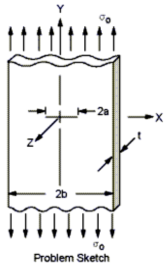


Fig. 1. Model of plate with center crack

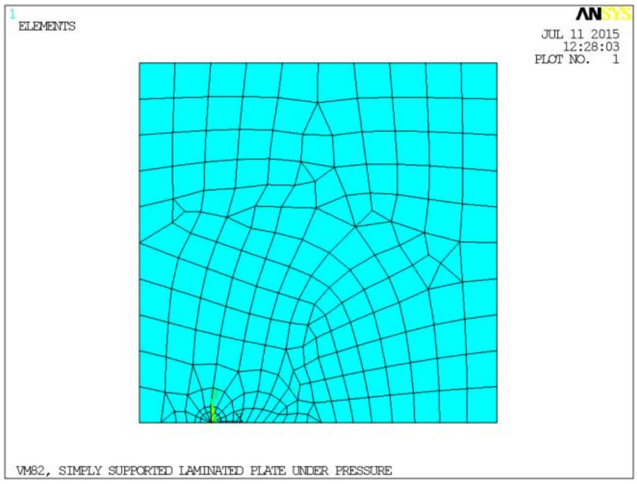


Fig. 2. FE Model of center crack

The SIF (K) is calculated using J-integral approach using the formula:

$$J=K^2/E \text{ per unit volume}$$

Where, E=Young's modulus

### B. *Case study-I: I Composite plates*

- Material properties:

*R-glass roving UD/Epoxy*
$E_x$ = 48.3 GPa
$E_y$=$E_z$ = 12.4 GPa
$\upsilon_{XY}$ = 0.16
$\upsilon_{YZ}$= $\upsilon_{ZX}$ = 0.28
$G_{xy}$ = 6.6 GPa
$G_{yz}$=$G_{zx}$ = 4.14 GPa
Density = 2 gm/cc

*S2 -glass fabric/Epoxy*
$E_x$ =$E_y$ = 22.925 GPa
$E_z$ = 12.4 GPa
$\upsilon_{XY}$ = 0.12
$\upsilon_{YZ}$= $\upsilon_{ZX}$ = 0.2
$G_{xy}$ = 4.7 GPa
$G_{yz}$=$G_{zx}$ = 4.2 GPa
Density = 1.8 gm/cc

*Carbon UD/Epoxy*
$E_x$ = 25 GPa

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$E_y$=$E_z$ = 10 GPa
$\upsilon_{XY}$ = 0.16
$\upsilon_{YZ}$= $\upsilon_{ZX}$ = 0.16
$G_{xy}$ = 5.2 GPa
$G_{yz}$ = 3.8 GPa
$G_{zx}$ = 6 GPa
Density = 2 gm/cc

- **Layer orientations:**

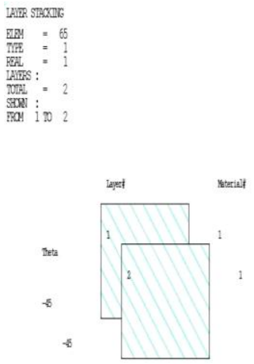


Fig. 3. Material with 2 layers

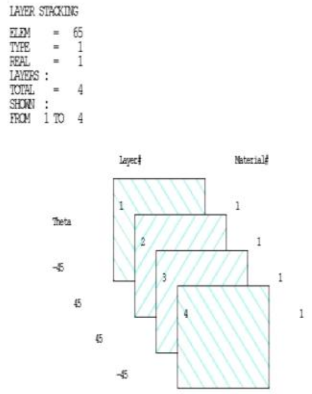


Fig.4. Material with 4 layers

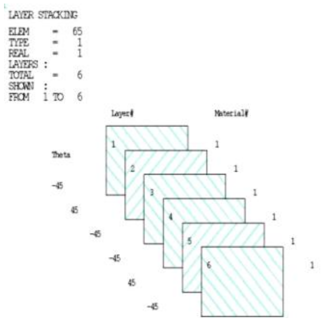


Fig. 5. Material with 6 layers

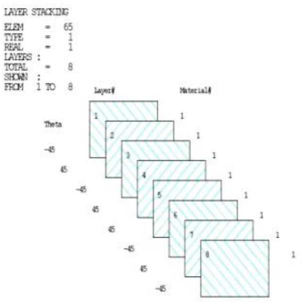


Fig. 6. Material with 8 layers

- **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.

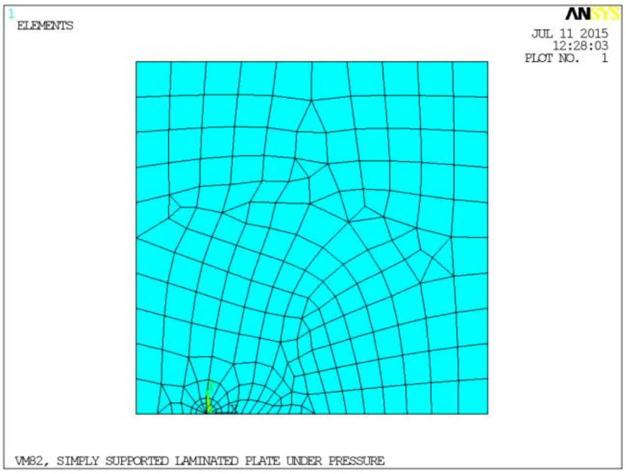


Fig. 7. FE Model of plate with center crack of a/b=0.2

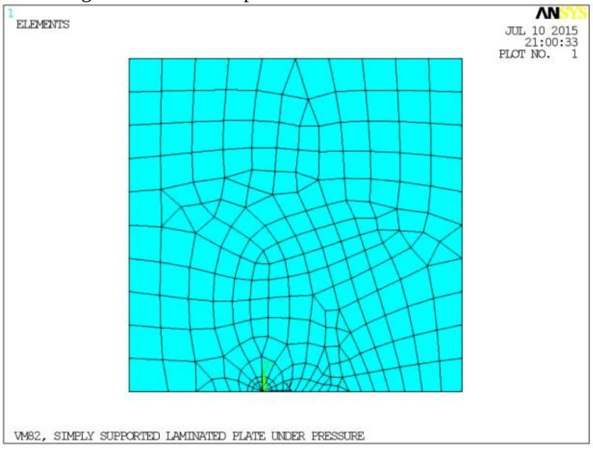


Fig. 8. FE Model of plate with center crack of a/b=0.4

- **Edge 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.

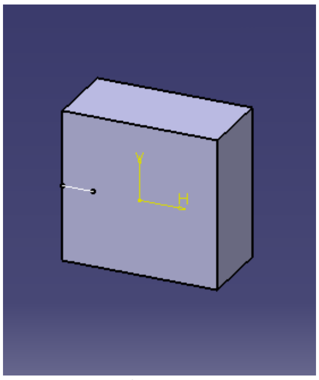

Fig. 9. Model of plate with edge crack

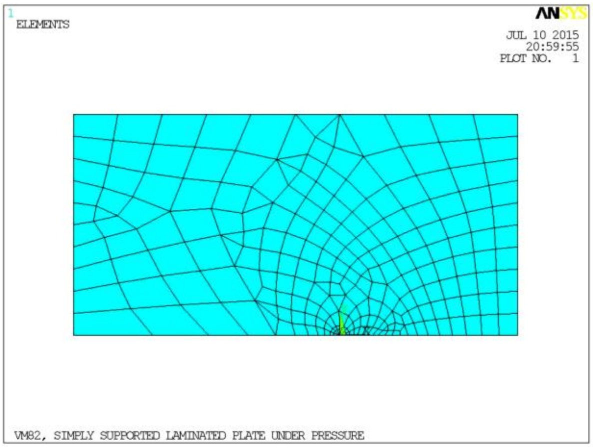

Fig. 10. FE Model of plate with edge crack of a/b=0.6

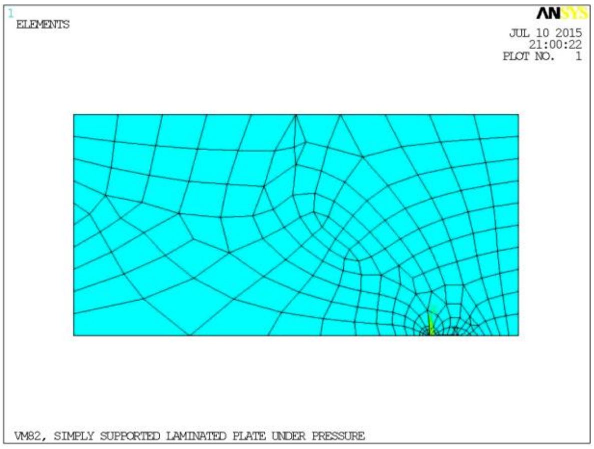

Fig. 11. FE Model of plate with edge crack of a/b=0.8

- **Compact Tension (CT) specimen**

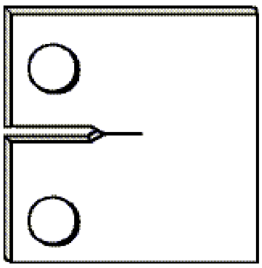
Fig. 12.(a) CT Specimen

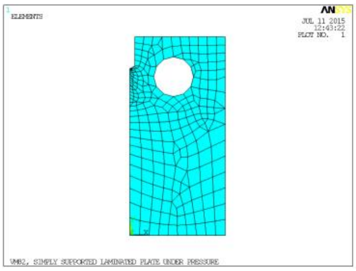
Fig. 12.(b) CT Developed Model

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.

*C. 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.

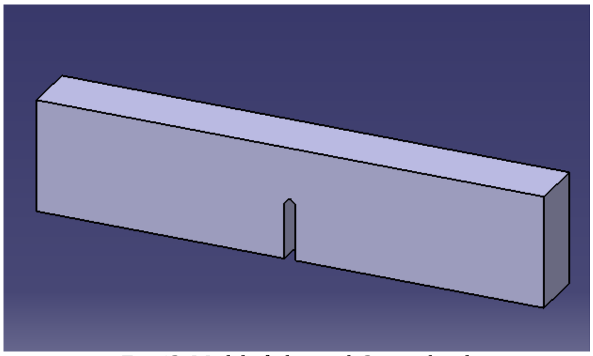
Fig. 13. Model of plate with 3-point bend

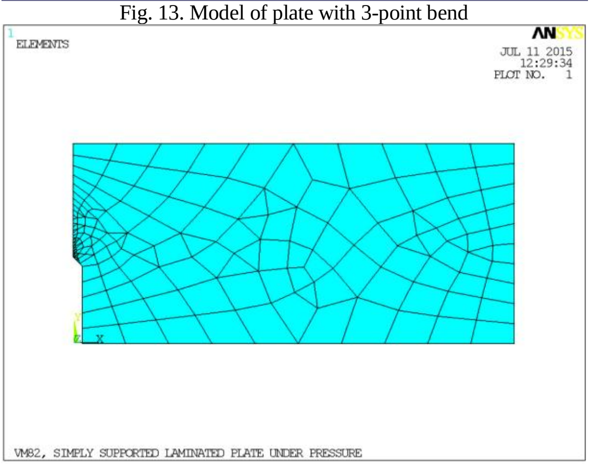

Fig. 14. FE Model of plate with 3-point bend

*D. 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.

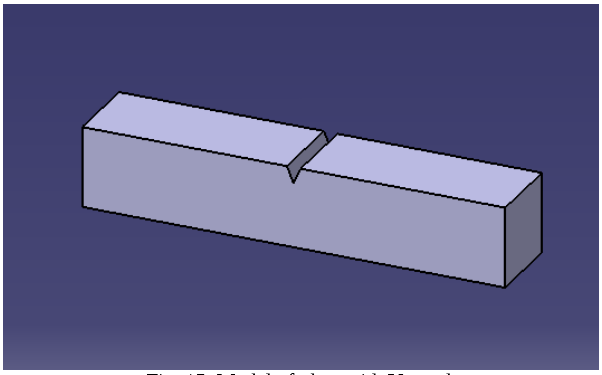
Fig. 15. Model of plate with V-notch

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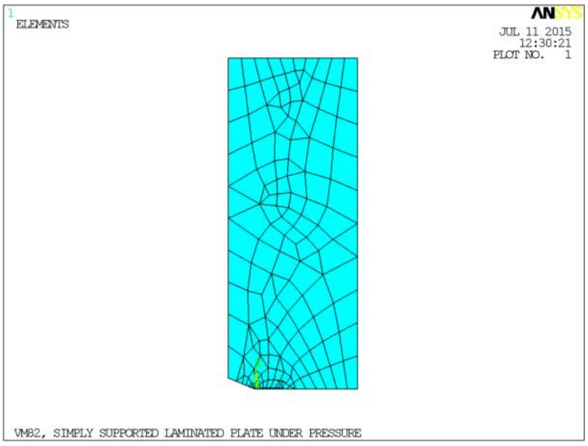


Fig. 16. FE Model of plate with V-notch

### E. 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.

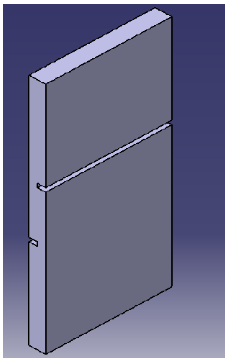

Fig. 17. Model of the plate with a double notch

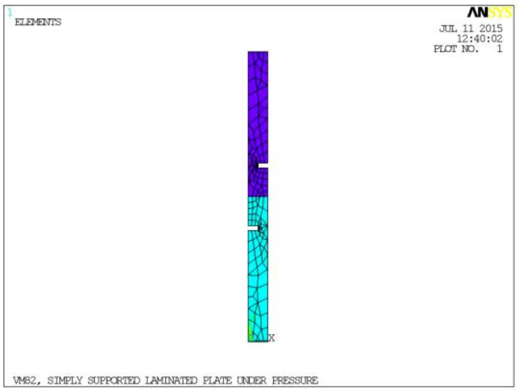


Fig. 18. FE Model of plate with double notch

## IV. Results and Discussions

### A. Composite Material

- Evaluation of stress intensity factor (SIF) in composite plate with center line crack.

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

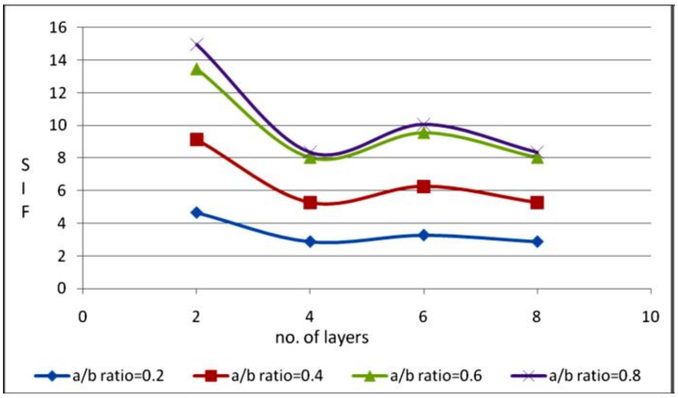


Fig. 19. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From fig 19. 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.

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

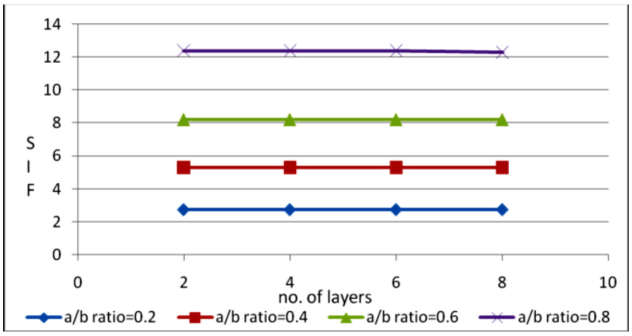


Fig. 20. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 20. 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 is high as the crack grows. However the variation of SIF with respect to number of layers is almost constant because the transverse modulus effect is neglected.

SIF's for different layers by varying a/b ratios of carbon UD/Epoxy material:

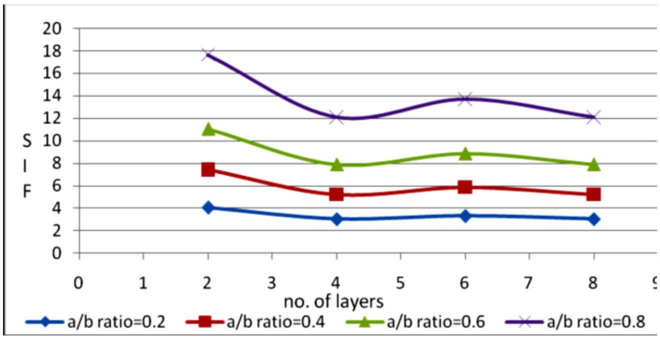


Fig. 21. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 21. 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 layup and when the crack is parallel to fiber direction the SIF is more and when it is in transverse direction the SIF is less.

The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus influence. In carbon composite, $E_y=E_z$ , Hence its SIF is less than R-glass.

*B. Evaluation of stress intensity factor (SIF) in composite plate with edge crack.*

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

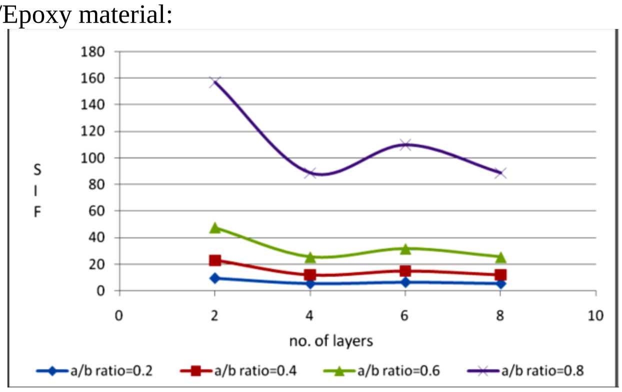


Fig. 22. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 22. 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 due to the symmetry lay up of even distribution. The SIF is higher at less number of layers and gradually decreases while increasing the number of layers symmetrically in odd numbers.

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

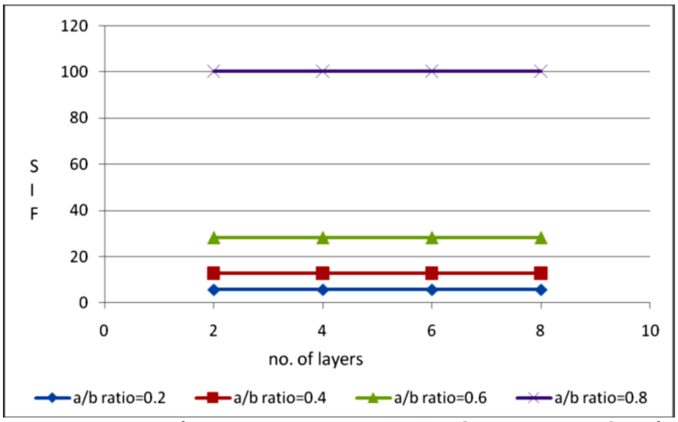


Fig. 23. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 23. 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 almost constant because the transverse modulus effect is neglected.

SIF's for different layers by varying a/b ratios of carbon UD/Epoxy material:

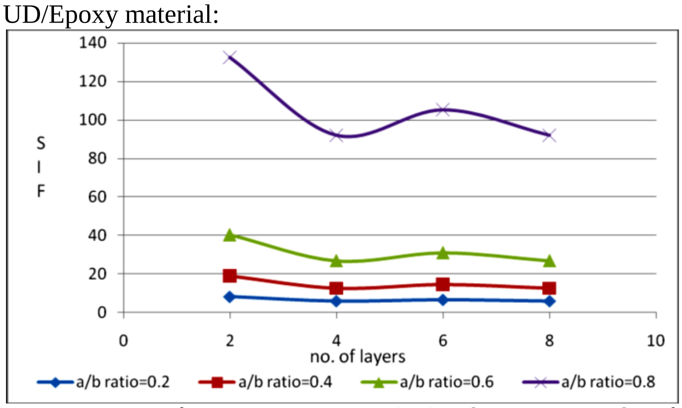


Fig. 24. Variation of Stress Intensity Factor (SIF) with increasing number of layers.

From Fig. 24. 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 due to the symmetry lay up of even distribution. The SIF is higher at less number of layers and gradually decreases while increasing the number of layers symmetrically in odd numbers.
The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus

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influence. In carbon composite, $E_y$=$E_z$, hence its SIF is less than R-glass.

*C. Evaluation of stress intensity factor (SIF) in composite plate with 3-point bend.*

SIF for different layers and different materials:

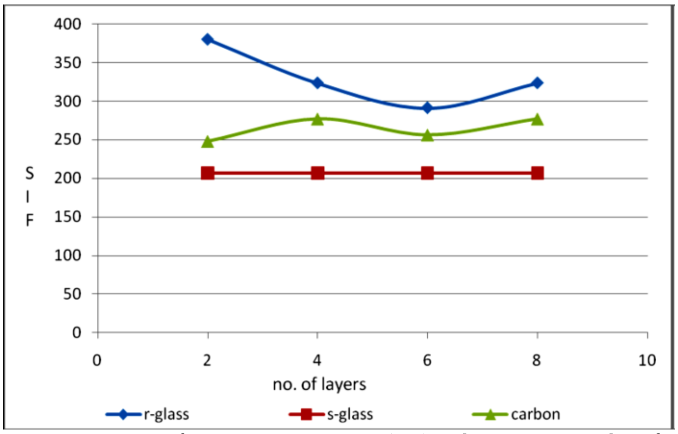


Fig. 25. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From table-5.7 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 these plates 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.
The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus influence. In carbon composite, $E_y$=$E_z$ ,hence its SIF is less than R-glass.

*D. Evaluation of stress intensity factor (SIF) in CT specimen*

- SIF for different layers and different materials

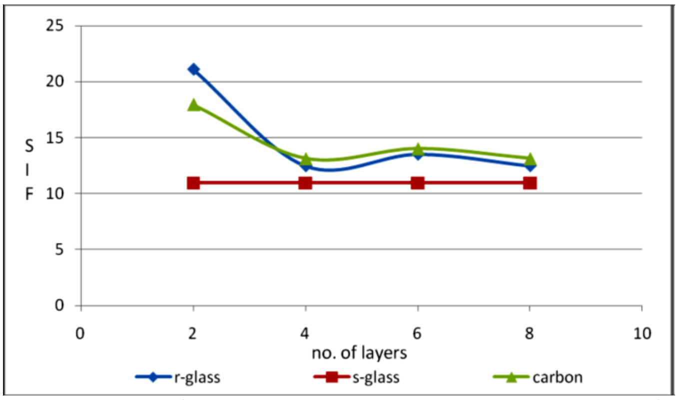


Fig. 26. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 26. 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 these plates 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.

The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus influence. In carbon composite, $E_y$=$E_z$ ,hence its SIF is less than R-glass.

*E. Evaluation of stress intensity factor (SIF) in composite plate with V-notch*

- SIF for different layers and different materials

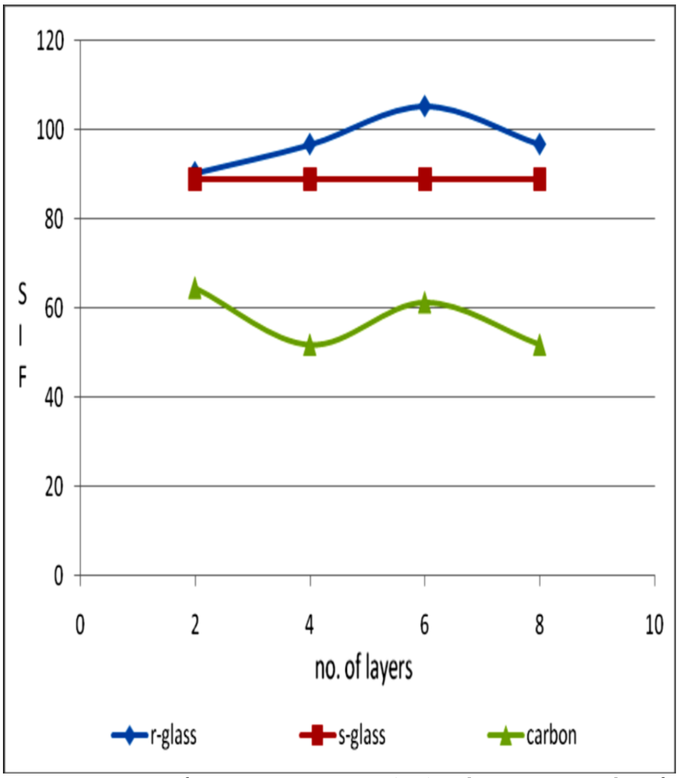


Fig. 27. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig. 27. 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 these plates 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.

The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus influence. In carbon composite, $E_y$=$E_z$ ,hence its SIF is less than R-glass.

*F. Evaluation of stress intensity factor (SIF) in composite plate with double-notch*

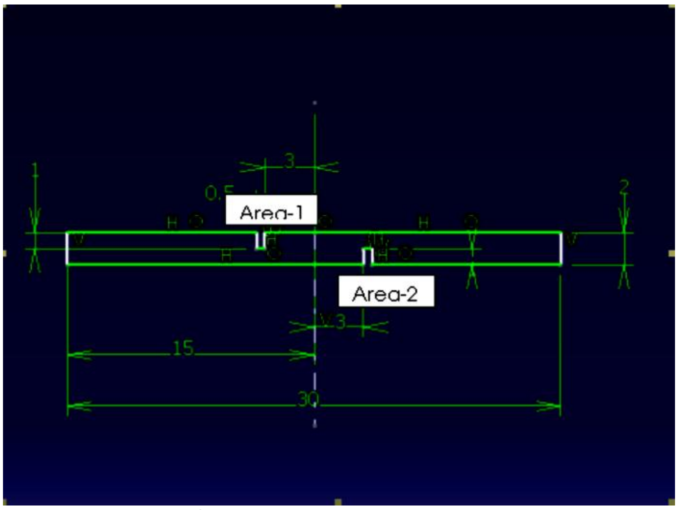


**Fig. 28. Model of plate with double notch showing the two areas**

- SIF for different layers and different material

Area 1

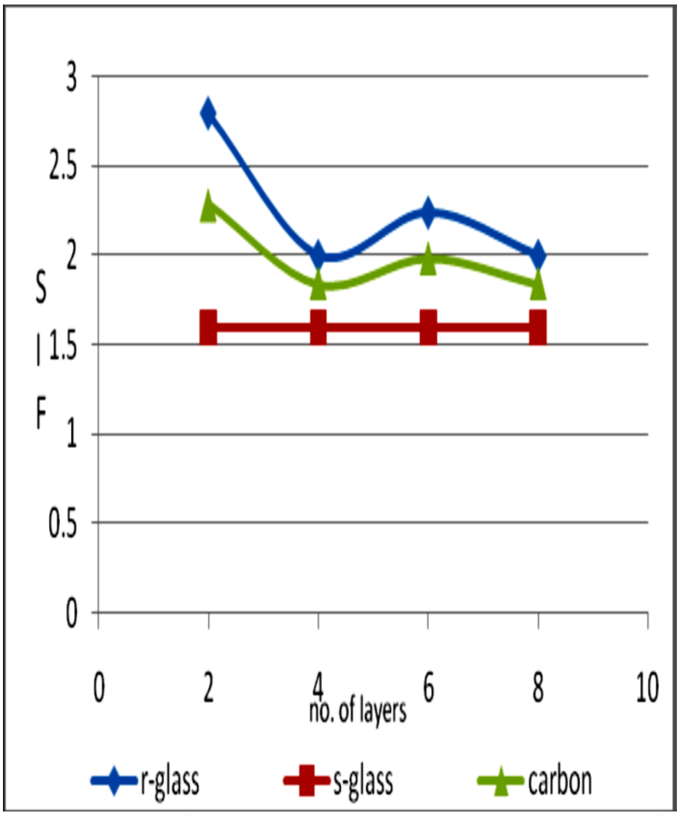


Fig. 29. Variation of Stress Intensity Factor (SIF) with increasing number of layers

Area 2

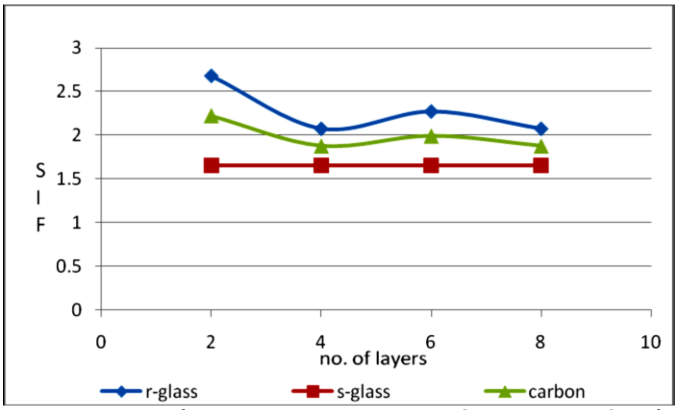


Fig. 30. Variation of Stress Intensity Factor (SIF) with increasing number of layers

From Fig 29-30. 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. And also it is observed that the difference in the stress intensity factor for the notches in area 1(A1) and area 2(A2) is very less.

The SIF is high in R-glass as compared to S-glass and Carbon composite due to longitudinal and transverse modulus influence. In carbon composite, $E_y=E_z$, hence its SIF is less than R-glass.

## V. CONCLUSIONS

The following conclusions are drawn from the present work:-

Singular finite element approach is used for calculating SIF's for plate made up of isotropic material and J-Integral approach is used for calculating SIF for both the plates made up of isotropic and orthotropic materials.

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.

## VI. FUTURE SCOPE OF WORK

In, dynamic crack growth a moving mesh approach gives better understanding for crack growth and failure phenomenon. Dynamic analysis will be helpful on this model as a comparative study and obtaining relatable results.

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REFERENCES

[1] J.Ahmad and F.T.Loo, “Solution of plate bending problems in fracture mechanics using specialized FEA”,engng fracture mechanics 661-672.

[2] Barna.A.Szabo and Glenn J.Sharmann, 1988, “International journal for numerical methods”,Vol.26, 1855-1881.

[3] Ang D.D.,Williams. M.L., 1961. Combined stresses in an orthotropic plate having a finite crack. ASME Journal of Applied Mechanics 28, 372-378.

[4] Sih, G.C., Chen, E.P.,1981. Cracks in composite materials. In : Mechanics of Fracture, vol.6.Martinus Nijhoff Publishers, The Hague.

[5] Yuan, F.G., Yang, S., 2000. asymptotic crack-tip fields in an anisotropic plate subjected to bending, twisting moments and transverse shear loads. Composites science and Technology 60,2489-2502.

[6] Yau, J., Wang, S., Corten, H., 1980. a mixed-mode crack analysis of isotropic solids using conservation laws of elasticity. Journal of Applied Mechanics 47, 335-341.

[7] Nakamura, T., 1991. Three-dimensional stress fields of elastic interface cracks Journal of Applied Mechanics 58, 939-946.

[8] Reddy P.R, Murthy.G.R, 1997, “Stress intensity factor using FEA in rectangular orthotropic composite annular disc”, Defense Science journal, Vol 47, No 1, pp 55-63.

[9] Reddy P.R, Jan 2005 “Fracture Analysis of ceramic matrix composites using FEM” Journal of aerospace quality and reliability, Vol 1 No1, pp 69-80.

[10] B.K.Thakkar and P.C.Pandey, 2006, “Continuum damage mechanics applied to progressive failure analysis of FRP composites- A review” Journal of Structural Engineering, Vol.33, No , pp 267-285.

[11] R.Kumutha, R.Vaidyanathan and M.S.Palanichamy, Dec 2006-Jan 2007, “Behaviour of concrete compression and specimens strengthened using glass fibre-reinforced plastics” Journal of Structural Engineering, Vol. 33, No.5, pp 01-405.

[12] X. M. Jia and F. Dai Q. Z. Wang ,Jan 2003, “Mechanics of various fibre reinforced materials” Jornal of Strucutral Engineering, Vol.45,No.5,pp 326-453.