R RAGHAVENDRA RAO
S PRADEEP
B S SHIVASHANKARA
AVINASH S
and
PRADEEP N B

Effect of fiber orientation on the mechanical properties of unidirectional basalt fiber reinforced polymer matrix composites

Polymer matrix composite materials have attracted the researchers over a period due to its superior specific strength, compared to conventional materials. Bio-based fibers have started to emerge rapidly for industrial components, encompassing the technological/scientific aspects and the economic, environmental and social issues. Amongst the variety of bio-based fibers, basalt fiber occupies a prominent position, due to its overall production and unique chemistry-related features. It is chemically inert and non-reactive. In the present investigation, unidirectional basalt fiber of 240GSM at different orientations is added as reinforcement with a fixed weight percentage of 55% to LY556-HY951 epoxy-hardener combination as matrix. Fabrication is carried out by conventional hand lay-up technique. Mechanical characterization such as, tensile, flexural, hardness and inter laminar shear strength tests are conducted for the fabricated material. Morphological studies are conducted using scanning electron microscope (SEM) to visualize the fiber pull out, presence of voids and matrix-fiber adhesion characteristics. From the results obtained, it can be concluded that the highest strengths are obtained for laminates with zero-degree fiber orientation, which makes it suitable to be used for engineering, structural and biomedical applications.

Keywords: Unidirectional basalt fiber; density; mechanical properties; SEM

1.0 Introduction

The polymer matrix composites have found its wide applications due to its higher strength to weight ratio, corrosion resistance, lighter weight, applicability, ease of getting shaped and suitability for various engineering applications. Even though the usage of polymer composites have started earlier in the 20th century but the wide use of it has started in the second half of 20th century.

Basalt is a non-polluting material that originate in volcanic rocks from frozen lava, having melting temperature between 1500 ºC and 1700 ºC (Militký et al., 2002). The density of basalt fibers ranges between 2.7g/cm^3 to 2.8 g/cm^3. It is extremely hard and has superior abrasion resistance (Di Ludovico et al., 2010). It is stated that, the basalt fiber could be a possible alternative to natural plant fibers (Tabi and J. Kovacs, 2011). It was also proved that the basalt could be considered as natural, because it is formed by the solidification of molten lava, which is bio inert and having higher mechanical properties (Czigány T, 2005). Botev M et al. 1999 have reported the effect of basalt fiber reinforced on commercial grade polypropylene (PP) composites with dynamic mechanical thermal analysis. The result showed that, the storage modulus (E') and also loss modulus (E'') of the produced composite has increased with increased content of basalt fiber. However, the damping value within the region decreased with increase in fiber loading. Fiore et al. 2011 have evaluated the influence of uniaxial basalt fabric on the mechanical properties of a glass matrix/epoxy composite. They administered three-point bending and tensile tests to gauge the outcome of number of basalt layers and its position on the mechanical behaviour of the fabricated composite. The outcome showed the presence of two external layers of basalt resulted in increased mechanical properties of produced laminates in comparison with GFRP laminates. In earlier studies, Venkatesha B K et al., 2020 have investigated the influence of stacking sequence of multi layered woven bamboo and glass fibers reinforced with epoxy matrix composites under static tensile and tension-tension fatigue loading. Six layers of bamboo fiber and seven layers of glass fiber has been used to prepare the samples by hand lay-up technique with [0°/90°] and [±45°]. The obtained results revealed that [0°/90°] lay-ups show better tension strength than [±45] laminate. Raghavendra Rao R et al. (Raghavendra Rao R et al., 2019) have studied the effect of hybridization of UHMWPE and basalt fibers at various percentages with L12

Messrs. R Raghavendra Rao, S Pradeep and B S Shivashankara, Department of Mechanical Engineering, Malnad College of Engineering, Hassan 573202, Affiliated to VTU Belagavi, Karnataka, Avinash S, School of Mechanical Engineering, REVA University, Bengaluru 560064 and Pradeep N B, Research Scholar, Department of Mechanical Engineering, JNNCE Shivamogga, India. E-mail: rrr@mcehassan.ac.in

epoxy as matrix. They have concluded that the inclusion of UHMWPE at the outer most layers has increased the flexural strength considerably, whereas the tensile strength reduced minimally. Venkatesha B K and Saravanan R., 2020 have studied the effect of cenosphere as particulate filler on mechanical behaviour of woven bamboo-glass hybrid composites. The hybrid composite consists of bamboo and E-glass fiber as reinforcement and epoxy as matrix. Cenosphere of different weight percentage (0.5, 1, 1.5 and 2 %) was added to the hybrid composite. It was found that the mechanical properties are significantly influenced by addition of waste ceramic filler cenosphere up to 2 wt.% and increases the tensile, flexural and inter-laminar shear strength in comparison with unfilled composite. Lopresto et al. 2011 have done the comparative study of basalt fiber reinforced polymer composite (BFRP) with the glass fiber reinforced polymer composites (GFRP). The results showed that BFRP exhibited better performance with respect to young modulus, compressive, bending and impact strengths. From the existing literatures it is found that, not much research articles have reported the effect of fiber orientations on the basalt fiber-reinforced epoxy composites on their static and dynamic properties using LY556 epoxy as a matrix. Venkatesha B K et al. 2021 have investigated the moisture absorption behaviour and its effect on mechanical properties of hybrid bamboo-glass fiber reinforced epoxy composites. The obtained results revealed that the effect of water absorption showed a significant reduction in the mechanical performance of all the composites.

2.0 Experimental details

2.1 Materials

Unidirectional basalt fabric of 240 GSM is used as reinforcement material. Details of fabrics are illustrated in Table 1. Araldite LY556 and HY951 are used as epoxy resin and hardener respectively, both with density of 1.2 g/cc.

Table 1: Represents the basic parameters of Basalt fabric

Parameters	Basalt fabrics
Density (g/cc)	2.7
Weight (gsm)	240
Thickness (mm)	0.20
Warp yarns (yarns/m)	900
Melting point (^{0}C)	1500-1700

2.2 Fabrication of composites

Conventional hand layup method was used in the fabrication of laminates. The basalt fabrics were cut to the dimensions of 300×300 mm^2 at different orientations for the preparation of composite laminates using scissor.

The laminates were prepared with 13 layers of basalt fabrics to maintain an approximate thickness of 3mm for different orientations of fibers with a constant fibre percentage of 55% as indicated in Table 2. The epoxy resin and hardener were mixed in the ratio of 100:10 by weight. First, wax was applied over the top of a mould and the fibre layers were stacked one after another in the mould and the measured quantity of epoxy was applied on each layer of the fibres. Then the epoxy was uniformly spread using roller. As soon as the last layer of fibre was properly rolled, the granite slab of required size was kept on top of the mould. On the top of the granite, dead weights are placed. The laminates were finally removed from the mould after a period of 24 hours. Then they were cut using water jet machining as per the ASTM standards to conduct several tests. Weight fraction (%) is calculated by using the Equation (1).

$$W_f = w_f / (w_f + w_m) \text{ and } W_m = w_m/(w_f + w_m) \quad \text{... (1)}$$

where W_f is weight fraction of fibre; w_f is weight of the fibre; w_m is weight of the matrix; W_m is weight fraction of matrix.

Table 2: Represents laminate stacking sequences

Laminates	Orientation angle in ^{0}	Basalt fabric weight fraction in %	Matrix weight fraction %
L1	0-0-0-0-0-0-0-0-0-0-0-0-0	55	45
L2	90-90-90-90-90-90-90-90-90-90-90-90-90	55	45
L3	0-90-0-90-0-90-0-90-0-90-0-90-0	55	45
L4	0-45-0-45-0-45-0-45-0-45-0-45-0	55	45
L5	0-30-60-30-60-30-60-30-60-30-60-30-0	55	45

3.0 Mechanical characterization

3.1 Tensile test

Tensile test was carried out on BISS-50KN universal testing machine (UTM) with data acquisition software. The sample (115×19×3 mm^3), with gage length of 33mm and cross head speed of 1.0 mm/min were selected as per ASTM: D638-IV standard and the test were conducted at a room temperature.

3.2 Flexural test

3-Point bending test is conducted as per ASTM: D790 standard using the same UTM. Testing was conducted at loading rate of 1.0 mm/min, at room temperature. The dimension of the specimen is 90×12.5×3 mm^3 and the flexural specimens were fixed between two jaws with span length of 60 mm and the load was applied at the center. The specimen is subjected to loading until the gage length increased and the specimen got ruptured.

3.3 Short beam strength test

Short beam strength test is conducted as per ASTM: D 2344/D 2344M standard using the same UTM to find the interlaminar shear strength. Testing was conducted at loading rate of 2.0 mm/min, at room temperature. The dimension of the specimen is 60×12.5×3 mm^3 and the specimens were fixed between two jaws with span length of 30 mm and the load was applied at the center. The specimen is subjected to loading until the gage length increased and the specimen got ruptured. 'Peak load is noted and ILSS is calculated using the formula

$$ILSS = 0.75 \times \frac{P_m}{b \times h}$$

where, ILSS=Inter laminar shear strength in MPa; P_m=Peak load; b=width of specimen; h=thickness of specimen

3.4 Shore 'D' hardness test

Shore 'D' hardness test is carried out using the shore durometer as per ASTM: D2240 standard. Hardness is determined by the penetration of durometer indenter into the specimen. During the test, the sample was kept on a flat, hard, horizontal surface and held the durometer between both hands over the sample so that the indenter touches it. Then it is pushed down perpendicularly until the presser foot makes firm contact with the sample. Then the reading is taken.

3.5 Surface morphology

Fractured tensile specimens were examined for microstructure using TESCAN-VEGA 3 LMU scanning electron microscope (SEM) at BMSCE, Bangalore. SEM was carried out to visualize the dispersion of fibers within the matrix and the adhesion characteristics amongst fiber and matrix. In order to enhance the conductivity of the samples, the surface of the sample was coated with a thin gold film and the micrographs were captured from the fractured samples for different magnifications.

4.0 Results and discussion

4.1 Tensile property evaluation

The tensile strengths of different laminates are shown in Fig.1. It is seen from the figure that the laminate L1 exhibited highest tensile strength and laminate L2 exhibited lowest tensile strength. It is concluded that, the orientation of unidirectional basalt fabrics in 0^o directions has substantially increased the tensile strength and modulus.

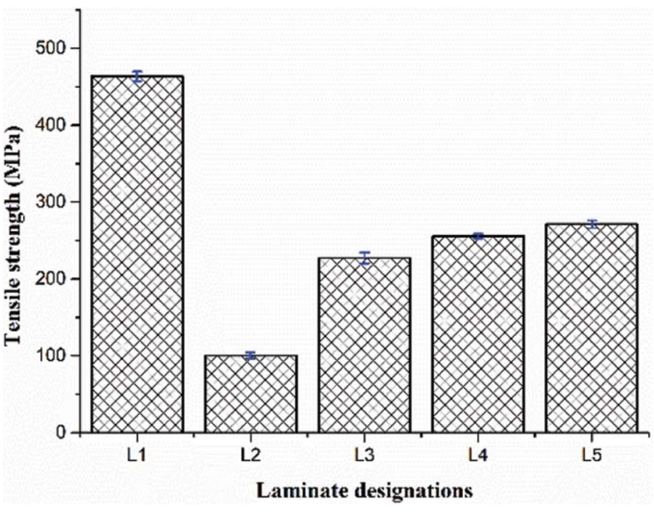

Fig.1: Tensile strength plot

4.2 Flexural property evaluation

The flexural strengths of different laminates are shown in the Fig.2. It is seen from that, the laminate L1 exhibited highest and laminate L2 exhibited lowest flexural strength. It is concluded that, the orientation of basalt fabrics in 0^o directions have substantially increased the flexural strength and modulus. The comparison of tensile and flexural strength is shown in Fig.5.

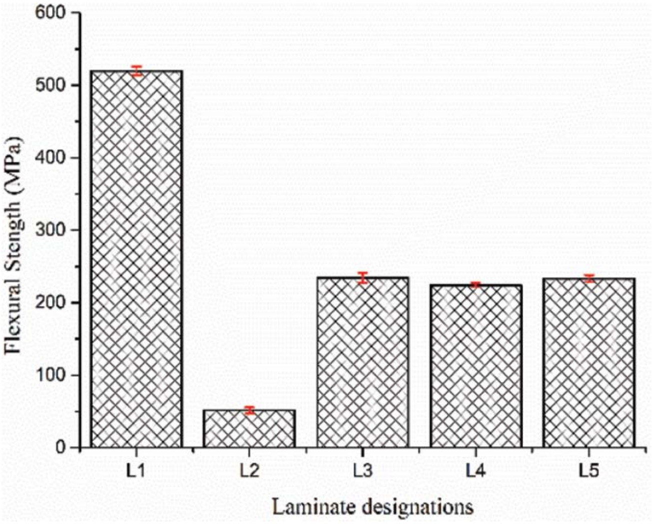

Fig.2: Flexural strength plot

4.3 Short beam strength test (Inter laminar shear strength)

The inter laminar shear strengths (ILSS) of different laminates are shown in the Fig.3. It is seen from the Fig.3 that the laminate L1 exhibited highest and the laminate L2 exhibited lowest inter laminar shear strength. It is concluded that, the orientation of unidirectional basalt fabrics in 0^o directions have lead to the highest ILSS.

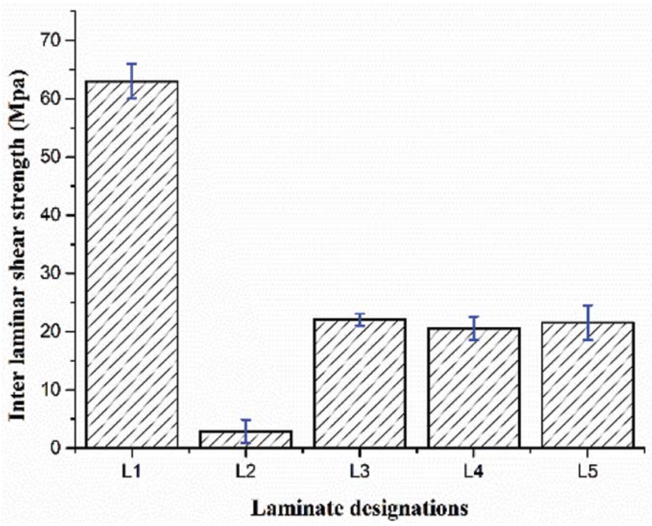

Fig.3: Inter laminar shear strength plot

4.4 Hardness test

The shore D hardness numbers of different laminates are plotted in Fig.4. The hardness is marginally varied for different laminates. The L3 laminate exhibited the highest hardness value of 84.5 SHN. The laminate L5 exhibited lowest hardness of 78.3 SHN.

4.5 Morphological studies through SEM

Micro structural studies were conducted to visualize the failure surfaces of the fabricated laminates subjected to tensile loading. The fracture in the tested samples takes place due to the application of uni-axial tensile loading.

The void content, fiber matrix adhesion, and pull out properties are analyzed using the SEM images. All the composite specimens were coated with gold before observing them through SEM. The fractured micrographs of various laminate designations L1, L2, L3, L4 and L5 are shown in Fig.6a-e, respectively. It is seen that the fiber filaments are almost completely covered with an epoxy system. It showed (Fig.6 a-e) fewer amounts of voids in the fractured samples of

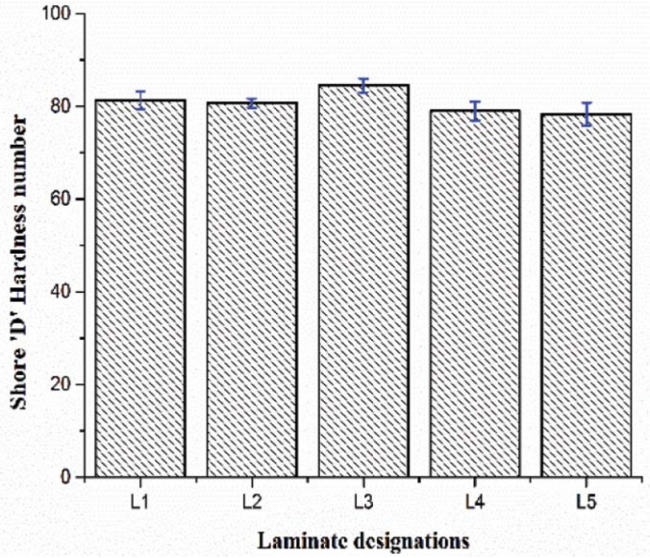

Fig.4: Hardness plot

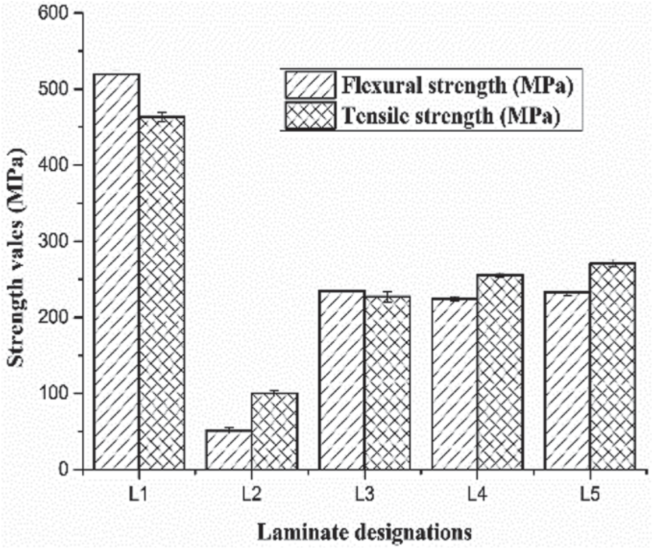

Fig.5: Comparison of tensile and flexural strengths

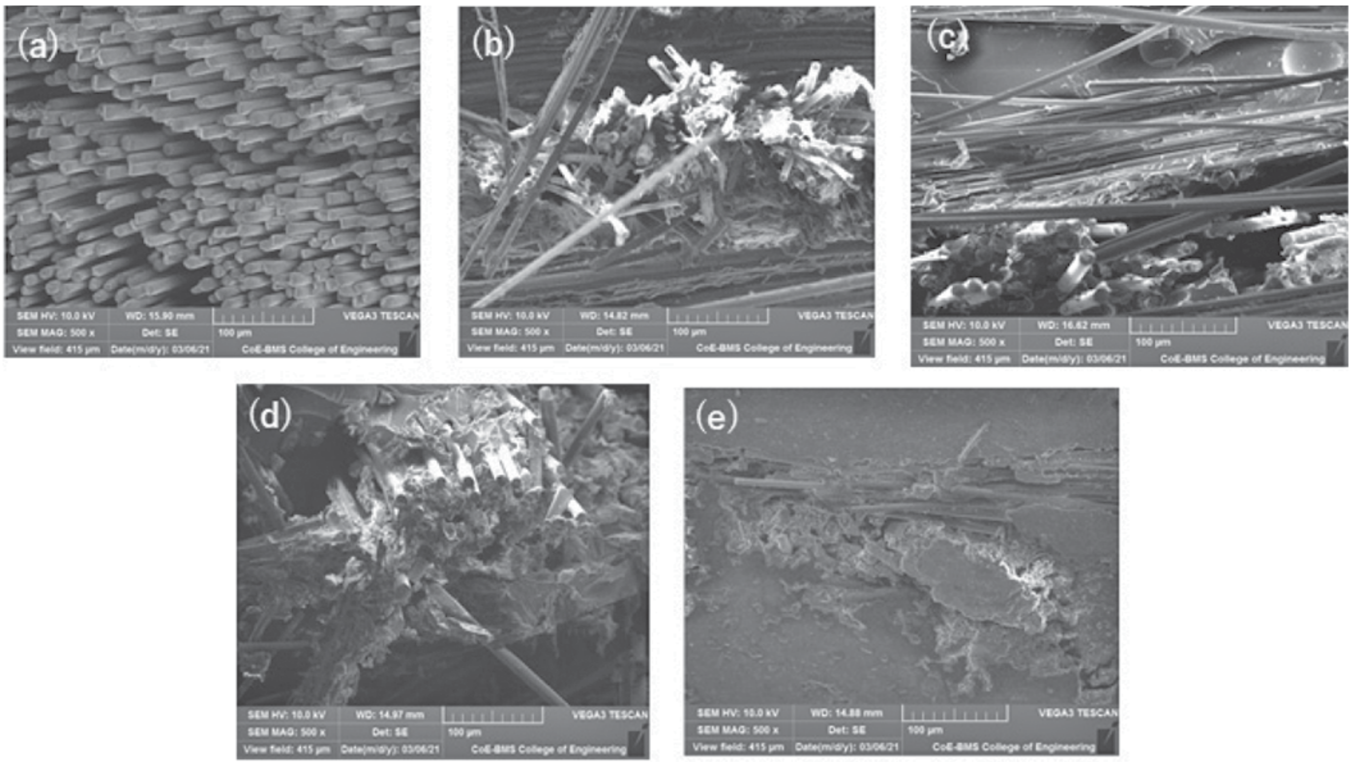

Fig.6: SEM images for (a) L1, (b) L2, (c) L3, (d) L4 and (e) L5 laminates

laminates except L2 laminate. Not much interfacial deboning, matrix cracking and delamination were observed in the case of L1, L3, L4 and L5 laminates. It is evident from the Fig.6b that the presence of voids, matrix cracking, fiber pull outs and delamination is predominant in the case of laminate L2. Comparatively L1 laminates had lesser amount of voids and cracks than other laminates, which helped to get better mechanical properties and improved adhesion amongst the fibers and matrix.

5.0 Conclusions

A novel hybrid composites comprising unidirectional basalt fabrics have been developed using hand layup method. The mechanical investigations such as tensile, flexural tests, ILSS and hardness of composites with 5 different fibre orientation sequences for fixed fiber percentage of 55% have been deliberated. These are the conclusions drawn from the research work carried out:

1. The composite laminate L1 indicated highest tensile strength of 463.6 MPa and laminate L2 indicated lowest tensile strength of 103.488 MPa.
2. The composite laminate L1 indicated highest flexural strength 519.56 MPa and laminate L2 indicated lowest flexural strength of 53.5 MPa.
3. The composite laminate L1 indicated highest inter laminar shear strength of 63.2 MPa and laminate L2 indicated lowest inter laminar shear strength of 2.8757 MPa
4. Laminate L3 shown highest hardness value ranging 84 SHN and laminate L4 shown the least hardness value of 78 SHN.
5. SEM analysis confirmed that, the L1 composite laminates showed lesser voids, better adhesion between fibres and matrix, appropriate fibre breakage and pullout.
6. So in all aspects, laminate L1 is better from the experiments carried out. So it is suggested to orient the fibers in 0^o to obtain the highest strengths.

References

1. Botev M, H Betchev, D Bikiaris, and C Panayiotou, (1999): Mechanical properties and viscoelastic behaviour of basalt fiber reinforced polypropylene, *J. Applied Polymer Science*, vol. 74, pp. 523-531.
2. Czigány T, (2005): Basalt fiber reinforced hybrid polymer composites, *J. Materials Science Forum*, pp. 59-66.
3. Di Ludovico M, A Prota, and G Manfredi, (2010): Structural upgrade using basalt fibers for concrete confinement, *J. Composites for construction*, vol.14, pp. 541-552.
4. FioreV, G Di Bella, and A Valenza, (2011): Glass–basalt/epoxy hybrid composites for marine applications, *J. Materials & Design*, vol. 32, pp. 2091-99.
5. Lopresto V, C Leone, and I De Iorio, (2011): Mechanical characterisation of basalt fibre reinforced plastic, *Composites Part B: Engineering*, vol. 42, pp. 717-723.
6. Militký J, V R Kovaèiè, and J Rubnerova, (2002): Influence of thermal treatment on tensile failure of basaltfibers, *J. Engineering fracture mechanics*, vol. 69, pp. 1025-1033.
7. Raghavendra Rao R, S Pradeep, C K Yogish, Nikhil R and Geetanjali Patil, (2019): Studies on Mechanical Properties of Ultra High Molecular Weight Poly Ethylene (UHMWPE)-Basalt Fiber Reinforced Hybrid Polymer Matrix Composite, *J. Polymer & Composites*; 7(3):pp.8–19;https://doi.org 10.37591./jopc.v7i3.3441
8. Tabi T and J Kovacs, (2011): Examination of starch pre-process drying and water absorption on injection molded poly (lactic acid)/starch blends, *Polym Eng Sci*, vol. 51, pp. 843-850.
9. Venkatesha B K, Pramod Kumar S K, Saravanan R and Aulia Ishak, (2020): Tension fatigue behaviour of woven bamboo and glass fiber reinforced epoxy hybrid composites, IOP Conf. Series: *Materials Science and Engineering*, volume 1003 (2020) 012087.
10. Venkatesha B K and Saravanan R, (2020): Effect of Cenosphere Addition on Mechanical Properties of Bamboo and E-Glass Fiber Reinforced Epoxy Hybrid Composites, *International Journal Vehicle Structures & Systems*", 12(4), ISSN: 0975-3060 (Print), 0975-3540 (Online), pp.447-451.
11. Venkatesha B K, Saravanan R and Anand Babu K, (2021): Effect of moisture absorption on oven Bamboo/Glass fiber Reinforced epoxy hybrid Composites, Materials Today Proceedings, volume 45, part 1, pp.216-221.