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Effects of Fiber Orientation on Mechanical Properties and Analysis of Failures for Kevlar Epoxy Reinforced Composites

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Abstract: **This paper is an outcome of investigation made on Kevlar epoxy composites made by altering the fiber orientation. It is an important region to emphasize the effect of fiber angle in the composite that results in performance. In the present research the Kevlar fiber is made by 18 layers with different angular orientation from 0º to 90º. While preparing the composite the reinforcement is made by the addition of SiC and acetone to have the firm binding ability. In addition to that right from the first layer of the fiber to the 18th layer the angle is varied progressively from 0º to 90º. After the fabrication process the Kevlar composite is tested as a flat plate and a flat plate with a circular hole in it. The analysis has involved the maximum stress theory and Tsai-wu theory for the findings on fiber orientation against failure. The test results have yielded that the fiber orientation has the significant effect on the composite plate with a circular hole in it.**

Index Terms: Kevlar epoxy composites, Mechanical characterization, Failure analysis

I. Introduction

Composites are a type of materials; possessing the properties that are to be tailored for meeting the higher level of anticipations including the aero space applications and outer space applications [1]. Researchers Mali et al [2] and Abd-Ali et. [3] had established the evidence by amending the fiber orientation with different angles in a type of composite laminate; hence, tracked down the different strengths that are to be accomplished. Hashimoto et al. [4] performed the research on tensile strength properties on the discontinuous and non uniform carbon fiber or polypropylene based composite with the disbursal of fiber direction. The exploration has proposed a ply-wise method to anticipate the discontinuous and non uniform fiber reinforced composite's strength in tension and also the simple micro-mechanical investigation. The analysis has yielded the principle of combining is efficient & effective for the qualitative anticipation of mechanical strength and witnessed the accuracy hang on fiber direction distribution in the composites. Retnam et al. [5] have also studied the consequences of the fiber direction on mechanical properties such as strength of the hybrid glass / bamboo fiber based polymer composites. In that study, the mechanical possessions of composites are tested using the tensile test, impact test and flexural test before the repercussion was analyzed using the Scanning Electron Microscope (SEM). The study divulges that the assimilation of composites escalate the mechanical properties next to improving the binding ability between the polyester resin and fiber. Due to its virtuosity and ruggedness, the Kevlar composite is one among the other composites that are chosen as advanced materials for the newfangled aircrafts. [6] In continuation with the engrossment, the researchers have started ushering studies in the domain of composite material. The cramming of composites have influenced the cut-out hole on the multilayered Kevlar/epoxy composite veneered plates has ushered by Talib et al. [7] for exploring the heterogeneity of acclimatization angles of the Kevlar fiber composite. The swatting was performed by the experimental ensuing by the simulation man oeuvre AUTODYN a part of ANSYS-12.1 software. With the outcomes, it was opined that the fiber angle and hole direction has influenced the Kevlar/epoxy composite material's stiffness and strength. Gillespie Jr and Nilakantan. [8] also ushered a study on plain woven type Kevlar fabrics to find the reverberations of yarn sizing, fabric pre-tension and pullout rate. The investigation in this research exemplified the potential to the tactical tailoring of the yarn surface and yarn sizing characteristics to hone the ballistic whack performance of Kevlar fabric. Despite the enormous studies on the characteristics of the composite materials however there is yet a lack of studies that are related to the Kevlar/epoxy composites; thus, the etiquette of these characteristics are to be understood further. Hence, the motto of this research paper is to explore the reverberations of fiber orientation angle to conventionally woven Kevlar/Epoxy composites under the compression mode with the finite element analysis (FEA) software such as ANSYS.

Sapuan et al. [9] has made the research on kevlar epoxy reinforced composites with the fillers of coconut shell and also reported that the flexural and tensile strength of the Kevlar composites are increased with an improvement in the matter of the fillers of coconut shell. The composites evinced tensile stress in linear behavior associated with sharp fracture. Likewise, Thakur and Singha [10] divulged the mechanical traits of Phenol Formaldehyde matrix type reinforced composite with a fiber named Hibiscus Sabdariffa. It is babbled that particulate reinforcement fiber is more divulge than tiny fiber in tensile strength of composites. The strength in compression of fiber composite is also revamped than the base polymer. Xu et al. [11] explored the mechanical properties of Kevlar epoxy reinforced composite with the ramie fiber. The strength in tension is improved by 27% with the NaOH used ramie natural fiber based composites. Biswas et al. [12] investigated the mechanical characteristics of Bamboo and Jute epoxy reinforced composites endorsing vacuum technique. It is behold that bamboo/epoxy reinforced composites betrayed higher flexural and tensile strength than jute/epoxy composites. Likewise, Gopinath et al. [13] contrasted the mechanical properties of Jute epoxy reinforced and polyester based matrix composites. The jute based epoxy composites yielded better than the polyester composites in the way of tensile strength but on the other hand the jute/polyester composites expressed best bending strength. Boopalan et al. investigated the mechanical properties of Kevlar epoxy composites along with the sisal and jute fibers and observed that the jute based reinforced composites shows good strength under the consideration NaOH treatment.

II. Methodology

The present work is performed in two-numerical stages. Stage 1 is about the Numerical Validation and the stage 2 is about the Failure and Displacement Analysis.

Stage 1: The Numerical Validation employs the FEA software that is important for the decrement of the cost and also to overcome the monotonous experimentations. Researchers like Blahous and Jiang have initiated the usage of computing applications for the analysis of the force (tension) value and further to find out the stress magnitudes for their investigation. Nevertheless, to corroborate the procured results whether they are valid or not, numerical validation is required as rehearsed by some old researchers. Present replica has been corroborated through the results in juxtaposition with the exact and confined solution from the previous studies, tabulated in table 1. The outcomes attained from the Finite Element software involved in this study are well founded since the percentage of error is obtained as less than 2%.

Stage 2: Failure and Displacement Analysis The failure anticipation are formulated on the available and built-in theories such as Maximum stress theory and Tsai-Wu failure theory with these the failure criterions function. The actual displacement of work piece plate is also recorded. Figure 1 depicts the total workflow of present study. The work is performed multiple times with the different alterations in the angles ranging from (θ = 0° to 90°) and also with the Maximum stress theory and Tsai-Wu failure theory to recognize the failure of first ply (FFP) and failure of last ply (FLP).

The kelvar reinforced composite have the following properties: Warp at 0^{o} direction is 3000D. Warp at 90^{o} direction is 3000D. Ends Nos./cm 6.7. Picks Nos./cm 6.7. Weave style is plain. The thickness of the material is 0.57mm. The width of the material is 1005 mm. The weight of the aerial fabric weight is 487 g/m^2. Linear density is 3040. The density in g/cc is 1.44. The modulus is > 72 GPa. Elongation at the time of the break is 2.8 % to 4.2 %. Tenacity N/tex is > 2.

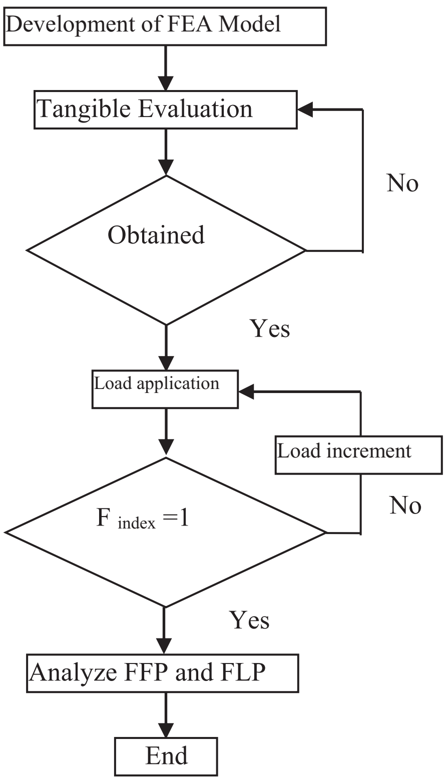

Figure 1. The analysis of failure of composite laminates

TABLE I.
Comparison of Present Model with Exact Solutions

Lamination scheme	UDL (Pa)	Exact solution (mm)	Presnet (mm)	Error (%)
0/90/0/90	689.5	0.00340	0.00348	0.59
0/90/90/0	689.5	0.00582	0.00579	0.52
45/-45/45/-45	689.5	0.00276	0.00274	0.72
15/-15/15/-15	689.5	0.00639	0.00636	0.43
45/-45	689.5	0.04066	0.04029	0.91
15/-15	689.5	0.06610	0.06576	1.42

TABLE II.
Comparison of Present Model with Exact Solutions

Lamination scheme	UDL (Pa)	Exact solution (mm)	Presnet (mm)	Error (%)
0/90/0/90	689.5	0.00340	0.00348	0.59
0/90/90/0	689.5	0.00582	0.00579	0.52
45/-45/45/-45	689.5	0.00276	0.00274	0.72
15/-15/15/-15	689.5	0.00639	0.00636	0.43
45/-45	689.5	0.04066	0.04029	0.91
15/-15	689.5	0.06610	0.06576	1.42

TABLE III.
COMPARISON OF PRESENT MODEL WITH EXACT SOLUTIONS

Lamination scheme	UDL (Pa)	Exact solution (mm)	Presnet (mm)	Error (%)
0/90/0/90	689.5	0.00340	0.00348	0.59
0/90/90/0	689.5	0.00582	0.00579	0.52
45/-45/45/-45	689.5	0.00276	0.00274	0.72
15/-15/15/-15	689.5	0.00639	0.00636	0.43
45/-45	689.5	0.04066	0.04029	0.91
15/-15	689.5	0.06610	0.06576	1.42

Models of the composites are in the orientation of the flat rectangular plates and flat rectangular plate with a separated circular hole (D = 0.03 meter) as shown in the figure 2 (a) and (b). Preparation of the model is done with the 18 layers laminates with the symmetry of (θ4/04/-θ4)s lay-up (where θ = 0° to 90°). The included angles range from 0° to 90° with 15° inclement. The model is made with the thickness of about 0.13432 mm and it is coupled with the compressive force for the study of repercussions of the circular hole and also the lamination angle scheme for the displacement of the layers in composites and also the first ply failure or fracture and last-ply failure or fracture of the prepared Kevlar epoxy reinforced composite materials. The material as well as the mechanical properties of the woven Kevlar epoxy composite is described in table 2. A FEA analysis based on failure theories and procedure is carried out with the academic software (ANSYS v18.1, 2019).

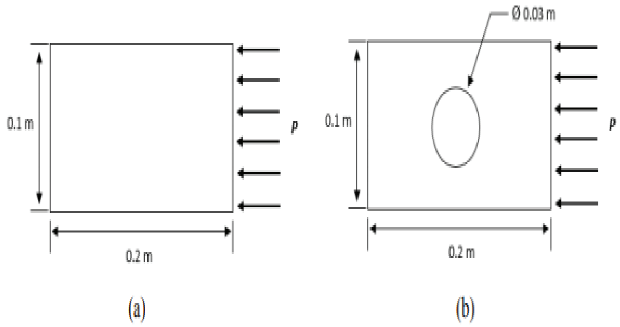

Figure 2. (a) Flat plate model (b) Flat plate Model with a circular hole

III. RESULTS AND DISCUSSIONS

Flat plate: The results of deformation for the flat plate are presented in the figure 3. From the figure in the orientation of change in dimension occurred. From the same figure, this is evident that maximum displacements took place in the direction of x-axis. The output curves describe the highest displacement in the x and y axis directions that took place at an angle of 45°. The minimum displacement location is obtained at 0° and 90 ° on both the x and y axis directions. There are no changes in dimensions observed in the z-axis direction.

The compression type of force is imposed in x-axis direction hence, results the larger amount of displacement in x-axis direction as verified with the y-axis direction. The outcomes of the FFP and FLP are calculated by using the Tsai-Wu and Maximum stress failure theory criteria that is been catalogued and exhibited in figure 4. Also from that graph, it is observed that, the curves pattern is symmetrical and found with a tiny gap difference in betwixt FFP and FLP. The highest stress recorded is found at an angle of 0° and 90° for both FFP and FLP. The outcomes dwindled proportionally apropos the 45° mark and also escalated back commensurate until it obtains 90°. It is also observed that the outcomes from twain the Tsai-Wu and Maximum stress are in good rapport for the test.

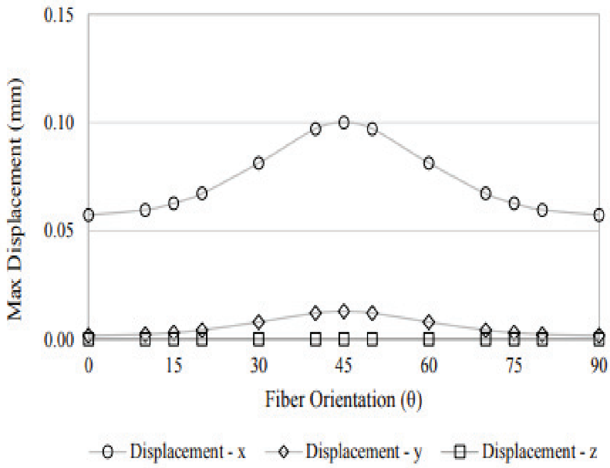

Figure 3. Displacement graph of Flat plate

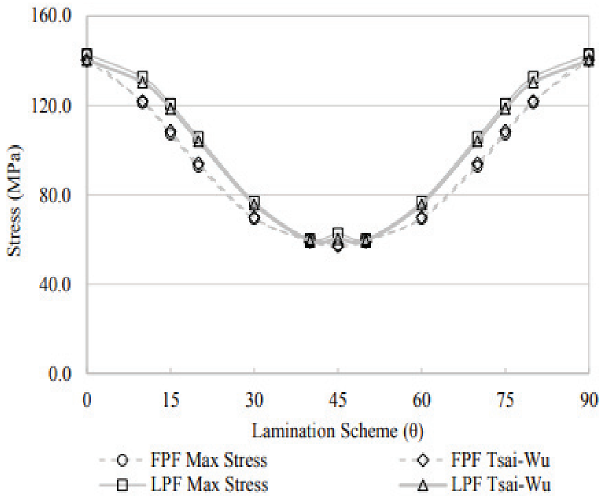

Figure 4. FFP and FLP for the flat plate (Tsai –Wu & Maximum stress)

The Flat plate along with a circular hole has the deformation that results for a flat plate along with a circular hole that has been documented and also presented in the figure 5. With reference to the figure 5, the deformation based curves for the flat plate is symmetrical however it is incompatible as compared to the curves of the flat plate. The peak displacement is observed in the x and y-axis direction at an angle of 0° and 90°. The curves in the x axis direction were observed to rise again after an angle of 30° until it has reached to the 45°. In y-axis direction some of the displacement is observed and no displacement is found in the z-axis direction. With the Tsai-Wu and Maximum stress failure theory, the graph derived from the outcomes of FFP

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and FLP on flat plate along with a circular hole presented in it as shown in figure 6.

Similar to the previous outcomes, a symmetrical shape is formed. Far from the flat plate curves, a line that shows an interstice results of FFP and FLP. The result of Tsai-Wu and Maximum stress failure theory yet is observed to be very nearer to each other barring for the outcomes on the FLP at 40º and 50º. Flat plate along with a circular hole then it is found that FFP and FLP took place on an alternate layer or ply in betwixt θ¸ ply, -θ and ply. With reference to the analysis carried out, it is observed that effects of the angle of fiber over the plate along with a circular hole that are more noteworthy than that of flat plate. The outcome harmonizing with results of the previous literature shows that the work piece material elimination from plate is dropped down its strength [10]. Hence, it is proven that the numerical analysis and its findings are predominant in succoring the practitioners and engineers in developing a robust and reliable Kevlar Epoxy reinforced composite laminates.

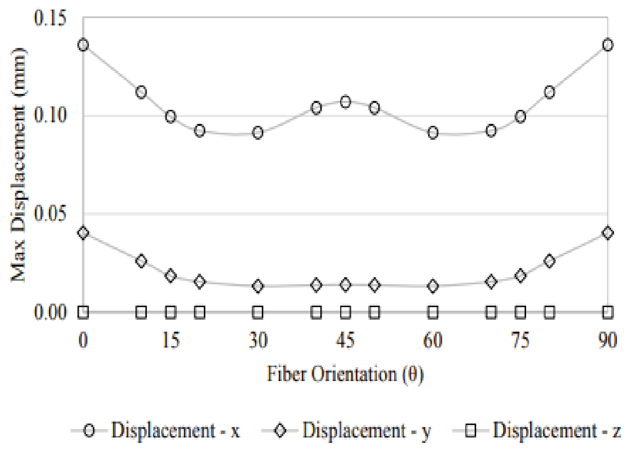

Figure 5. Flat plate with circular hole displacement graph

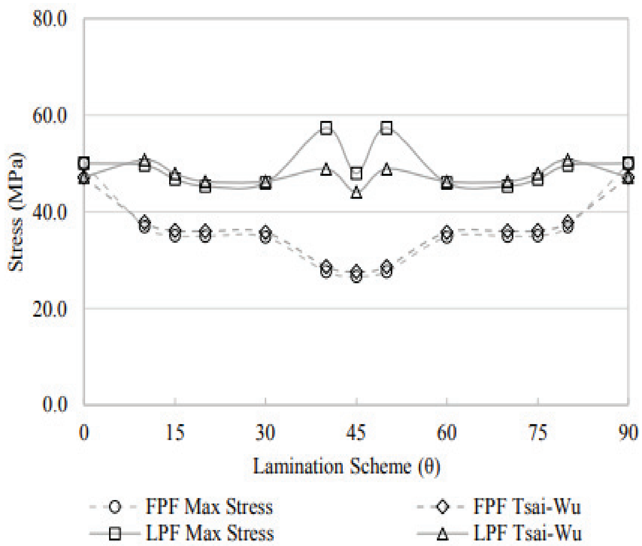

Figure 6: FPF and LPF for Flat plate with circular hole (Tsai-Wu & Maximum Stress)

TABLE III.
MATERIAL PROPERTIES OF KEVLAR EPOXY COMPOSITES

$E_1 = E_2 = E_3$	26180 MPa	X_T=Y_T	420 MPa
$V_{12} = V_{13} = V_{23}$	0.11	X_C=Y_C	150 MPa
$G_{12} = G_{13} = G_{23}$	1533 MPa	S	106 MPa

IV. CONCLUSIONS

This research paper has analyzed, discussed and presented about the impact of the orientation and fiber angle to a flat plate along with another flat plate along with a circular hole in it. Thus it is made up of woven type Kevlar Epoxy reinforced composite laminates under compressive state. It is significant in the composite with a hole in it as compared to a plane plate.

Hence the failure behavior for both flat plate and flat plate with circular hole is different and is more abrupt in the later case. The major findings that are to be taken out from this analytical investigation are effect of fiber orientation and its impact on both flat plate and flat plate along with a circular hole in it. The major deformation transpires when the reduction of area of the plate along the orchestration of force is imposed.

Different deformations are recorded on each and every angle of fiber orientation that is tested as it shows the fiber direction and orientation angle affects on the deformation of work piece i.e., Kevlar Epoxy reinforced composites. Over the flat plate, it is observed to be more stronger at an angle θ = 0º and 90º due to resistance in the orientation of the fiber orientation with regard to the compressive force. The mechanical strength moderately abates along with angle of fiber direction, at an angle of 45º layup; the flat plate is originated to be at the least strength. On the other hand, the alteration in the fiber direction has found that it has no note worthy influence over the mechanical strength of the Kevlar Epoxy reinforced composite flat plate along with a circular hole in it. The space in between the FFP and FLP curves shows that for flat plate with a circular hole is observed to be much larger as compared to normal flat plate. The outcomes from the Tsai-Wu and Maximum stress failure theory are observed to be very close and provide a good rapport to each other. Hence, it can be culminated that the present cramming is helpful in bestow note worthy knowledge for extension of failure phenomenal understanding of the Kevlar Epoxy reinforced composite.

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