FE Parametric Analysis to Analyze Discontinuities in Composite Plate

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Abstract— Composite materials are finding a wide range of applications in structural design, especially for lightweight structure that have stringent stiffness and strength requirements. They are attractive replacement for metallic materials for many structural applications. Composites are used more and more often for load carrying and safety structures in all kind of applications for aviation and space technology, for vehicles etc. Composite materials have been introduced progressively in automobiles, production industries. We know that composite is combination of resin and fiber. Strength of composite is depending on fiber and its orientation. It is required to find out efficient composite structure design that meets all requirements of specific application. This is achieved by tailoring of material properties through selective choice of orientation, no. of stacking sequence of layers that make up composite material. The presented work was carried out to find out the various mechanical properties of acrylic and FRP on UTM. To fulfill the requirements of validation FEA is carried out with the help of material properties obtained from mechanical testing.

***Keywords*—Acrylic, Composite, FEA, Fiber orientation, FRP, UTM.**

1. INTRODUCTION

Composite materials are extending the horizons of designers in all branches of engineering. After all, the eye does not see beyond the glossy exterior or the race performance of a yacht, nor does it sense the complexity of the structure of a composite helicopter rotor blade or of a modern tennis racket. Nevertheless, this family of synthesized materials offers the possibility of exciting new solutions to difficult engineering problems. "Composite is a materials system composed of two or more physically distinct phases whose combination produces aggregate properties." The 'composites' concept is not a human invention. Wood is a natural composite material consisting of Cellulose fibers - good strength and Resin matrix – stiffness. The advantages exhibited by composite materials are aHigh 'strength or stiffness to weight' ratio. As result weight savings are significant, ranging from 25-45% of the weight of conventional metallic designs, High resistance to conduction and corrosion, Improved friction and wear properties, High resistance to impact damage, Directional capabilities meet the design requirements. The fiber pattern can be laid in a manner that will sustain the structure to the applied loads. Composites are dimensionally stable i.e. they have low thermal conductivity and low coefficient of thermal expansion, The improved weather ability of composites in a marine environment as well as their corrosion resistance and durability reduce the down time for maintenance, Excellent heat sink properties of composites, especially Carbon-Carbon, combined with their lightweight have extended their use for aircraft brakes. The common limitations are High cost of raw materials, Transverse properties may be weak, Matrix is weak, therefore, low toughness, Reuse and disposal may be difficult, difficult to attach, Analysis is difficult, Matrix is subject to environmental degradation. Thus, Increasing performance and structural demands in various applications such as production industries aerospace automotive, electrical, appliance, food processing service, and energy industries, among others, plus the rising cost of metals and polymer-concrete, is prompting design engineers to consider Composite technology as a replacement for existing materials. Composite materials have many unique properties - exceptional strength, light weight, corrosion resistance, UV resistance, electrical non-conductance, and exceptional thermal properties. Composite materials are finding a wide range of applications in structural design, especially for lightweight structure that have stringent stiffness and strength requirements. They are attractive replacement for metallic materials for many structural applications. Composites are used more and more often for load carrying and safety structures in all kind of applications for aviation and space technology, for vehicles etc. Composite materials have been introduced progressively in automobiles, production industries. We know that composite is combination of resin and fiber. Strength of composite is depending on fiber and its orientation. It is required to find out efficient composite structure design that meets all requirements of specific application. This is achieved by tailoring of material properties through selective choice of orientation, no. of stacking sequence of layers that make up composite material. The research work presented by Pachpore S.S et.al [1] clearly studied stresses and deformation of cantilever plate with central hole and overcome that by patch reinforcement. Thus under the scope of study the same problem is taken into consideration and analyse the same with various fibre orientations of composite plates. Initially determine mechanical properties of: Matrix (Acrylic) and Composite with different fibre orientation (fibre reinforced plastic with 0°,30°,60°,90° fibre orientation). Later on in second stage FE simulation to find out deformation and stress concentration for various parameters such as plate thickness, dimensions and shape of discontinuities, etc and in last stage validation is carried out. Thus initially the survey was carried out to address the problem with respect to composite structures, FE simulations carried out by various researchers out of which Bernard. L., Lotfi. T. and Moussa. K. [2], entitles paper on 'Stress concentration in a circular hole in composite plate' in which they studied a non-contact measurement method, namely electronic speckle pattern interferometer (ESPI), was used to investigate the tensile strain field of a composites plate in the presence of stress concentrations caused by a geometrical defect consisting of circular hole. The strain concentration in woven fabric composites with holes is influenced by the loading direction; there is a high agreement between those stresses for woven fabric composite with an on-axis (00direction) tensile load. However, in the off-axis direction (900, 450), It is also evident that the influences of the holes on the strength properties are more pronounced which includes ultimate tensile strength and also ultimate yield strength. Soutis C., fleck N.A., Curtis P.T. [3], presented paper on composite behaviour entitled 'Hole-hole interaction in carbon fibre/epoxy laminates under uniaxial compression'. In this paper the results of a series of uniaxial compressive tests are presented. Two cases considered are one hole and two hole plates. X-ray radiography, sectioning technic was used in order to determine the compressive failure mechanism. Finite element analysis was performed to calculate the stress distribution in the region near holes and to find the minimum hole-hole separation for no hole interaction. Diantang Z., Ying S., Li C. [4], presented paper on 'Prediction of Macro Mechanical Properties of 3d Braided Composites Based on Fibre Embedded Matrix Method.' In this paper a study is conducted with the aim of developing fibre embedded matrix method for evaluating mechanical properties such as ultimate tensile strength. Bernard. L., Lotfi. T. and Moussa. K. (2005) [5], presented paper on "Stress concentration in a circular hole in composite plate." In this paper this stress concentration characterization study of a laminate carbon/epoxy has been carried out. Also the strain concentration in woven fabric composites with holes is influenced by the loading direction; there is a high agreement between those stresses for woven fabric composite with a non-axis (weft direction 0_) tensile load. However, in the off-axis direction (90_, 45_), the comparison does not show a good agreement between those stresses for woven fabric of different direction composite with tensile load. Bulent M. (Ic ten), Karakuzu R., Toygar M.E.(2006) [6], entitles paper on 'Failure analysis of woven Kevlar fibre reinforced epoxy composites pinned joints' deals with the failure mode and the failure load of mechanically fastened joints in woven Kevlar epoxy composite plates. Two-dimensional finite element analysis is used to predict damage initiation, progression and final position of failure which are important to understand the strength of joints and failure mode and the failure load. Fu-kuochang and Scott R. [7], entitles paper on 'Failure strength of nonlinearly elastic composite laminates containing a pin loaded hole' [8] which deals with nonlinear behaviour of composite material containing hole. Finite element analysis was presented for calculating the failure strengths and failure modes of laminates due to the sudden forces applied on the various pin loaded holes. Guo S.J.[8], presented paper on 'Stress concentration and buckling behaviour of shear loaded composite panels with reinforced cut-outs by Guo S.J. presented a study of shear loaded carbon/epoxy composite square panels with cutout that was reinforced in order to reduce the stress concentration and enhance load carring capacity. This study included numerical modelling by FEA and experimental tests. G.Rathnakar, Dr. H.K.Shivanand [9], presented paper on 'Fibre Orientation and Its Influence on the Flexural Strength of Glass fibre and Graphite fibre reinforced polymer composites.' This paper investigates the effect of fibre orientation on the flexural strength of fibre reinforced –epoxy laminated composite material, with the variation in the orientation of the reinforced fibres there will be a substantial variation in the flexural strength and tensile strength of the laminated composites. Prashanth Banakar, H.K. Shivananda and H.B. Niranjan [10], presented paper on 'Influence of Fibre Orientation and Thickness on Tensile Properties of Laminated Polymer Composites.' The objective of this research was to gain a better understanding of tensile properties of epoxy resin composites reinforced with glass fibre. The effect of fibre orientation & thickness of laminates has been investigated & experimentation was performed to determine property data for material specifications, the laminates were obtained by hand layup process. The laminates were cut to obtain ASTM standards. The test ready specimens were subjected to tensile loads on UTM machine. This research indicates that tensile strength is mainly dependent on the fibre orientation & thickness of laminated polymer composites. Bakir, and Haithem. Hashem [11], presented paper on 'Effect of Fibre Orientation for Fibre Glass Reinforced Composite Material on Mechanical Properties.' This study was designed to evaluate the effect of glass fibre orientation of reinforced composite material on mechanical properties: tensile strength, hardness, toughness, also microstructure were tested .The study used to compare the effect of direction of fibres in order to improve strength and toughness. This study show that best strength are when fibre perpendicular to tensile force then with angle 45° then the parallel direction and all this is less than discontinuous type strength ,hardness be effected directly to number of laminated fabricated and orientation of fibre with respect to force. Rameshwari Vivek Lalge [12], presented paper on 'Analysis of Stress Concentration of Laminated Composite Plate with Circular Hole.' The study was conducted for finding efficient composite structure design that meets all requirements of specific application. This is achieved by tailoring of material properties through selective choice of orientation, no. of stacking sequence of layers, and their respective thickness of resin and fibre that make up composite material. Shao-Yun Fu & Bernd Lauke [13], presented paper on 'Effects of Fibre Length and Fibre Orientation Distributions on the Tensile Strength of Short-Fibre-Reinforced Polymers.' This paper presents an analytical method considering the effects of fibre length and fibre orientation distributions for predicting the tensile strength (TS) of short-fibre-reinforced polymers (SFRP). This model provides the necessary information to determine what fibre length distribution, what fibre orientation distribution and what interfacial adhesion are required to achieve a desired composite strength. The present theory is then applied to existing experimental results, its necessary calculation and their important consideration and the agreement is found to be satisfactory. Sultan Erdemli Günaslan, Abdulhalim Karaşin and M. Emin Öncü [14], presented paper on 'Properties of FRP Materials for Strengthening.' In this study it is aimed to discuss advantages of FRP usage as a composite material. It is noted that the mechanical properties of these materials shows a useful behavior for strengthened theoretically to satisfy safe cross-section with FRP materials. Sandeep M.B, D.Choudhary, Md. Nizamuddin Inamdar, Md. Qalequr Rahaman [15], presented paper on 'Experimental Study of Effect of Fibre Orientation on the Flexural Strength of Glass/Epoxy Composite Material.' Polymer matrix composite materials are anisotropic in nature, the mechanical properties of these materials are different for different constituents and orientation of reinforcing material. In this paper, the effect of fibre orientation on the flexural strength for pure glass/epoxy composite material is presented. The experimental results showed the difference in flexural strength in bidirectional glass fibers at 0°, 30°, 60°, and 90° orientation. Nitin Kumar Jain [16], presented paper on 'Analysis of stress concentration and deflection in isotropic and orthotropic rectangular plate with central circular hole under transverse static loading.' The distribution of stresses and deflection in isotropic and orthotropic rectangular plate with central circular hole have been studied using finite element method. The aim of author is to analyze the effect of D/A ratio (where D is hole diameter and A plate width) upon stress concentration factor deflection I isotropic and orthotropic plate under transverse static loading. The analysis is done for isotropic and two different orthotropic materials. The structural finite element formulation is carried by Nagrik Kunal et.al [17] for analysis of cylinder head was very much useful. Also the FE analysis for estimating modal parameters and transient analysis when plate under consideration used under industrial application are clearly given by Pachpore S S et.al in [18] and [19].

Outcome of the Survey:

Composite materials have been introduced progressively in automobiles, production industries. We know that composite is combination of resin and fibre. Strength of composite is depending on fibre and its orientation. It is required to find out efficient composite structure design that meets all requirements of specific application. Seeking forward with this firstly there's need to study effect of fibre orientation on strength of composite material with various discontinuities.

2. PROBLEM STATEMENT

To analyze parametric discontinuities in composite plate Dimension of plate considered is 100x300 mm with hole at centre of dia. 20 mm, while thickness of plate is 5 mm. Boundary condition applied to the plate is force of 2000N at one end while other end is kept fixed as shown in fig 1.

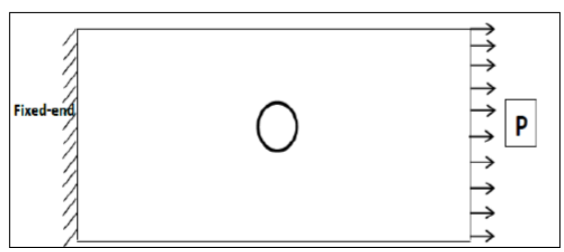

Fig 1. Plate Geometry Taken under Consideration

To carry out experimentation tensile testing using UTM to obtain mechanical properties of composite plates. a. Preparation of tensile test specimen for tensile strength and elongation using ASTM D 638 (Std. Type III) shown in fig. 2, impact strength using ASTM D 256, flexural strength, flexural modulus using ISO 178 and ASTM D 792 for density.

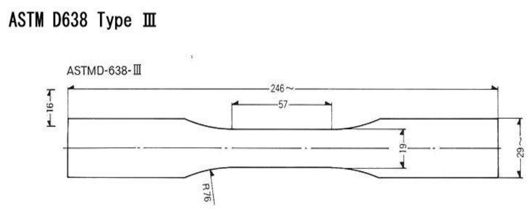

Fig 2. ASTM D638 TYPE III Std. Specimen

For making of sample specimen for testing Resin-Terephthalate Resin is considered with CA-103 Cobalt octoate accelerator (3% Cobalt), M-108 Methyl ethyl ketone peroxide (8% Active Oxygen) as main constituent with Viscosity: 330cp and Density: 1.10 gm/cc with detailed specification shown in Table I and material sequence with considered composition as 300/1200/180/1200/180/1200/300 along with Thickness of 5 mm and Final product –FRP sheet.

Table No. I Material specifications

Density gm/cc	Weight Gm	Thickness Mm
180	0.400	0.2
300	0.640	0.6
1200	900	1.2

For manufacturing of the plates for testing Hand Lay-up technique was used shown in fig. 3with test specimen dimensions shown in Table II.

Table No. II Test Dimensions

<table>
<tr><td>Plate</td><td colspan="2">100 x 300 x 5 mm</td></tr>
<tr><td>Hole dimensions</td><td colspan="2">D=20 mm</td></tr>
<tr><td rowspan="4">Hole patterns</td><td colspan="2">Without hole</td></tr>
<tr><td>Single hole</td><td>Central</td></tr>
<tr><td>Circular pattern</td><td>four holes, central radius R30 mm</td></tr>
<tr><td>Circular pattern</td><td>Six holes, central radius R30 mm</td></tr>
</table>

Fig 3. Specimen formation for different fiber orientation

3. MATHEMATICAL MODELLING

An orthotropic material has three planes of symmetry that coincide with the coordinate planes. It can be shown that if two orthogonal planes of symmetry exist, there is always a third orthogonal plane of symmetry. Nine constants are required to describe this type of material. The symmetry planes can be Cartesian, as shown in fig 4, or they may correspond to any other coordinate representation (cylindrical, spherical, etc.). For example, the trunk of a tree has cylindrical orthotropy because of the growth rings. However, most practical materials exhibit Cartesian orthotropy. A unidirectional fibre reinforced composite may be considered to be orthotropic. One plane of symmetry is perpendicular to the fibre direction, and the other two are orthogonal to the fibre direction and among themselves. In this case, 3D Hooke's law reduces to And in terms of the compliances to

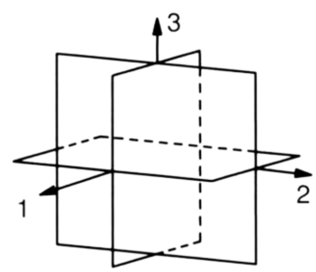

Fig 4. Orthotropic Material Plane

$$\begin{bmatrix}\sigma_1\\\sigma_2\\\sigma_3\\\sigma_4\\\sigma_5\\\sigma_6\end{bmatrix}=\begin{bmatrix}C_{11}&C_{12}&C_{13}&0&0&0\\C_{21}&C_{22}&C_{23}&0&0&0\\C_{31}&C_{32}&C_{33}&0&0&0\\0&0&0&C_{44}&0&0\\0&0&0&0&C_{55}&0\\0&0&0&0&0&C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\\varepsilon_2\\\varepsilon_3\\\varepsilon_4\\\varepsilon_5\\\varepsilon_6\end{bmatrix}$$

$$\begin{bmatrix}\varepsilon_1\\\varepsilon_2\\\varepsilon_3\\\varepsilon_4\\\varepsilon_5\\\varepsilon_6\end{bmatrix}=\begin{bmatrix}S_{11}&S_{12}&S_{13}&0&0&0\\S_{21}&S_{22}&S_{23}&0&0&0\\S_{31}&S_{32}&S_{33}&0&0&0\\0&0&0&S_{44}&0&0\\0&0&0&0&S_{55}&0\\0&0&0&0&0&S_{66}\end{bmatrix}\begin{bmatrix}\sigma_1\\\sigma_2\\\sigma_3\\\sigma_4\\\sigma_5\\\sigma_6\end{bmatrix}$$

For an orthotropic material, the compliance matrix [S'] is defined in the material coordinate system as

$$[S'] = \begin{bmatrix} \frac{1}{E_1} & \frac{-\nu_{21}}{E_2} & \frac{-\nu_{31}}{E_3} & 0 & 0 & 0 \\ \frac{-\nu_{12}}{E_1} & \frac{1}{E_2} & \frac{-\nu_{32}}{E_3} & 0 & 0 & 0 \\ \frac{-\nu_{13}}{E_1} & \frac{-\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{13}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}$$

It is important to note that because of the symmetry of the compliance matrix, the following restrictions on engineering constants apply Hence, only nine constants are independent in the matrix [S']. Then compliance becomes

$$[S'] = \begin{bmatrix} \frac{1}{E_1} & \frac{-\nu_{12}}{E_1} & \frac{-\nu_{13}}{E_1} & 0 & 0 & 0 \\ \frac{-\nu_{12}}{E_1} & \frac{1}{E_2} & \frac{-\nu_{23}}{E_2} & 0 & 0 & 0 \\ \frac{-\nu_{13}}{E_1} & \frac{-\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{13}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}} \end{bmatrix}$$

Now, after applying transformation as in above eq. [S'] is transferred from material co-ordinate system to global system [S] which can be represented as follow,

$$[S] = \begin{bmatrix} \frac{1}{E_x} & \frac{-\nu_{xy}}{E_x} & \frac{-\nu_{xz}}{E_x} & 0 & 0 & 0 \\ \frac{-\nu_{xy}}{E_x} & \frac{1}{E_y} & \frac{-\nu_{yz}}{E_y} & 0 & 0 & 0 \\ \frac{-\nu_{xz}}{E_x} & \frac{-\nu_{yz}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{yz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{xz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{xy}} \end{bmatrix}$$

Therefore, it is possible to compute the apparent engineering properties of a laminate in terms of the global compliance, as follows

$E_x = {}^{1}/_{S_{11}}$	$G_{yz} = {}^{1}/_{S_{44}}$	$\nu_{xy} = {}^{-S_{21}}/_{S_{11}}$
$E_y = {}^{1}/_{S_{22}}$	$G_{xz} = {}^{1}/_{S_{55}}$	$\nu_{xz} = {}^{-S_{31}}/_{S_{11}}$
$E_z = {}^{1}/_{S_{33}}$	$G_{xy} = {}^{1}/_{S_{66}}$	$\nu_{yz} = {}^{-S_{32}}/_{S_{22}}$

Based on above mentioned emperical relations and assumed material properties with applied geometric transformation for all fiber orientation following results were obtained. For calculation of Von misses stresses, The stress-strain relation for a three-dimensional linear, elastic, anisotropic material is {σ} = [C] {ε} which is also known as Hooke's law. {σ} and {ε} are stress and strain vectors respectively. The [C] matrix is called material stiffness matrix, which has 21 independent material constants. For plane stress problems, where the external stresses are in the plane of plate, Hooke's law could be simplified to

$$\begin{bmatrix} \sigma 1 \\ \sigma 2 \\ \tau 12 \end{bmatrix} = \begin{bmatrix} Q11 & Q12 & 0 \\ Q21 & Q22 & 0 \\ 0 & 0 & Q66 \end{bmatrix} \begin{bmatrix} \varepsilon 1 \\ \varepsilon 2 \\ \gamma 12 \end{bmatrix}$$

Here,

$$Q11 = \frac{E1}{1-\mu 12 \times \mu 21}$$

$$Q12 = Q21 = \frac{\mu 12 \times E2}{1-\mu 12 \times \mu 21} = \frac{\mu 21 \times E1}{1-\mu 12 \times \mu 21}$$

$$Q22 = \frac{E2}{1-\mu 12 \times \mu 21}$$

$$Q66 = G12$$

Here, E1 is the elasticity modulus in the fibre direction, E2 is the elasticity modulus in the transverse direction, ν12 and ν21 are the Poisson's ratio, and G12 is the shear modulus.

4. SIMULATION AND VALIDATION OF SPECIMENS

Parametric FE simulation with the obtain properties for composite plate with discontinuities. (ANSYS Mechanical APDL 14.5) and following results were obtained and boundary conditions are shown in in fig 5

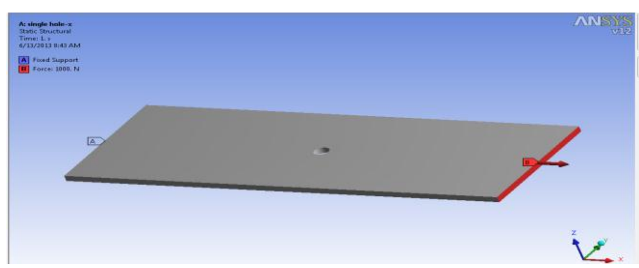

Fig.5. Boundry Conditions

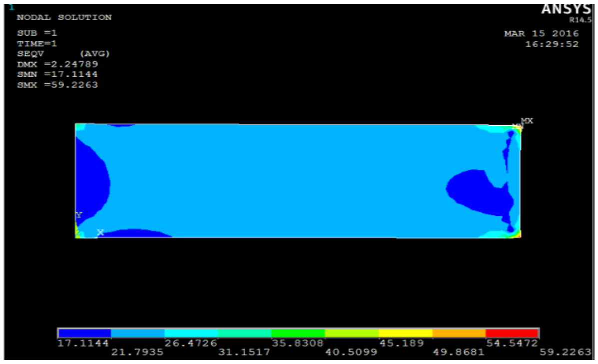

Fig 6. Acrylic Plate Stress Distribution

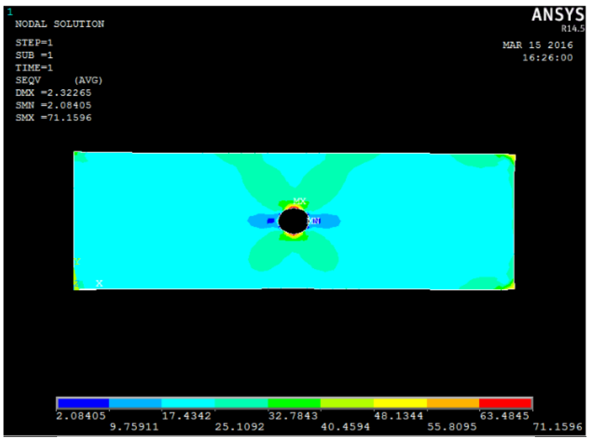

Fig 7. Plate with 1 hole Stress Distribution

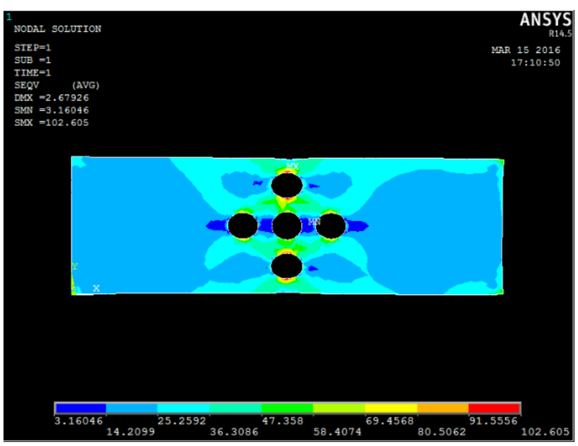

Fig 8. Plate with 5 hole Stress Distribution

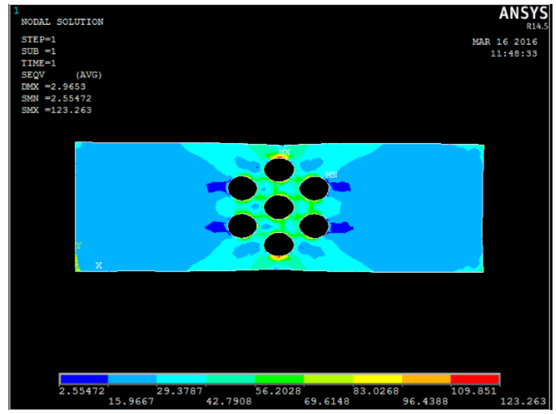

Fig 8. Plate with 7 hole Stress Distribution

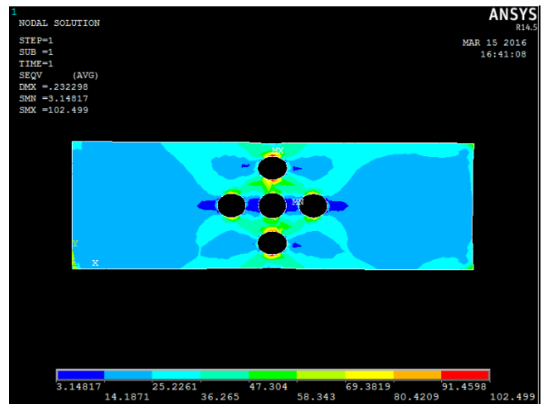

Fig 10. Plate with 5 hole Stress Distribution for 0^0 Fiber Orientation

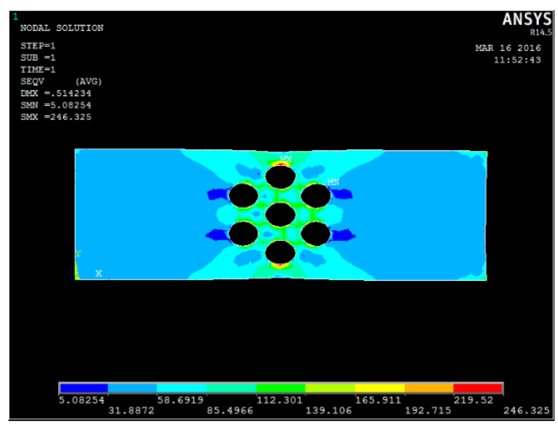

Fig 11. Plate with 7 hole Stress Distribution for 0^0 Fiber Orientation

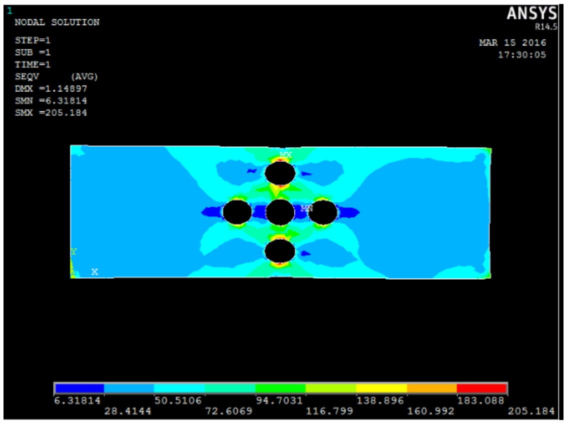

Fig 12. Plate with 5 hole Stress Distribution for 30^0 Fiber Orientation

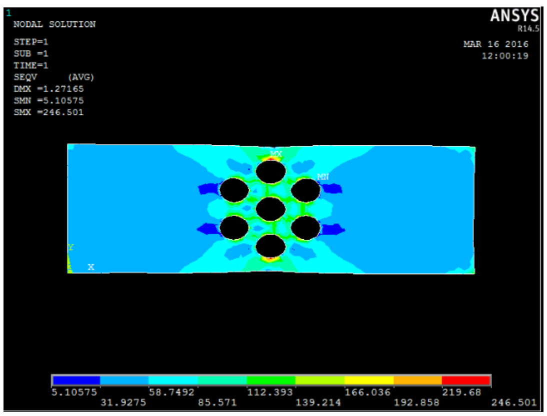

Fig 13. Plate with 5 hole Stress Distribution for 30^0 Fiber Orientation

Similarly results were obtained for remaining fiber orientation and summary of the same is mentioned below.

Table IV: Results for Acrylic Plate

	Analytical	FEM	% Variation
Plate without hole	51.39	59.22	13.22
Plate with one hole	64.59	71.15	9.21
Plate with 5 hole	84.49	102.60	17.64
Plate with 7 hole	93.58	123.26	24.07

Table V: Results Fiber Reinforced Plastic 0° Orientation (Von Misses Stress

	Analytical	FEM	% Variation
Plate with 5 hole	121.18	102.49	15.42
Plate with 7 hole	215	246.32	12.64

Table VI: Results Fiber Reinforced Plastic 30° Orientation (Von Misses Stress

	Analytical	FEM	% Variation
Plate without hole	116.20	118.47	2
Plate with one hole	145.54	142.31	2.21
Plate with 5 hole	172.41	205.18	15.97
Plate with 7 hole	258.35	246.50	4.58

Table VII: Results Fiber Reinforced Plastic 60° Orientation (Von Misses Stress

	Analytical	FEM	% Variation
Plate without hole	140.12	118.58	15.37
Plate with one hole	180	142.25	20.97
Plate with 5 hole	197.3	204.99	3.75
Plate with 7 hole	280	246.32	12.02

Table VIII: Results Fiber Reinforced Plastic 90° Orientation (Von Misses Stress

	Analytical	FEM	% Variation
Plate without hole	113	118.65	4.76
Plate with one hole	125	142.18	12.03
Plate with 5 hole	200	204.49	2.19
Plate with 7 hole	300	245.98	18

Similarly, graphical relationship for variation stress for different fiber orientation are shown below;

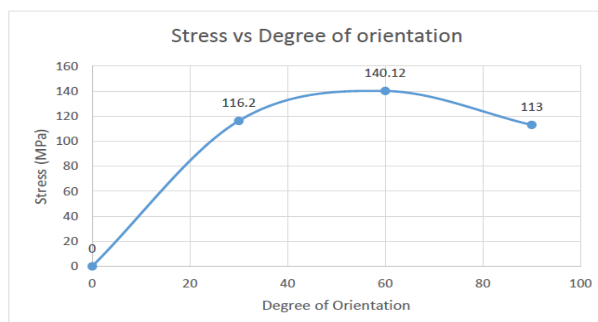

Fig No. 14 Von-misses stress for plate without hole

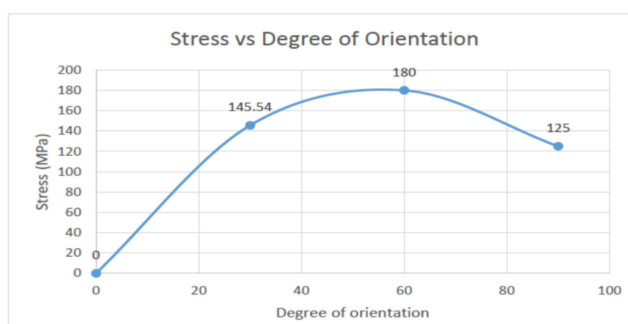

Fig No. 15 Von-misses stress for plate with 1 Hole

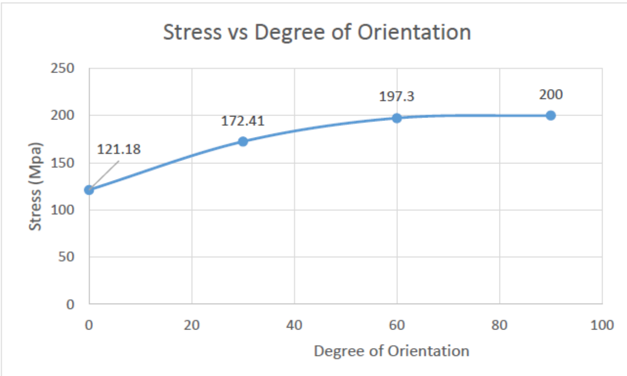

Fig No. 16 Von-misses stress for plate with 5 Hole

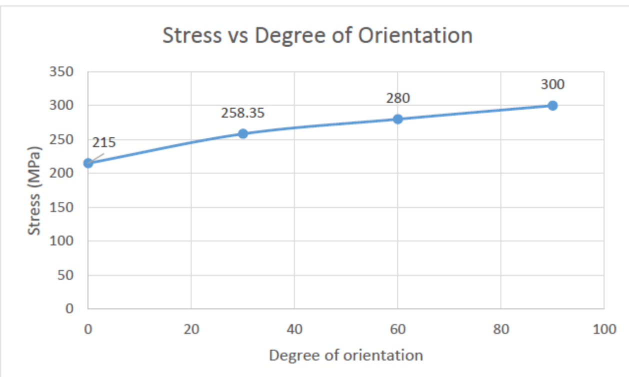

Fig No. 17 Von-misses stress for plate with 7 Hole

From any supported analysis system, Design Modeler, and various CAD systems. Responses can be studied, quantified, and graphed. Using a Goal Driven Optimization method, the deterministic method can obtain a multiplicity of design points. It can also explore the calculated Response Surface and generate design points directly from the surface.

5. CONCLUSION

The obtained results clearly stars importance for usage of composite over metals. The developed FRP for various fiber orientations clearly gives better mechanical properties over metal f studied in correlation with the loading pattern and can be stated that tensile strength of 0° fiber orientation is greater than other fiber orientation. And also under maximum loading conditions stress and deformation values for all the orientations are found to be significant but particularly with 0° fiber orientation was less as compared to other fiber orientation. Thus metals can be successfully replaced with 0° for given loading conditions and area of applications.

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