Effect of Kevlar Ply Orientation on Mechanical Characterization of Kevlar-Glass Fiber Laminated Composites

A Vasudevan1*, Pandiyarajan R2, B Navin Kumar1, J Vijayarangam3

1Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai-602105, India.
2Department of Mechanical Engineering, K.L.N College of Engineering, Sivagangai, India– 630612.
3GF, BITS PILANI-WILP, Chennai

* Corresponding author: vasudevana.sse@saveetha.com

Abstract. Composite materials are highly suitable to withstand with mechanical loads compared to conventional materials. At present, these materials are being substituted with composite materials due to their superior properties and broadly used in aerospace industries and other industries. In this work, investigations are conducted out to determine the mechanical properties of composite laminates, for various orientations (0°/30°/45°/60°) of kevlar fibres with glass fibres. The different mechanical testing such as tensile test, flexural test and dynamic Mechanical Properties of the hybrid composite material with various orientations of the top and bottom Kevlar laminates were evaluated. It is concluded that the Fabricated hybrid composites with 0° orientation of the Kevlar fibres exhibit higher tensile Strength as well as flexural strength compared to the composites with oriented kevlar fibres (30°/45°/60°). The increased mechanical properties of the 0° hybrid is due the alignment of the kevlar fibres in loading direction which causes it to act as the primary load bearing structure whereas in the oriented hybrid composites the glass fibre acts as the initial load bearing structure.

1. Introduction
Continuous Fiber Reinforced Plastic (CFRP) composites has been employed as alternative materials for existing engineering materials for various applications more than five decades [2]. The utilization of polymer matrix composites reinforced with kevlar and glass fibres are increasing in the aerospace and defence sectors due to their specific properties. Kevlar fibres, known for their stiff and tough nature have occupied an indefinitely unchanging position in the aerospace industry as a reinforcing material in the aircraft wing and tail structures. Glass fibres, predominantly used for light weight, high strength applications such as in high speed boat hulls and they are also employed along with aluminium metal sheets as fibre metal laminated (FML) composites for aircraft fuselage structures but metal sheets as a reinforcement tends to increase the weight of the composite. Most CFRPs’ contain reinforcing fiber (single-fiber-type composites, SET) [1] that limits the strength of the composite to that of the fibre used. In a hybrid composite, on the other hand, several types of fibres are combined [1] to meet the demands of the rigorous mechanical specifications in the aerospace industries, as these composites exhibit a wider range of mechanical properties [9] owing to the highly nonlinear behavior of the fibres [5]. Thus, two
different fibres with low and approximately equal densities may be combined to make the composite stiffer and extremely light weight.

In this work, glass fibres have been stacked together with top and bottom Kevlar laminates to make a combination of Kevlar and glass fibre reinforced hybrid polymer (epoxy) matrix composites. The hybrid composites fabricated by vacuum bag moulding and subjected to mechanical testing such as tensile and flexural test along with the Dynamic Mechanical Analyzer (DMA) to check the resistance of these composites to high frequency vibrations commonly encountered in the aircraft wings. Generally, E-glass, S-glass, carbon, Kevlar are used to reinforce the polymer matrix composites. Reinforcing materials like Carbon and S-glass are stiffer but lack in ductility when compared with E-glass and Kevlar. In order to improve the toughness. The researchers promote the hybrid composites by incorporating more ductile fibers Pandya et al. (2011), a hybrid composite will have more than one reinforcing element to achieve enhanced properties. Hybrid composites offer the superior benefits of the fibers and these hybrid composites will be a good alternative in developing of light weight, low cost composite structures with better mechanical properties. The current utilization of hybrid composites is presently being used in the construction of aircraft wing, propeller blades in the turboprop engine aircrafts and tail structures and marine applications Ying et al. (2017); Sismanoglu et al. (2017) have studied the tensile and three-point bending behavior of (carbon/Kevlar/epoxy) interply composite and three different inter-intraply hybrid composites such as carbon/hybrid (carbon glass)/epoxy, Hybrid (carbon-glass)/Kevlar/epoxy and carbon fibre /Kevlar fibre/hybrid (carbon-glass)/epoxy laminated composites. They have found the tensile strength, strain, bending strength and moment are higher for interply hybrid (carbon-Kevlar/epoxy) composites while carbon-hybrid/epoxy has the highest Young’s modulus.

K. Naresh et al. (2017) conducted experiments to determine the tensile properties of the composite laminates, for various orientations [(0/90/30/60), and (0/90/45/-45) and (30/-60/60/-30)] of glass fibre/epoxy and carbon fibre /epoxy composites. Using two-parameter the Weibull distribution, the theoretical tensile properties values are calculated for glass fiber reinforced polymer (GFRP) and carbon fiber reinforced polymer (CFRP) composites for different strain rates by a linear curve fitting.it was observed that the values match well.

Pegoretti et al. (2004) investigated the tensile and impact properties of polyester resin reinforced by E-glass and poly vinyl alchol (PVA) fabrics of three different combinations, namely homogeneous and interply and intraply hybrid composites. The tensile tests were performed on the Instron UTM (4502) equipped with the load cell of capacity 10 kN. The impact test was conducted using the Charpy pendulum impactor. The tensile properties were found to be higher for interply hybrid composites whereas the intraply hybrid composites hindered the crack propagation and exhibited the maximum energy absorption which can be attributed to ductile behaviour of intraply fabrics compared to the other combinations.K. Naresh et al. (2017) studied, the influence of strain rate on the tensile strength of glass fibre/epoxy, carbon/epoxy and hybrid (glass-carbon/epoxy). The composite materials are experimentally and theoretically investigated.

2. Experimental Methodology

The composites consist of two major constituents i.e matrix (polymer, ceramic or metal) reinforced with fibers (graphite, glass or aramid fibers, etc.) or particles. Most of the composite material contain only one type of reinforcing fiber (single-fiber-type composites, SET). In a hybrid composite, to obtain the benefits of each fibre, several types of fibers are combined in the material. In this work, the following materials are utilized to fabricate the composite material. The Bidirectional Glass fibres (600 GSM) and Unidirectional Kevlar fibres (200 GSM) are used as reinforcing element, Epoxy (LY566) as a matrix and hardener (HY951) is used to fabricate the material.

2.1. Fabrication of the hybrid composites by Vacuum Bag Moulding

The hybrid composites of dimensions 300 × 300 mm were fabricated by vacuum bag moulding technique as shown in figure 2.1. The hybrid composites composed of four layers of the bidirectional glass fibres was sandwiched between two layers of Kevlar fibres of varying orientations (0°/30°/45°/60°) as shown in figure 2.2, constituting six layers in total. Epoxy (LY566) along with hardener (HY951), procured from Huntsman, was thoroughly mixed in the proportion of 100 parts to 10 parts in terms of weight.
respectively to serve as matrix material. Vacuum Bag moulding technique was employed for the manufacture of the hybrid composites due to its advantages of providing a higher fibre content as well as minimization of voids. Initially the mold is cleaned using acetone to clean dirt and impurities. The fibres were stacked carefully to obtain the desired alignment with proper fibre orientation. Double side tapes were utilized for holding the fibres as well as the spiral tube that runs along the mould boundary. A nylon cloth was placed over the fibres and then covered with sheet mesh, wherein the former provides surface finish while the latter provides uniformity in resin distribution. A plastic sheet bag has been covered on all ends using the double side tapes. Proper arrangements were made to create vacuum conditions to aid the curing process. The resin has been shifted through the pipe whose the end was inserted in a cup containing epoxy resin mixture and the other end is attached to vacuum bag. A motor was operated simultaneously to facilitate pumping of the resin into the mould. Precautions were ensured to avoid surplus or deficiency of epoxy matrix in the composite. When the fibres were enclosed by a sufficient amount of resin they were allowed to cure for four to five hours at ambient temperature. Several test specimens were manufactured with different orientations (0°/30°/45°/60°) of the Kevlar fibres for subsequent testing.

3. Mechanical Testing

3.1. Tensile testing
The tensile testing is generally conducted to determine the maximum load (tensile strength) that a material or a product can withstand. In this work, samples of dimensions 250×25 mm are subjected to tensile testing in the Instron 5500 Universal Testing Machine with a capacity of 200KN. The constant strain rate at 1.3 mm per minute was followed according to the ASTM D3039 standard.

3.2. Flexural Bending Test
The Flexural bend test has been conducted using a three-point bend test on the hybrid composite specimens of dimensions 127 × 12.7 mm in the Instron 5500 Universal testing machine with a capacity of 200KN. The flexural properties of the composite specimens were found out according to ASTM D790 standard.

3.3. Dynamic Mechanical Analysis
Dynamic Mechanical Analysis was conducted on the hybrid composite specimens of dimensions 70×12 mm according to the ASTM D 4065 standard specification. Machine was utilized for the testing of the specimens. The composite specimen was subject to sinusoidal stress of frequency 1 Hz in cyclic manner with the temperature raising at the rate of 20 °C/min. The analysis was carried out in order to determine the storage modulus E’, loss modulus E” and damping factor (Tan δ).

4. Results and discussion

| Orientation of Kevlar ply | Max. Load (N) | Ultimate Tensile strength (MPa) | Elongation @ break (%) | E-modulus (MPa) |
|--------------------------|---------------|--------------------------------|------------------------|-----------------|
| 0°                       | 17353.19      | 326.5669                        | 5.91677                | 6662.97         |
| 30°                      | 11866.17      | 241.2491                        | 4.49864                | 6382.20         |
| 45°                      | 11035.69      | 238.6096                        | 4.44317                | 5984.24         |
| 60°                      | 15376.55      | 332.4656                        | 5.17958                | 6984.01         |
Table 1 depicts the results of evaluation of mechanical properties such as tensile strength and % elongation of the Kevlar – Glass fibre Epoxy hybrid composites with varying Kevlar fibre orientation (0°/30°/45°/60°) by performing tension test using universal tensile testing machine. The composite with the 45° Kevlar laminate showed the least maximum load carrying capacity while the 0° Kevlar composite showed the maximum load carrying capacity. Similar results were observed for the tensile stress at break and elastic modulus. It is clear from the table 3.1 and figures 1–4 that the 0° oriented Kevlar laminated composite showed highest mechanical properties with respect to tensile strength and elastic modulus. Figures 1–4 shows the stress – strain diagram of the hybrid composites with differing orientation of the Kevlar laminate (0°/30°/45°/60°). Also, the 0° hybrid composite exhibited the maximum elongation on contrary to the 45° Kevlar laminated composite.

As the glass fibres used in the composite were bi-directional, the enhanced elongation and modulus of the 0° hybrid composite is attributed to the applied stress acting along the length of Kevlar fibres, thus enabling the Kevlar fibre to extend to its fullest maximum as opposed to other oriented hybrid composites, in which, the stress acted at an angle to the Kevlar fibres. Figure 5 shows the tensile fracture of 0° hybrid composite. Delamination of the Kevlar- glass fibres laminates occurred at intermediate stress levels as shown in figure 6, followed by the fracture of the Kevlar fibres and then glass fibres near the breaking stress of hybrid composite suggesting that the load was majorly carried by the Kevlar fibres resulting in fibre breakage. Figure 7–9 shows the fractured specimens of 30°, 45°, 60° composite respectively. Similar fracture mechanism was noticed in all the three hybrid composites (30°/45°/60°). Delamination of the specimens were observed and it was examined that fracture of glass fibres occurred first in 30°/45°/60° oriented hybrid composites while only necking of the Kevlar fibres was observed. This suggests that the glass fibres were the major load carrying fibres in these composites as the Kevlar fibres were oriented at an angle to the normal stress, and the bulk of the load was carried by the bi-directional glass fibres of these composites. Thus, failure occurred by glass fibre breakage and the mechanical behaviour of the Kevlar fibres were under-utilized in 30°/45°/60°.

![Figure 1. Stress – strain curve for 0° oriented hybrid composite](image1)

![Figure 2. Stress – strain curve for 30° oriented hybrid composite](image2)
Figure 3. Stress – strain curve for 45° oriented hybrid composite

Figure 4. showing glass fibre fracture and delaminated 45° hybrid composite

Figure 5. showing glass fibre fracture and delaminated 60° hybrid composite
4.1. Flexural Test

Table 2 represent the flexural strength and maximum deflection that accounts for the bending strength of the Kevlar – glass epoxy composites for different orientations (0/30/45/60) of the top and bottom Kevlar laminates. Flexural properties obtained were analogous to the tensile test with the 0° hybrid composite exhibiting the highest loading carrying capacity and maximum flexural modulus. The entire hybrid composites irrespective of their orientation show limited flexural strength because of the low flexural modulus of the glass fibres compared to the Kevlar fibres. Figure 6 – 9 show the stress – strain diagram for the hybrid composite (0°/30°/45°/60° respectively). The graph shows that the hybrid composite exhibited a limited elasticity region that in turn was responsible for the low flexural modulus of the composite. An extensive yielding of the hybrid composite was observed after the elastic region due to the delamination of the Kevlar – glass fibre laminates. Inspire of the high ductility of the Kevlar fibres, due to the low flexural modulus of the glass fibres, the glass fibres tend to delaminate with the yielding Kevlar fibres resulting in matrix strains that ultimately result in glass fibre pull out eventually resulting in glass fibre breakage.

Table 2. Results of Flexural test for different samples

| Orientation of the Kevlar ply | Max. Flexure load (N) | Flexure stress at Maximum Flexure load (MPa) | Experimental Young’s Modulus (MPa) |
|------------------------------|-----------------------|---------------------------------------------|----------------------------------|
| 0°                           | 235.83                | 389.9305                                    | 22979.01                        |
| 30°                          | 170.4539              | 281.8352                                    | 17587.14                        |
| 45°                          | 136.3359              | 225.4231                                    | 14933.20                        |
| 60°                          | 220.9759              | 365.3703                                    | 23188.56                        |

Figure 6. Flexural Stress- strain curve for 0° oriented hybrid composite
Figure 7. Flexural Stress-strain curve for 30° oriented hybrid composite

Figure 8. Flexural Stress-strain curve for 45° oriented hybrid composite

Figure 9. Flexural Stress-strain curve for 60° oriented hybrid composite
Dynamical Mechanical Analyzer (DMA) is broadly used for accessing the viscoelastic properties of the materials at varying conditions of frequency and temperature. DMA gives clear picture and valuable insight into the level of interfacial adhesions between the fiber and matrix in terms of storage modulus (ES), loss modulus (EL) and loss tangent Sreenivasan et al. (2015). Dynamic Mechanical Properties of the hybrid composites with various orientations of the top and bottom Kevlar laminates were evaluated using Dynamic Mechanical Analyzer Instrument and different hybrid laminated specimens with TA instrument make (DMA-Q-800) with dual cantilever fixture as shown in figure 10, over a range of temperature 30 – 150°C at different frequencies (1, 10, 50 and 100 Hz). The thermal scans were performed at a heating rate of 5°C/min. The DMA tests was carried out as per ASTM D4065 standard, the dimensions of the test specimen are 70 x12.7 x 3 mm.

![Figure 10](image)

**Figure 10** (a). DMA experimental setup, (b). Dual cantilever experimental fixture

The Figures 11 – 14 show the DMA curves for the hybrid composites with Kevlar ply orientations 0°/30°/45°/60° respectively. The storage modulus E’ is defined as the stress in phase with the sinusoidal shear deformation strain divided by the strain for a particular temperature. As shown by the DMA curves the storage modulus E’ of the all hybrid composites declines with rise in temperature due the advent of movement of the epoxy molecules.

![Figure 11](image)

**Figure 11.** DMA curve showing the E’ curve (green curve), E” curve (blue curve) and Tan δ curve (red curve) for 0° oriented hybrid composite.

The loss modulus E” is the measure of viscous response of the material, i.e., the energy dissipated as heat by the material for a cycle of load. As seen from the DMA curves the loss modulus E” increases
sharply at the $T_g$ of the matrix material, but a broadened loss modulus peak was observed for the hybrid composites owing the high fibre content of the composite that resists the softening of the epoxy matrix. There is a substantial rise in the loss modulus peak occurring at higher temperatures for 30°/45°/60° hybrid composites compared to the 0° hybrid composite. This could be attributed to the increase in rigidity of the polymer chains owing to the increase in material heterogeneity.

Figure 12. DMA curve showing the $E'$ curve (green curve), $E''$ curve (blue curve) and Tan δ curve (red curve) for 30° oriented hybrid composite.

Figure 13. DMA curve showing the $E'$ curve (green curve), $E''$ curve (blue curve) and Tan δ curve (red curve) for 45° oriented hybrid composite.

4.2. Damping factor, Tan δ
The Damping factor or Tan δ is defined as the ratio of loss modulus $E''$ to the storage modulus $E'$ of the material with respect to temperature. The form and distribution of the fibres inside the matrix influence the dampening characteristics of the composite. The damping factor of the composite is proportional to the matrix content of the composite. Higher fiber content and stronger fibre - matrix interface results in lesser dissipation of energy through the matrix and results in less damping effect. The tan δ curves were higher and broader for the hybrid composite with 30°/45°/60° orientations than the 0° composite. The oriented (30°/45°/60°) hybrid composite therefore show good damping at the softening temperature $T_g$ of the matrix material. Higher fibre content of both glass and Kevlar fibres can be reasoned to the broadening of the tan δ peaks thus enabling the hybrid composite to be used for applications where temperature variations are unstable, particularly in aircraft wing curvatures.
4.3. Damping factor, Tan δ
The Damping factor or Tan δ is defined as the ratio of loss modulus E” to the storage modulus E’ of the material with respect to temperature. The form and distribution of the fibres inside the matrix influence the dampening characteristics of the composite. The damping factor of the composite is proportional to the matrix content of the composite. Higher fiber content and stronger fibre - matrix interface results in lesser dissipation of energy through the matrix and results in less damping effect. The tan δ curves were higher and broader for the hybrid composite with 30°/45°/60° orientations than the 0° composite. The oriented (30°/45°/60°) hybrid composite therefore show good damping at the softening temperature $T_g$ of the matrix material. Higher fibre content of both glass and Kevlar fibres can be reasoned to the broadening of the tan δ peaks thus enabling the hybrid composite to be used for applications where temperature variations are unstable, particularly in aircraft wing curvatures.

5. Conclusion
The Fabricated hybrid composites with 0° orientation of the Kevlar fibres exhibit higher tensile Strength as well as flexural strength compared to the composites with oriented kevlar fibres (30°/45°/60°). The increased tensile strength of the 0° hybrid is due the alignment of the kevlar fibres in loading direction which causes it to act as the primary load bearing structure whereas in the oriented hybrid composites the glass fibre acts as the initial load bearing structure resulting in premature failure and underutilization of the composite. Though the flexural strength of 0° hybrid composite is relatively higher, all the hybrid composites exhibit poor flexural strength due to the low modulus of glass fibres in contrast to the Kevlar resulting in delamination. It can be inferred from the DMA curve that the oriented hybrid composite (30°/45°/60°) shows better damping capacity at softening temperature.

6. References
[1] Hauke Stumpf, Peter Schwartz, Markus Lienkamp; “S-Glass/Kevlar-149 Hybrid micro composites in stress-rupture: A Monte Carlo Simulation”, J.Composite Science and Technology,Vol.54,(1995), pp. 211-221.
[2] Amin Salehi-Khojin, Reza Bashiradeh, Mohammad Mahinfallah, Reza Nakhaei-Jazar; “The role of temperature on impact properties of Kevlar/fiberglass composite laminates”, J.Composites: Part B,Vol.37,(2006), pp. 593-602.
[3] Min-Soek Sohn, Xiao-Zhu Hu; “Mode-II delamination toughness of carbon fibre epoxy composites with chopped Kevlar fibre reinforcement”, J.Composites Science and Technology,(1994).
[4] Heitor Luiz Ornaghi Jr, Alexandre Sonaglio Bolner, Rudinei Fiorio, Ademir Jose Zattera, Sandro Campos Amico; “Mechanical and Dynamic Mechanical Analysis of Hybrid composites molded by Resin Transfer Molding”,

[5] Deju Zhu, Barzin Mobasher, Aditya Vaidya, Subramaniam D, Raham; “Mechanical behaviors of Kevlar 49 fabric subjected to uniaxial, biaxial tension and in-plane large shear deformation”, J.Composites Science and Technology, Vol.74, (2013),pp. 121-130.

[6] Yue C.Y., Padmanabhan K.; “Interfacial studies on surface modified Kevlar fibre/epoxy matrix composites”, J.Composites: Part B,Vol.30,(1999),pp. 205-217.

[7] Gang Li, Chen Zhang, Yang Wang, Peng Li, Yunhua Yu, Xiaolong Jia, Haiyang Liu, Xiaoping Yang, Zhongmin Xue, Seungkon Ryu, “Interface correlation and toughness matching of phosphoric acid functionalized Kevlar fibre and epoxy matrix for filament winding composites”, J.Composites Science and Technology, Vol.68,(2008), pp. 3208-3214

[8] Meyer P.I.; “Low velocity Hard-Object Impact of Filament – Wound Kevlar/Epoxy Composite”, J.Composites Science and Technology,Vol.33,(1988), pp. 273-299.

[9] Yiping Qiu, Peter Schwartz; “Micromechanical behavior of Kevlar-149/S-Glass hybrid seven - fibre micro composites II: Stochastic modelling of stress-rupture of hybrid composites”, J.Composites Science and Technology, Vol.74, (2013), pp 121-130.

[10] Phillips, L. N., The development and uses of glass/carbon hybrids. Proc. Int., Conf Compos. Mater. AIME, New York, 1978.

[11] Lin T.K., Wu S.J., Lai J.G., Shyu S.S.; “The effect of chemical treatment on reinforcement/matrix interaction in Kevlar-Fibre/bismaleimide composites”, J.Composites Science and Technology, Vol.60,(2000), pp. 1873-1878.

[12] Duvis.T, Papaspyrides C. D.; “Polyamide coating on Carbon fibres and potential application in Carbon/Kevlar/Epoxy hybrid composites”, J.Composites Science and Technology, Vol.48, (1993), pp. 127-133

[13] Ting-Ting Li, Rui Wang, Ching-Wen-Lou, Jia-Horng Lin; “Static and dynamic behaviors of compound fabrics with recycled high-performance Kevlar fibres”, J.Composites: Part B, Vol.59, (2014),pp. 60-66.

[14] Qiu, Y. & Schwartz, P., Micromechanical behaviour of Kevlar-149/S-glass hybrid seven-fiber microcomposites: I. Tensile strength of the hybrid composite. Comp. Sci. Technol., 47 (1993) 289-301.

[15] Ganczakowski H.L., Ashby M.F., Beaumont P.W.R., Smith P.A.; “The behavior of Kevlar Fibre -Epoxy laminates under static and fatigue loadings part 2: Modelling”, J.Composites Science and Technology,Vol.37,(1990), pp. 371-392

[16] Ganczakowski H.L., Beaumont P.W.R.; “The behavior of Kevlar Fibre -Epoxy laminates under static and fatigue loadings part1: Experimental”, J.Composites Science and Technology,Vol.36,(1989), pp. 299-319.

[17] Wagner, H. D., Schwartz, P. & Phoenix, S. L., Lifetime statistics for single Kevlar-49 filaments in creep-rupture. J. Mater. Sci., 21 (1986) 1868-78.

[18] Ike Y. Chang; “Thermoplastic Matrix Continuous Filament Composites of Kevlar ® Aramid or Graphite Fiber”, J. Composites Science and Technology, Vol.24, (1985),pp. 61-79.

[19] Dobb, M. G. & Robson, R. M., Structural characteristics of aramid fibre variants. J. Mater. Sci., 25 (1990) 459-64.

[20] Dai S.-R., Pigott M.R.; “The strength of Carbon and Kevlar fibres as a function of their length”, J.Composites Science and Technology,Vol.49,(1993), pp. 81-87

[21] Bao-Zong Huang, Xiao-Zhi Hu, Jun Liu; “Modelling of interlaminar toughening from chopped Kevlar Fibres”, J. Composites Science and Technology, Vol 64,(2004), pp. 2165-2175.

[22] Murayama, T 1978, ‘Dynamic mechanical analysis of polymeric material’, Amsterdam, Elsevier.

[23] Li, G. Lee-Sullivan, P & Thring, R 2000, ‘Determination of activation energy for glass transition of an epoxy adhesive using dynamic mechanical analysis’, Journal of thermal analysis and calorimetry, vol. 60, pp. 377-390.
[24] Ahmad, MAA, Majid, MA, Ridzuan, MJM, Mazlee, MN & Gibson, AG 2018, ‘Dynamic mechanical analysis and effects of moisture on mechanical properties of interwoven hemp/polyethylene terephthalate (PET) hybrid composites’, Construction and Building Materials, vol. 179, pp. 265-276.

[25] Aslan, Z, Karakuzu, R & Sayman, O 2002, ‘Dynamic Characteristics of Laminated Woven E-Glass–Epoxy Composite Plates Subjected to Low velocity Heavy Mass Impact’, Journal of Composite materials, vol. 36, no. 21, pp. 2421-2442.

[26] Chen, W, Meng, Q, Hao, H, Cui, J, & Shi, Y 2017, ‘Quasi-static and dynamic tensile properties of fiberglass/epoxy laminate sheet’, Construction and Building Materials, vol. 143, pp. 247-258.

[27] Devi, LU, Bhagawan, SS & Thomas, S 2010, ‘Dynamic mechanical analysis of pineapple leaf/glass hybrid fiber reinforced polyester composites’, Polymer composites, vol. 31, no. 6, pp. 956-965.

[28] Eksi, S & Genel K 2015, ‘Three Point Bending Behavior of Woven Glass, Aramid and Carbon Fiber Reinforced Hybrid Composite Tube’, Acta Physica Polonica A, vol. 128, pp. 59-61.

[29] Goertzzen, WK & Kessler, MR 2007, ‘Dynamic mechanical analysis of carbon/epoxy composites for structural pipeline repair’, Composites Part B: Engineering, vol. 38, no. 1, pp. 1-9.

[30] Hara, E, Yokozeiki, T, Hatta, H, Ishikawa, T & Iwahori, Y 2010,'Effects of geometry and specimen size on out-of-plane tensile strength of aligned CFRP determined by direct tensile method', Composites Part A: Applied Science and Manufacturing, vol. 41, no.10, pp. 1425-1433.

[31] Hatakeyama, T & Quinn, F 1999, ‘Thermal analysis: fundamentals and applications to polymer science’, 2nd ed, Chichester, UK: John Wiley & Sons.

[32] K. Naresh, K. Shankar and R. Velmurugan,2018, ‘Reliability analysis of tensile strengths using Weibull distribution in glass/epoxy and carbon/epoxy composites’ Composites Part B: Engineering, vol. 133, pp. 129-144.

[33] Y.S. Joshan, Neeraj Grover, B.N. Singh, 2017, Analytical modelling for thermo-mechanical analysis of cross-ply and angle-ply laminated composite plates, Aerospace Science and technology,70(2017) 137-151.

[34] K. Naresh, K. Shankar, B.S. Rao, R. Velmurugan,2016, Effect of high strain rate on glass/ carbon/ hybrid fiber reinforced epoxy laminated composites, Composites Part B: Engineering, vol. 100, pp. 125-135.

[35] Idricala, M, Malhotra, SK, Joseph, K & Thomas, S 2005, ‘Dynamic mechanical analysis of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites’, Composites Science and Technology, vol. 65, no. 7-8, pp. 1077-1087.

[36] Joseph, PV, Mathew, G, Joseph, K, Groenincx, G & Thomas, S 2003,'Dynamic mechanical properties of short sisal fiber reinforced polypropylene composites’, Composites Part A, vol. 34, pp. 275-290.

[37] Navin Kumar, B. & Parammasivam, K. M. Wind Turbine Aerodynamic Braking System Analysis Using Chord Wise Slot. In Applied Mechanics and Materials (Vol. 787, pp. 217-221). Trans Tech Publications 2015.

[38] Kumar, B. Navin, K. M. Parammasivam, M. Prasanna, and AZG Mohamet Karis. "Computational Fluid Dynamics Analysis of Aerodynamic Characteristics of NACA 4412 vs S809 Arifoil for Wind Turbine Applications." International Journal of Advanced Engineering Technology 7 (2016): 168-173.

[39] Navin Kumar B, Parammasivam KM. Wind Turbine Aerodynamic Braking System Analysis Using Chord wise Spacing. In Applied Mechanics and Materials 2015 (Vol. 787, pp. 217-221). Trans Tech Publications Ltd.

[40] Kazemhavazi, S, Kiele, J & Zenkert, D 2010, ‘Tensile strength of UD composite laminates With multiple holes’, Composites Science and Technology, vol. 70, no. 8, pp. 1280-1287.
[41] Naresh, K, Shankar, K, Velmurugan, R & Gupta, NK 2017, ‘Probability-based Studies on the Tensile Strength of GFRP, CFRP and Hybrid Composites’, Procedia engineering, vol. 173, pp. 763-770.

[42] OrnaghiJr, HL, Bolner, AS, Fiorio, R, Zattera, AJ & Amico, SC 2010, ‘Mechanical and dynamic mechanical analysis of hybrid composites moulded by resin transfer moulding’, Journal of Applied Polymer Science, vol. 118, no. 2, pp. 887-896.

[43] Poyyathappan, K, Bhaskar, GB, Pazhanivel, K & Venkatesan, N 2014, ‘Tensile and flexural studies on glass-carbon hybrid composites subjected to low frequency cyclic loading’, Int. J. Eng. Technol, vol. 6, no. 1, pp. 83-90.