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Mechanical performance of woven carbon reinforced epoxy composites with varied orientation angle

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Abstract

The mechanical properties of woven carbon fibre reinforced epoxy composites laminated with different orientation angle in stacking sequence were investigated. Woven fabric layers with different linear density carbon tow have been produced on modified rigid rapier sample loom and impregnated with epoxy by hand lay-up technique for composite preparation. Curing of composite was carried out at room temperature for 2 h. Five different laminar composites were prepared with different orientation angles [(0/0/0/0), 0/+30/-30/0, 0/+45/-45/0, 0/+60/-60/0 and 0/+90/-90/0]. The mechanical properties like tensile, flexural, and impact test) were analysed in both longitudinal and transverse directions. Physical properties such as density and fibre volume fraction were analysed. While comparing the layers of orientation of woven composites, the results of tensile and flexural showed higher properties in [(0/0/0/0), and 0/+90/-90/0] stacking in both directions than others. Impact showed higher properties in 0/+45/-45/0 stacking than others.

1. Introduction

Composite is a unique combination of two or more materials at macroscopic level with characteristically different individual properties that results in a material with unique properties than those of the material used alone as defined by Mark [1]. Many researchers have stated that composite materials have high strength to weight and stiffness to weight ratios which enable its use in producing component with less weight and high performance [2-5]. Most of researchers have reported that composites have anisotropic properties, higher properties when load is applied in the direction of load and lower properties at different angles to direction of reinforcement [5-7]. Designing of composite is difficult due to this anisotropy. Sevkat *et al.* have propounded that hybrid composites lead to a better solution to obtain a product with desired properties and cost effectiveness [8]. Many researchers have stated that composites are affected by orientation angle of fabric layer at different angle used for reinforcement [6,7, 9-16]. The properties of the composites as engineered by hybridisation by varied orientation angle and matrix to modify the function as demanded by application. Woven composite laminates deliver functional properties like excellent integrity, conformability, good resistance to fracture as well as transverse rupture, high impact strength and balanced properties within the fabric plane. These properties have promoted its use in structural applications such as automobile, aircraft, marine and civil structures as per suggested by several studies [9,17-19]. The basis of any structural application is its loading transferring capacity. The load transfer depends on physical and mechanical properties of the interface. Mechanical properties like tensile strength, flexural strength and impact strength are important for evaluation of any engineering materials. The service life of the composites is highly affected by its toughness which is one of the most critical mechanical property of engineering material. Impact strength gives idea about the toughness of the composite material.

The basic focus in this study, woven carbon reinforced composite was prepared for studying the effect of orientation angle on mechanical properties of composites. The prepared composites were analysed by standard techniques for their physical and mechanical properties. Mechanical strengths were evaluated and compared in both directions, longitudinal and transverse as textile composites demonstrates anisotropic behaviour.

2. Materials and methods

2.1 Materials

Raw material 12K and 6K Carbon tow having the grade TC-36s and TC-35 respectively were used for preparation of woven reinforcement fabric. The physical properties of these fibers are presented in Table 1. The woven fabric was manufactured with plain weave on CCI rigid rapier sample loom with required modifications as suggested by Agrawal [20]. The fabric consists of 12K carbon yarn in weft and 6K carbon yarn in warp. The materials used for preparation of matrix were functionalised Epoxy resin grade Polysil 100EC along with catalyst (VT – 150C), Coupling agent (VT – 400CA) and air releasing agent (VT– 450ARA).

Table 1. Physical properties of the reinforcement yarns.

Reinforcement yarn	Density ($g \cdot cm^{-3}$)	Linear density (tex)	No. of filaments/tow	Tensile strength ($g \cdot tex^{-1}$)	Tensile strength (MPa)	Strain (%)	Modulus of elasticity (MPa)
12K C*	1.81	817	12000	92.4	1630	2.64	617.4
6K C*	1.81	400	6000	99.98	1764	1.63	1082

*C- Carbon

2.2 Preparation of composites

Composite was fabricated using hand lay-up technique (Figure 1) wherein fabric layers were laid down on a smooth surface as per the stacking sequence and were subsequently cured by the simultaneous application of pressure. Woven composites were allowed to cure at room temperature for 2 h. Proper loading was provided to obtain uniform thickness of approximately 2 mm for every sample.

The stacking sequence as [(0/0/0/0), 0/+30/-30/0, 0/+45/-45/0, 0/+60/-60/0 and 0/+90/-90/0] was followed for preparation of four layered composite sample. The schematic representation of stacking sequence with different angles of orientation are given in Figure 2. The composites were then ready for characterization.

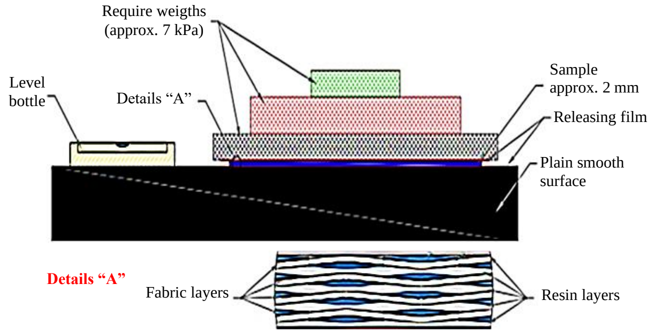

Figure 1. Schematic diagram of hand lay-up technique used for formation of composite.

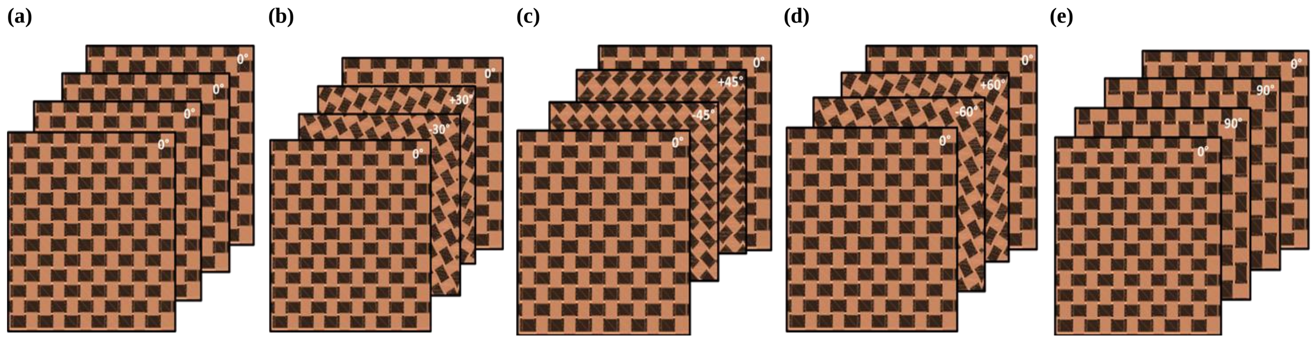

Figure 2. Schematic diagram of stacking sequence of woven laminate composite with different orientation angles. (From left to right: a; (0/0/0/0), b; 0/+30/-30/0, c; 0/+45/-45/0, d; 0/+60/-60/0, e; 0/+90/-90/0 where ±30, ±45, ±60, ±90 indicate the warp yarn fibres in fabric are having 30°, 45°, 60°, 90° angle respectively with standard normal fabric with horizontal).

2.3 Physical tests

To determine the density of the woven composite laminates, Archimedes principle by mixing two fluids having different densities was used as defined by Agrawal [21]. Fiber volume fraction was measured by using modified equation for woven composites as formulated by Agrawal [22].

2.4 Mechanical tests

Tensile strength and elongation at break were determined on Universal Testing Machine (TINIUS OLSEN/L-Series H50KL), capacity 5000 kg according to ASTM D 3039. Tensile modulus was calculated. Flexural strength was determined by three-point bending test on Universal Mechanical Testing Machine at CHT 1.3 $mm \cdot min^{-1}$ and hold time as 1 s. Flexural modulus was calculated. The Izod impact Test was carried out using Impact pendulum tester XJUD-5.5. The notching of samples was done by using JJANM- 21 notching machine. Five specimens for each type of composite laminate were tested for all the tests. The average values of test results are being depicted here.

3. Results and discussion

3.1 Physical properties

The physical properties of woven composite are depicted in the Table 2. It is understood from the results that the samples CC1, CC2, CC3, CC4 and CC5 vary in their angle of orientation but does not show appreciable variation in the density. That means the effect of varied stacking sequence is negligible on the density.

From the result of fibre volume fraction (V_f), it is understood that effect of stacking sequence at different angle of orientation does not have considerable effect on V_f. The sample show negligible variation of 5% in V_f as the construction of composite is made from same fabric at varied angles. Thus, effect of varied orientation angle in the stacking sequence is not considerable on fibre volume fraction values.

Table 2. Physical properties of the reinforcement yarn.

Sample code	Stacking sequence	Density ($g \cdot cm^{-3}$)	Fibre vol. Fraction V_f (%)
CC1	0/0/0/0	1.3349	65.90
CC2	0/+30/-30/0	1.3285	61.13
CC3	0/+45/-45/0	1.3328	68.39
CC4	0/+60/-60/0	1.3298	69.52
CC5	0/+90/-90/0	1.3402	68.77
Matrix	-	1.233	-

*C- Carbon

3.2 Tensile properties

The stress-strain curves of the woven composites with different orientation angles in both longitudinal and transverse direction are shown in Figure 3(a) and (b). The tensile test results of the woven composite samples are presented in Table 3. Analysis of results shows that CC5 (456.73 MPa) and CC1 (980.06 MPa) shows highest stress in longitudinal and transverse direction, respectively. Variation in the stress value is high considering CC1 to CC5 in both directions. Referring to Figure 3(a) and (b), it is noticed that strain response is different for same stress value. It is apparent that strain progressively increases from CC5-CC4-CC5-CC2-CC1 in longitudinal direction whereas in transverse direction the trend is increase from CC1-CC5-CC2-CC4-CC3.On comparing all the test results, it is found that CC1 composite laminate in transverse direction gives maximum ultimate tensile strength that is about 980 MPa. Next highest strength of 450 MPa is achieved by CC5 in longitudinal direction. CC1 and CC5 have achieved this tensile strength due to its orientation of fabric layers in particular direction which is different than other samples. The orientation angle of stacking sequence of CC1 and CC5 has been unique in terms of no skewness of fibres in direction of load in either of directions (longitudinal and transverse). All four fabric layers used for composite preparation are being placed in the direction of application of load in these samples as elucidated in Figure 4. It can be observed that CC2, CC3 and CC4 have two fabric layers laid at angle whereas two layers in the direction of application of load as explained in Figure 4. During the load application in axial direction, the fabric layers in the stacking sequence which are at an angle strive to align itself in the direction of load. During the loading, this process is restricted by the bonding between fibre and matrix and shear stress. This ultimately leads to breakage of adhesion and early failure of the sample. This can be the reason for lesser tensile strength of CC2, CC3 and CC4.

The results of tensile modulus of elasticity of all the specimens are depicted in Table 3. It is observed that maximum modulus of elasticity of 15.6 GPa is obtained in CC1 composite laminate in transverse direction. It is also observed that CC3 have got least value of modulus of elasticity in both longitudinal and transverse direction. Thus, higher tensile strength in both lengthwise and crosswise is obtained but at different angle the strength of composites is not that much as compared to the axial and cross direction.

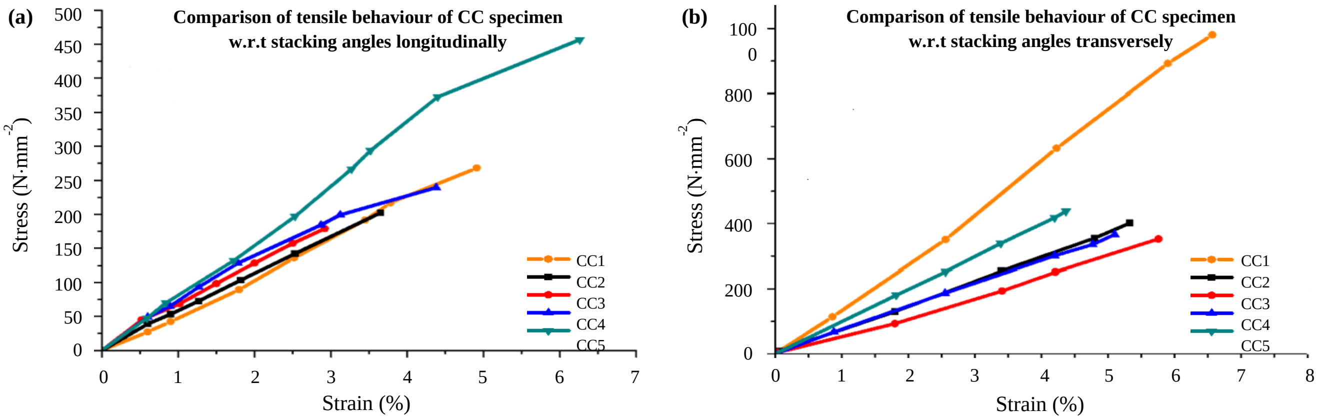

Figure 3. Effect of orientation angle on tensile behavior of woven composite (a) Longitudinal direction, and (b) Transverse direction.

Table 3. Tensile properties of woven carbon epoxy composite.

Sample code	Stacking sequence	Longitudinal		Transverse	
		Stress (MPa)	Modulus of Elasticity (GPa)	Stress (MPa)	Modulus of Elasticity (GPa)
CC1	0/0/0/0	268.98	5.475	980.06	15.63
CC2	0/+30/-30/0	202.43	5.164	401.01	7.524
CC3	0/+45/-45/0	175.70	5.134	352.68	6.124
CC4	0/+60/-60/0	239.45	5.471	365.78	7.179
CC5	0/+90/-90/0	456.73	7.292	437.00	10.18

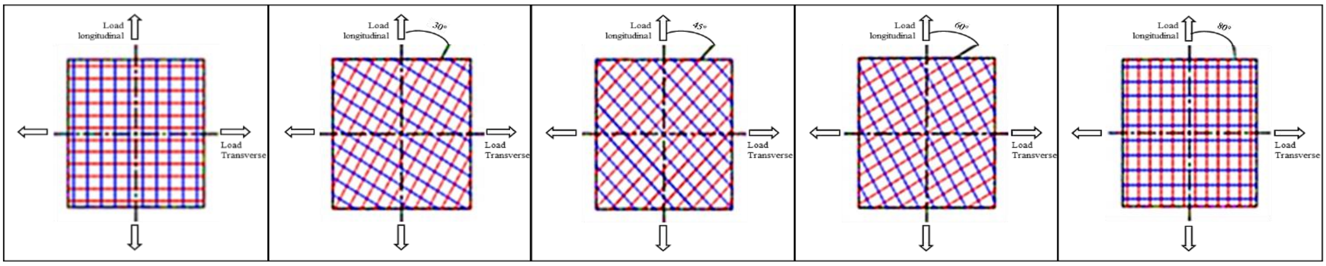

Figure 4. Schematic diagram of effect of orientation angle on tensile properties of woven composite.

3.3 Flexural properties

The flexural test results of the composite samples are presented in Table 4. The load–displacement (CHT – cross head travel) graphs for woven composite flexural behavior in terms of orientation angle in both longitudinal and transverse directions is depicted in Figure 5. The load–displacement graphs demonstrate that curves for transverse directions are steeper than longitudinal direction. It entails that in transverse direction higher load is required the same displacement as compared to longitudinal direction. CC1 displays the steepest curve in both directions. From the graphs the almost linear rise of flexural load up to the maximum load on the specimen is observed. Subsequently, the load value on the samples sharply decreased due to major multiple fibre breakages. Then, minor slip and stick failures were observed.

From Table 4, the results of flexural properties show that flexural strength is highest in CC5 (386.95 MPa) in longitudinal direction whereas CC4 (567.77 MPa) shows maximum flexural strength in transverse direction. Highest flexural modulus 56.83 GPa was demonstrated by CC4 in transverse direction. In longitudinal directions CC5 reveals highest flexural modulus 0.39 GPa whereas all other specimens showed less than 0.3 GPa. This distinct behaviour among longitudinal and transverse direction is due is to the type of fibre in line of axis of loading. In case of for transverse direction, the 12K Carbon fibre are in line of loading of the axis, whereas in case of longitudinal direction 6K Carbon fibre are in line of loading of the axis. The fiber is placed at the bottom (tension side) affect the flexural strength and modulus of the specimen. In case of longitudinal direction 6K Carbon will have higher effect on flexural properties. Though 6K Carbon has higher tensile strength than 12K carbon, due basic weaving process chances are of deterioration of yarn strength [20]. This can also be cited as one of the reasons for this behaviour. The same trend is observed in tensile modulus (Table 1) for the same reasons.

In case of CC5 there is no skewness in orientation angle along longitudinal and transverse directions. Due to this, the adhesion between the reinforcement and matrix is stronger than other samples. This strong adhesion enables better load transfer to the reinforcement. CC4 possess highest flexural strength in transverse direction among all specimens. One of reasons can be given as CC4 has higher fibre volume fraction (Table 1) as compared to another specimen. CC4 shows higher flexural strength as significant parts of the fibre surface was observed intact. This shows that, the interface plays important role as far as adhesive failure for all specimens is concerned. The sample CC4 showed splits of carbon tow of layers in the stacking sequence has considerable influence on the impact strength of the prepared woven composites. The reason for such behavior can be understood by the bonding between fiber and matrix. This phenomenon can be explained by the interface bonding. A strong interface bonding permits higher load stress transfer through the composite fibres. Whereas a weak interface bonding will deprive adhesion between the fibres and matrices. As soon as, the force acting on the composite supersede a bonding force, it causes the fibres to snap and pull out. The variation in behavior in values shows that orientation angle of fabric layers in the stacking sequence have prominent effect on the flexural property of the woven composite.

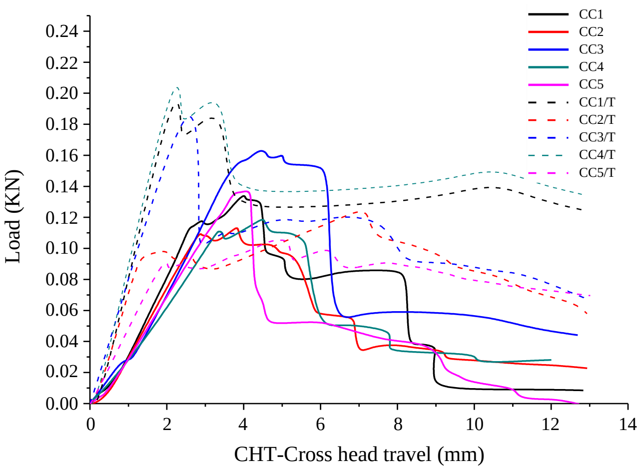

Figure 5. Effect of orientation angle on flexural behavior of woven composite in both longitudinal and transverse directions. (CC 1-5 longitudinal direction: CC/T 1-5 Transverse direction).

Table 4. Flexural properties of woven carbon epoxy composite.

Sample code	Stacking sequence	Longitudinal		Transverse	
		Flexural strength (MPa)	Flexural modulus (GPa)	Flexural strength (MPa)	Flexural modulus (GPa)
CC1	0/0/0/0	260.39	0.26	280.45	17.78
CC2	0/+30/-30/0	235.42	0.24	187.18	12.78
CC3	0/+45/-45/0	274.42	0.27	359.67	24.88
CC4	0/+60/-60/0	312.49	0.31	567.77	56.83
CC5	0/+90/-90/0	386.95	0.39	235.39	11.00

3.4 Impact properties

The impact test results of the composite samples are presented in Table 5. The comparison of impact strength (kJ·m^{-2}) of woven composite with respect to the varied orientation angle in the stacking sequence is showed in Figure 6. It is depicted from the figure that in transverse direction impact strength is higher than longitudinal direction. The order of impact strength from highest to lowest is CC3 > CC5 > CC1 > CC4 > CC2 in both directions. CC3 specimen shows highest impact strength as compared to others in both the directions. The impact strength of CC3 is 99.9 (kJ·m^{-2}) and 76.41 (kJ·m^{-2}) in transverse and longitudinal directions, respectively. CC3 specimen has orientation angles as (0/+45/-45/0), this distribution exhibits equal distribution of fibers in all directions thus this sample behaves as pseudo isotropic and behaves as metal. This arrangement provides maximum resistance against impact as compared to others. In case of other samples there is concentration of fibers in irregular direction which leads to their fracture on application of impact force. It is observed that SD value of impact strength along longitudinal and transverse directions reflects considerable variation in the impact strength value with respect to orientation angle of fabric layers. Thus, orientation angle of layers in the stacking sequence has considerable influence on the impact strength of the prepared woven composites.

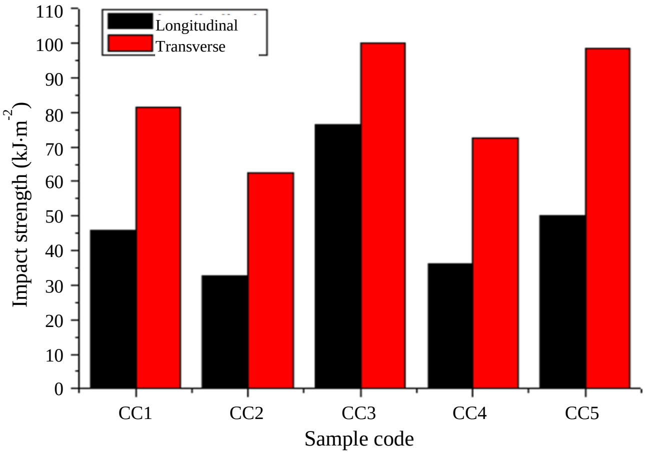

Figure 6. Effect of orientation angle on impact behavior of woven composite in both longitudinal and transverse directions.

Table 5. Impact properties of woven carbon epoxy composite.

Sample code	Stacking sequence	Longitudinal	Transverse	
		Impact strength (kJ·m^{-2})	Impact strength (kJ·m^{-2})	SD (kJ·m^{-2})
CC1	0/0/0/0	45.854	81.336	25.08956
CC2	0/+30/-30/0	32.771	62.548	21.05552
CC3	0/+45/-45/0	76.413	99.906	16.61206
CC4	0/+60/-60/0	36.233	72.448	25.60787
CC5	0/+90/-90/0	50.056	98.287	34.10447

4. Conclusion

This research aimed to determine the mechanical properties of woven carbon fiber reinforced epoxy composites laminated with different orientation angle in stacking sequence. For this study factors like resin type, no of layers in the stacking sequence, matrix curing time and temperature, pressure used for loading were kept constant. This will allow establishing a baseline on comparison of the specimen prepared. It can be concluded that woven composites samples CC5 (0/+90/-90/0) and CC1 (0/0/0/0) has shown maximum tensile strength and modulus in longitudinal and transverse direction, respectively. As the orientation angle of fabric deviates from axis of loading, reduction in strength and modulus is witnessed. Woven composites samples CC5 (0/+90/-90/0) and CC4 (0/+60/-60/0) has shown maximum flexural strength and modulus in longitudinal and transverse direction, respectively. Woven composites sample CC3 has shown maximum impact strength in longitudinal and transverse direction, respectively. Overall, it can be summarized orientation angle of fabric layers in a stacking sequence has effect on tensile, flexural, impact properties of woven composites.

References

[1] H. F. Mark, *Encyclopedia of Polymer Science and Technology*, John Wiley & Sons, Composite materials, vol. 9, 2004.

[2] M. A. Lamontia, Gruber, M.B. Smoot, M.A. Sloan, and Gillespie, "Performance of a filament wound graphite/ thermoplastic composite ring- stiffened pressure hull model," *Journal of Thermoplastic Composite Materials*, vol. 8, pp. 15-36 ,1995.

[3] M. K. Bannister, "Development and application of advanced textile composites," *Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications*, vol. 218, no. 3, pp. 253-260, 2004.

[4] R. M. Jones, *Mechanics of composite materials*, CRC Press, 1998.

[5] S. A. Agrawal and S.S. Bhattacharya, "Textile reinforced structure: A Review", *International Journal of Engineering Research and Application*, vol. 7, no. 7, pp. 84-86, 2017.

[6] S. Adanur, *Handbook of Industrial Textiles*, Wellington Sears, Technomic publishing Co. Inc, 1995.

[7] Swayam-NPTEL course for technical textiles, IIT Madras. Available: https://nptel.ac.in/courses/116/102/116102057/

[8] E. Sevkat, B. Liaw, F. Delale, and B. B.Raju ,"Drop-weight impact of plain-woven hybrid glass–graphite/toughened epoxy composites", *Composites Part A:Applied Science and Manufacturing*, vol. 40, Elsevier, 8, pp. 1090-1110, 2009.

[9] H. H. Allameh, R. Zahari, W. Kuntjoro, and Y. Taib,"Tensile strength of notched woven fabric hybrid glass, carbon/epoxy composite laminates", *Journal of Industrial Textiles*, vol. 43, 2012.

[10] W. Steinmann, and A. K. Saelhoff, "fibrous and textile materials for composite applications," Textile Science and Clothing Technology, Springer Science, Business Media Singapore, 2016.

[11] M. A. Abd El-baky, "Impact performance of hybrid laminated composites with statistical analysis," *Iranian Polymer Journal*, vol. 27, pp. 445-459, 2018.

[12] G. Acıkbas and S. Ozcan, "Production and characterization of a hybrid polymer matrix composite," *Polymer Composite*, 2017.

[13] G. Fernando, R. F. Dickson, T. Adam, H. Reiter, and B. Harris, "Fatigue behavior of hybrid composites-Part 1 Carbon/Kevlar hybrids," *Journal of Material Science*, vol. 23, no. 10, pp. 3732-3743,1988.

[14] E. Fitzer, D. D. Edie, and D. J. Johnson, Carbon fibers-present state and future expectation; Pitch and mesophase fibers; Structure and properties of carbon fibers. In *Carbon Fibers Filaments and Composites,* 1st ed.; Figueiredo, J.L., Bernardo, C.A., Baker, R.T.K., Huttinger, K.J., Eds.; Springer: New York, NY, USA, 1989; pp. 3-41, 43-72, 119-146.

[15] M. Idicula, S. K. Malhotra, K. Joseph, and S. Thomas, "Effect of layering pattern on dynamic mechanical properties of randomly oriented short banana/sisal hybrid fiber–reinforced polyester composites," *Journal of Applied Polymer Science*, vol. 97, pp. 2168-2174, 2005.

[16] B. Philippe, *Composite Reinforcements for Optimum Performance*, Woodhead publishing, UK, 2011.

[17] R. Murugana, R. Ramesh, and K. Padmanabhan, "Investigation on static and dynamic mechanical properties of epoxy based woven fabric glass/carbon hybrid composite laminates," Elsevier, ScienceDirect, *Procedia Engineering*, vol.97, pp. 459-468, 2014.

[18] C. Hochard, J. Payan and C. Bordreuil, "A progressive first ply failure model for woven ply CFRP laminates under static and fatigue loads," *International Journal of Fatigue*, vol. 28, pp.1270-1276, 2006.

[19] P. Shembekar, and K. Naik, "Notched strength of fabric laminates. II: Effect of stacking sequence," *Composites Science and Technology*, vol. 44, no. 1, pp. 13-20, 1992.

[20] S. A. Agrawal, and S. S. Bhattacharya, "Carbon Weaving: Impediments Experienced," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 6, no. 7, pp. 2017.

[21] S. A. Agrawal, "simplified measurement of density of irregular shaped composites material using archimedes principle by mixing two fluids having different densities," *International Research Journal of Engineering and Technology*, vol. 8, no. 03, pp. 1005-1009, 2021.

[22] S. A. Agrawal, "To study the physical and mechanical properties of textile Composite's laminates produced by Orienting fabric layers differently," PhD dissertation, Dept. of Textile Engineering, The Maharaja Sayajirao University of Baroda, Gujarat, India.