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Fabrication and Testing of E-Glass Fiber Reinforced Composite for Different Fiber Orientation

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Abstract: Fiber reinforced polymer (FRP) composites are being extensively used in structural and non-structural applications of Mechanical Engineering. The types of reinforcement, its geometry, volume fraction, orientation of fibers, etc. are some of the parameters that affect the properties of the FRP composites. In this work an attempt has been made to fabricate FRP composites to study the effect of orientation of E-glass fibers fabric in epoxy resin for maximum tensile, flexural and impact properties. Glass fiber reinforced polymer (GFRP) laminated plates were fabricated using vacuum bag moulding technique, while maintaining the fiber volume fraction approximately to 0.6. Four different types of laminated plates were fabricated with following fiber orientation: [0°/-45°/+30°/-30°/+45°/0°], [0°/0°/+30°/-30°/0°/0°], [0°/-45°/0°/0°/+45°/0°], and $[0°]_6$ along with fifth type which have no fibers in it. Specimens cut from the above plates are tested according to ASTM standards. The specimens with more number of fiber fabric layers orientated along the loading direction (0°) shows increase in tensile strength and absorption of impact energy. The specimens having 30° fiber fabric orientation showed better flexural strength compared to that of specimens without 30° fiber fabric orientation.
Keywords: Fiber orientation, Fiber volume fraction, GFRP, Tensile properties, Flexural properties, Impact properties.

I. INTRODUCTION

Composite material or composite is the combination of two or more materials of different chemical and physical properties on the microscopic or macroscopic scale to form a useful third material. It is the combination of two materials, reinforcement phase in the form of particles, fibers or sheets and matrix phase in the form of polymer, metal or ceramic. Matrix phase transfer stresses between fibers, protect fibers and provide barrier to environment.

Composite materials are been extensively used in many different area of application of engineering. This is due to enhanced properties of composite material when compared to the properties of individual component materials of composite. Metal matrix composite, ceramic matrix composite and polymer matrix composite are three main classifications of the composites.

Fiber reinforced polymer (FRP) composites are being extensively used in structural and non-structural applications of mechanical engineering. This is due to the fact that FRP composites are processing high strength to weight ratio, durability, stiffness, wear resistance, corrosion resistance, etc. The reinforcement material of FRP composite plays a very important role in detecting the properties of the composite. The type of reinforcement, its geometry, volume fraction, fiber, filler material, orientation of reinforcement, thickness of the specimens, etc. are some of the parameters that affect the properties of the FRP composite.

Many researches have been done on FRP composites. Mr. Mahesh Chandrashekhar Swamy et al. Investigated the flexural properties of E-glass fiber (Unidirectional, Bidirectional woven and 2D (0°-90°) type) epoxy composite with 2mm, 4mm and 6mm thickness experimentally. They found that, Flexural strength increases as thickness increases and the composite with unidirectional fiber reinforced showed more flexural strength compared to other types [4]. Mr. Sagar S Chavan et al. investigated the tensile and flexural properties of jute fiber reinforced epoxy composite with different fiber orientations as $[90°/0°/90°]_S$, $[+45°/0°/-45°]_S$ and $[+60°/0°/-60°]_S$. They found that $[90°/0°/90°]_S$ and $[+60°/0°/-60°]_S$ type showed maximum tensile and flexural strength in longitudinal direction respectively, with $[+45°/0°/-45°]_S$ type showed minimum tensile and flexural strength in transverse direction [5]. Mr. Santhosh Kumar M et al. investigated the tensile and flexural properties of Carbon, E-glass and S-glass fibers reinforced epoxy composites with different fiber orientation as ± 30°, ± 45° and ± 60° and with different thickness 2mm and 3mm. they found that, in case of tensile specimens tensile strength, percentage of elongation and Young's modulus increases as thickness increases, but in case of bending specimens flexural strength and modulus increases as thickness decreases. Also ± 30° specimens showed more tensile strength and Young's modulus, ± 45° specimens showed more elongation [6]. Tensile strength and flexural strength increases with increase in percentage of graphene powder (1%, 3% and 5%) in laminate for bi-woven E-glass fiber cloth reinforced epoxy composite was investigated by Dr. R Jyothilakshmi et al. [8]. Mr. Keerthi Gowda B S et al. investigated the impact properties of treated and untreated Sisal fiber reinforced polyester composite with different fiber volume fraction (10%, 15%, 20%, 25% and 30%) and with different thickness (2mm, 3mm, 4mm, 5mm and 6mm). They found that impact strength increases with increase in thickness and fiber volume fraction. Untreated sisal fiber polyester composite showed highest compared to treated sisal fiber polyester composite [2]. S. Eksi et al. investigated the mechanical properties of Carbon, E-glass and Aramid fibers (unidirectional and woven type) reinforced epoxy composite. They found that the mechanical properties of 0°-oriented was better than the 90°-oriented unidirectional fiber reinforced composite [9]-[3] and woven aramid fiber reinforced composite showed better mechanical properties compared to the other woven fiber reinforced composite [3]. Patil Deogonda et al. investigated the mechanical properties of GFRP with varying percentage (0%, 1%, 2% and 3%) of TiO_2 and ZnS powder as filler material and with different thickness for tensile, bending and impact test as 4mm, 6mm and 10mm respectively. The results from test showed that the Tensile, Bending and Impact strength increases with addition of filler material and ZnS filled composite shows significantly good results than TiO2 filled composites [1].

II. EXPERIMENTAL STUDIES

A. Materials used

In this work unidirectional stitched E-glass fiber fabric cloth of 220 GSM and 0.2 mm thickness was used as the reinforcement material and Epoxy L-12 and Hardener K-6 in the ratio of (10:1) was used as the matrix material.

B. Specimen preparation

Vacuum bag moulding technique was employed to fabricate the composite laminate plates of 300mm × 300mm × 2mm. Fiber volume fraction was maintained approximately 0.6 while fabricating the composite material. Four laminates with six layers of E-glass fiber fabric with different stacking sequence as [0°/-45°/+30°/-30°/+45°/0°], [0°/0°/+30°/-30°/0°/0°], [0°/-45°/0°/0°/+45°/0°] and $[0°]_6$ were prepared. Separately an epoxy resin plate was prepared without fibers in it.

Three types of specimens/coupons were cut out from the each laminated plates, using Diamond cutter tool. Total twelve specimens were cut for each tensile test and bending test with dimensions, 250mm × 25mm according to ASTM D3039 and 130mm × 20mm according to ASTM D790 respectively. For Izod impact test sixteen specimens were cut with dimensions, 65mm × 12.5mm according to ASTM D256. Separately two tensile, two bending and three impact test specimens were cut out from the epoxy plate. Fig. 1 shows the tensile, bending and impact specimens used.

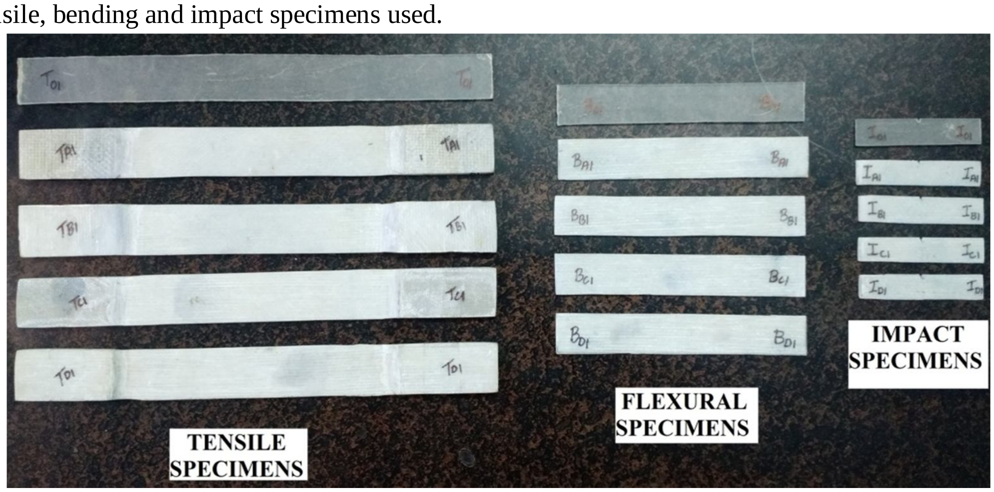

Fig. 1 Test specimens

C. Tensile test

For tensile test twelve specimens were used with varying fiber orientation and two with no fibers in it. The overall length of the tensile test specimen was maintained at 250 mm and width of 25 mm with thickness of 2 mm as show in Fig. 2. The tensile tests on specimens were conducted using Electronic Tensometer. Tensile test was conducted as per ASTM D3039 norms with pulling speed of 2 mm/min as shown in Fig. 3.

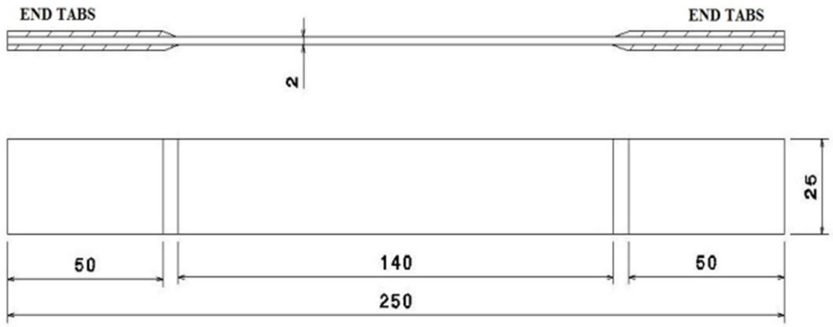

Fig. 2 Drawing of Tensile test specimen

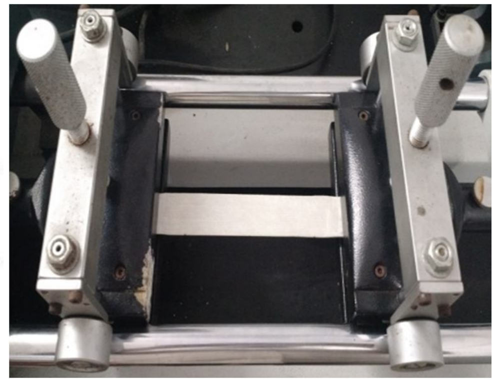

Fig. 3 Tensile specimen with fixture

1) *Formula Used:* To find the mechanical properties of tensile test specimens following formulas are used:

a) Stress, $\sigma = \frac{P}{A}$ N/mm^2

b) Strain, $\varepsilon = \frac{\delta}{L}$ mm/mm

c) Ultimate tensile strength, $\sigma_{uts} = \frac{P_{max}}{A}$ N/mm^2

d) Young's Modulus, $E = \frac{\sigma}{\varepsilon}$ N/mm^2 (From the slope of the stress - strain graph)

e) Percentage of Elongation = $\frac{L_f - L}{L} \times 100$ %

Where,

'P' is the load applied across the specimen (N),
'A' is the cross-section of the specimen (mm^2),
'δ' is the change in length (mm),
'L' is the original length of the specimen (mm),
'L_f' is the final length of the specimen (mm),
'P_{max}' is the maximum load before the specimen fractures (N).

D. Three point bending test

For three point bend test twelve specimens were used with varying fiber orientation and two with no fibers in it. The overall length of the bending specimen was maintained at 130 mm and width of 20 mm with thickness of 2 mm as show in Fig. 4. To determine the flexural strength the three points bending test was carried out on the Electronic Tensometer as show in Fig. 6. Bending test was conducted as per ASTM D790 norms with central loading rate of 5mm/min as shown in Fig. 5.

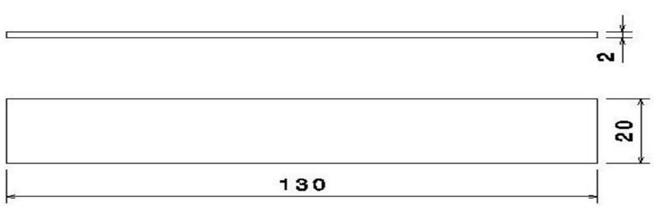

Fig. 4 Drawing of bending test specimen

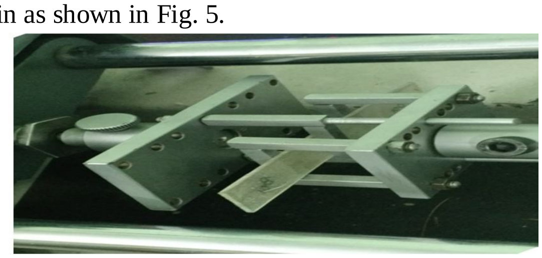

Fig. 5 Bending specimen with fixture

Fig. 6 Electronic Tensometer

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2) *Formula Used:* To find the mechanical properties of bending test specimens following formulas are used:

a) Flexural strength, $\sigma_f = \frac{3P_{\max}L}{2bd^2}$ N/mm^2

b) Flexural Modulus, $E_f = \frac{L^3 m}{4bd^3}$ N/mm^2

Where,

'P_{max}' is the maximum load before the specimen fractures (N),
'L' is the span length (mm),
'b' is the width of the specimen (mm),
'd' is the depth/thickness of the specimen (mm),
'm' is the slope of the load - deflection graph.

E. Izod impact test

Izod impact test was used to test the impact strength of specimens which is commonly accepted. To determine the impact strength the Izod impact test was carried out. For impact test sixteen specimens were used with varying fiber orientation and three with no fibers in it, with dimensions of 65mm × 12.5 mm × 2mm as shown in Fig. 7.

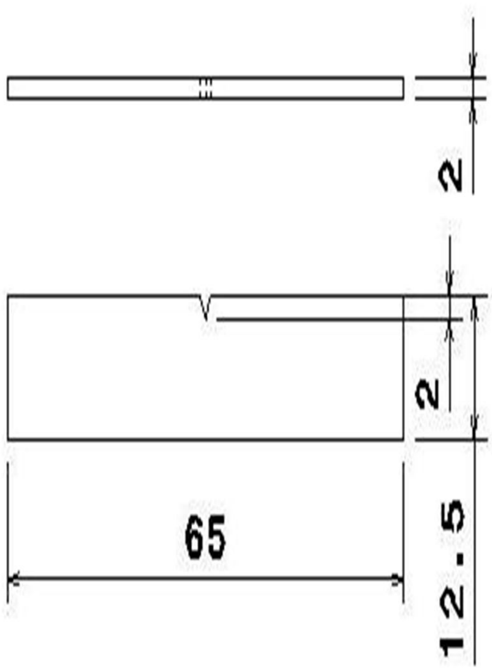

Fig. 7 Drawing of bending test specimen

Fig. 8 Digital Impact test machine

A V- groove (notch) of depth 2mm is provided on the specimens as shown in Fig. 7. Test was carried out on the digital impact testing machine as show in Fig. 8. Impact test was conducted as per ASTM D256 norms.

F. Formula Used

To find the mechanical properties of Izod impact test specimens following formulas are used:

a) Impact strength, $= \frac{U}{A}$ J/mm^2

Where,

'U' is the impact energy absorbed by the specimen before fracture (J) and
'A' is the cross-section area at the notch (mm^2).

III. RESULTS AND DISCUSSION

The test specimens with different fiber orientation i.e. A as [0°/-45°/+30°/-30°/+45°/0°], B as [0°/0°/+30°/-30°/0°/0°], C as [0°/-45°/0°/0°/+45°/0°], D as $[0°]_6$ and O as one without fibers were used for the experiments.

A. Tensile Test

The tensile test was carried out on specimens as per ASTM D3039 standards and results are tabulated in TABLE I.

TABLE II
Tensile Test Results For Gfrp Specimens

Specimen Type	Specimen number	Maximum Deformation (mm)	Maximum load (N)	Ultimate Tensile strength (N/mm^2)	Percentage of elongation (%)	Average Ultimate Tensile strength	Average Young's Modulus (GPa)
O	T_{O1}	5.592	1755.50	35.110	3.99	34.26	0.727
	T_{O2}	5.694	1670.90	33.420	4.06		
A	T_{A1}	11.753	8698.80	173.976	8.40	178.941	2.398
	T_{A2}	13.552	8923.70	178.474	9.68		
	T_{A3}	11.074	9218.60	184.372	7.91		
B	T_{B1}	12.512	9963.90	199.278	8.68	223.861	2.492
	T_{B2}	9.997	10317.0	206.340	7.14		
	T_{B3}	12.737	13298.3	265.966	9.10		
C	T_{C1}	14.333	11503.6	230.072	10.24	228.05	2.568
	T_{C2}	13.289	11700.4	234.008	9.49		
	T_{C3}	12.992	11003.5	220.070	9.28		
D	T_{D1}	12.771	11101.5	222.030	9.12	237.263	2.707
	T_{D2}	13.798	11542.8	230.856	9.86		
	T_{D3}	15.809	12945.2	258.904	11.29		

It is clear from the test that the fracture of GFRP composite specimens was purely due to the fiber rupture, transverse crack and delamination of the fibers. Delamination of the fiber layers occurred due to poor inter-laminar resistant. The result shows that as the number of fiber fabric layers with 0° fiber orientation increases in the specimens the Ultimate tensile strength and Young's modulus increases. The GFRP composite specimens with $[0°]_6$ type can resists more tensile load compared to other types. Therefore the specimens with $[0°]_6$ type exhibited maximum Ultimate tensile strength and Young's modulus. The average Young's modulus of the fabricated composite are summarized in the bar graph for better comparison as shown in Fig. 10.

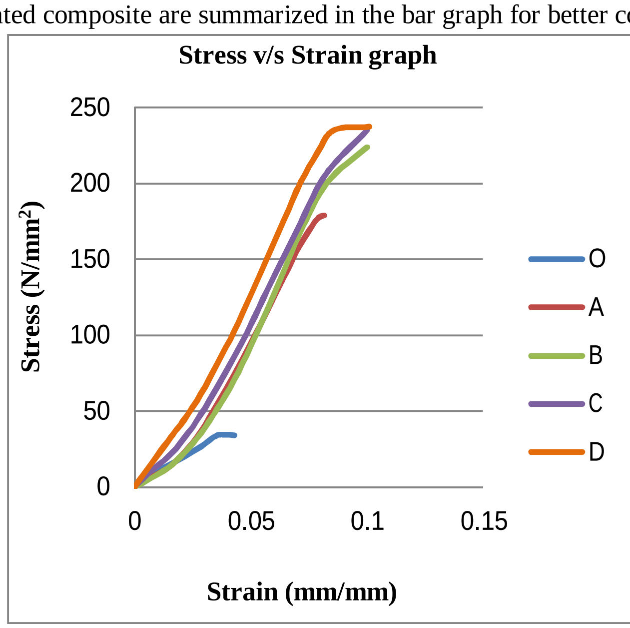

Fig. 9 Stress v/s Strain graph for tensile test specimens

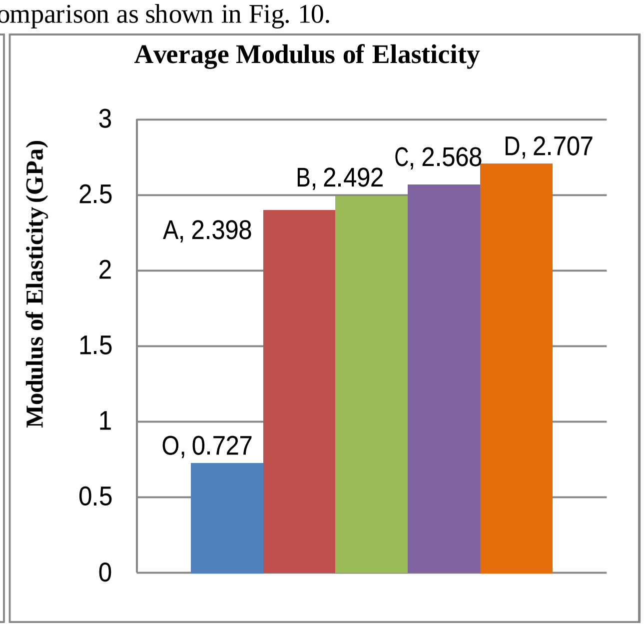

Fig. 10 Bar chart of Average Young's modulus for tensile test specimens

Stress v/s Strain graph has been plotted for different types of specimens as shown in Fig. 9. It was seen that GFRP composite specimens with fiber orientation as $[0°]_6$ showed highest tensile strength and Young's modulus as 237.263MPa and 2.707 GPa respectively. The GFRP composite specimens with fiber orientation as [0°/-45°/+30°/-30°/+45°/0°] showed lowest tensile strength and Young's modulus as 178.931MPa and 2.398GPa respectively.

B. *Three Point Bending Test*

The three point bending test was carried out on specimens as per ASTM D790 standards and results are tabulated in TABLE IIII.

TABLE II
Bending Test Results For Gfrp Specimens

Specimen Type	Specimen number	Peak load (N)	Maximum deflection (mm)	Flexural strength (N/mm^2 or	Average Flexural strength	Average Flexural Modulus
O	B_{O1}	107.9	2.503	121.388	154.463	6.986
	B_{O2}	166.7	5.414	187.538		
A	B_{A1}	500.2	7.459	562.725	492.825	20.240
	B_{A2}	411.9	8.189	463.388		
	B_{A3}	402.1	6.645	452.363		
B	B_{B1}	470.7	8.019	529.540	549.676	20.743
	B_{B2}	475.3	7.705	534.713		
	B_{B3}	519.8	8.834	584.775		
C	B_{C1}	390.2	10.998	438.975	422.138	16.851
	B_{C2}	411.9	8.503	463.388		
	B_{C3}	323.6	5.796	364.050		
D	B_{D1}	255	9.411	286.875	353.063	10.899
	B_{D2}	362.9	10.531	408.263		
	B_{D3}	323.6	8.970	364.050		

This data is often used to select materials for parts that will support loads without flexing. In bending the materials experiences both tensile and compression loading. The specimens with [0°/0°/+30°/-30°/0°/0°] type showed maximum Flexural strength and Flexural modulus. The specimens having 30° fiber fabric orientation showed better flexural strength compared to that of specimens without 30° fiber fabric orientation. This may be due to the fiber fabric layer of 30° orientation offer resistance to combined loading caused due to bending. Therefore GFRP composites specimens which contains 30°- oriented fibers can resists more bending load compared to other types. The average flexural modulus of the fabricated composite are summarized in the bar graph for better comparison as shown in Fig. 12.

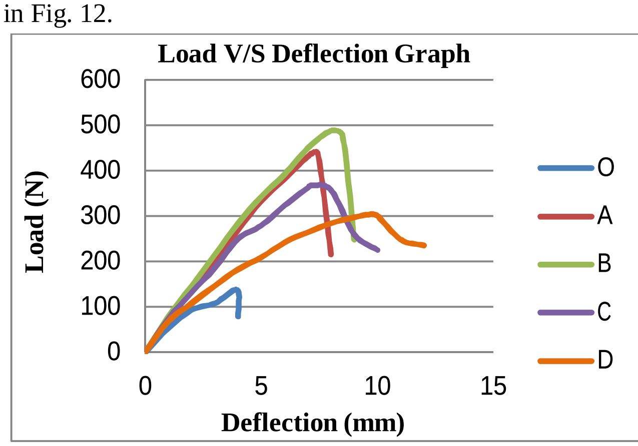

Fig. 11 Load v/s Deflection graph for bending test specimens

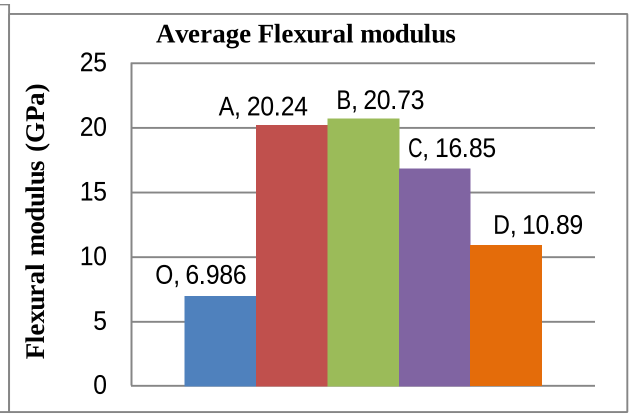

Fig. 12 Bar chart of Average Flexural modulus for bending test specimens

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Load v/s Deflection graph has been plotted for different types of specimens as shown in Fig. 11. It was seen that GFRP composite specimens with fiber orientation as [0°/0°/+30°/-30°/0°/0°] showed highest flexural strength and flexural modulus as 549.676MPa and 20.743GPa respectively. The GFRP composite specimens with fiber orientation as $[0°]_6$ showed lowest flexural strength and flexural modulus as 353.063MPa and 10.899GPa respectively.

C. Izod Impact Test

The Izod impact test was carried out on specimens as per ASTM D256 standards and results are tabulated in TABLE IVII.

TABLE III Impact Test Results For Gfrp Specimens

Specimen Type	Specimen number	Impact energy (J)	Average Impact energy (J)	Average Impact strength (J/ mm^2)
O	I_{O1}	2.00	2.0667	0.0984
	I_{O2}	2.00		
	I_{O3}	2.20		
A	I_{A1}	4.00	4.7850	0.2279
	I_{A2}	4.00		
	I_{A3}	4.00		
	I_{A4}	7.14		
B	I_{B1}	7.47	7.6875	0.3661
	I_{B2}	7.17		
	I_{B3}	8.14		
	I_{B4}	7.97		
C	I_{C1}	8.01	8.3975	0.3999
	I_{C2}	8.47		
	I_{C3}	8.27		
	I_{C4}	8.84		
D	I_{D1}	10.17	10.4450	0.4974
	I_{D2}	10.00		
	I_{D3}	10.57		
	I_{D4}	11.04		

Impact test is where in which rapid propagation of cracks without any excessive plastic deformation at a stress level below the yield stress of the material. From the Fig. 13 & 14, it can be seen as the number of fabric layers with 0^o fiber orientation increases the impact energy and impact strength increases. This may be due to stretching and compressing of fiber fabric layers on the either side of the neutral plane during Izod impact test the 0° fibers which are along the pull direction resisted the load. Therefore specimens with $[0^o]_6$ type absorbed maximum impact energy and have maximum impact strength. The GFRP composite specimens with $[0°]_6$ type can resists more impact load compared to other types.

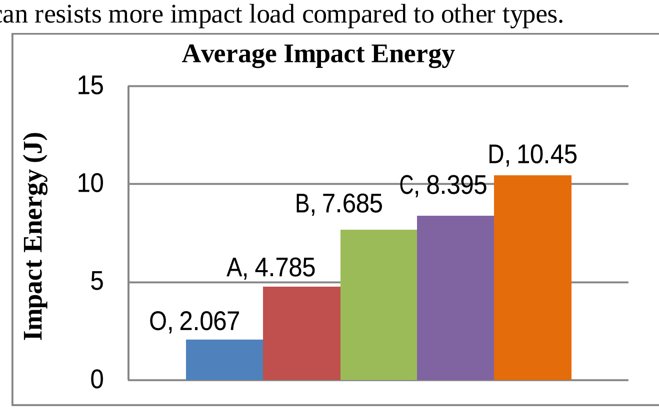

Fig. 13 Bar chart of Average impact energy for Izod impact test specimens

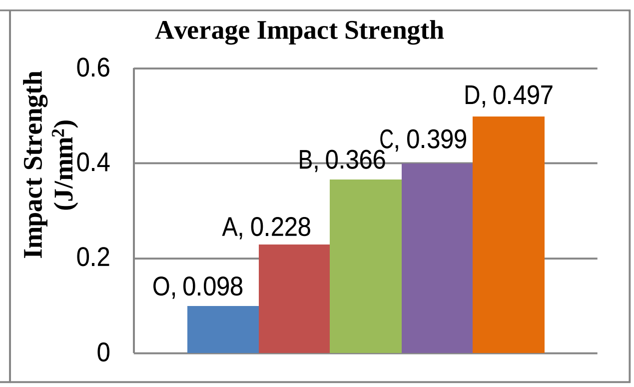

Fig. 14 Bar chart of Average impact strength for Izod impact test specimens

From the test, it was seen that the GFRP composite specimen with fiber orientation as $[0°]_6$ showed highest absorbed impact energy and impact strength as 10.445 J and 0.4974 J/mm^2 respectively. The GFRP composite specimen with fiber orientation as [0°/-45°/+30°/-30°/+45°/0°] showed lowest absorbed impact energy and impact strength as 4.785 J and 0.2279 J/mm^2 respectively.

IV. CONCLUSIONS

The following conclusions are drawn the results obtained by investigation of GFRP composite for Tensile, Flexural and Izod impact testing.

A. The specimens A, B, C and D with different fiber orientation and with 0.6 fiber volume fraction exhibited better mechanical properties than specimen O with no fibers.
B. The specimens with more number of fiber fabric layers orientated along the loading direction (0°) the tensile strength increased. Hence, the specimens with $[0°]_6$ type exhibited maximum tensile strength and Young's modulus. The specimens with [0°/-45°/+30°/-30°/+45°/0°] type exhibited the least tensile strength and Young's modulus among GFRP tensile specimens.
C. The specimens having 30° fiber fabric orientation showed better flexural strength compared to that of specimens without 30° fiber fabric orientation. Hence, the specimens with [0°/0°/+30°/-30°/0°/0°] type exhibited maximum Flexural strength and Flexural modulus. The specimens with $[0°]_6$ type exhibited the least Flexural strength and Flexural modulus among GFRP bending specimens.
D. The Impact test shows that as the number of fiber fabric layers of 0° orientation increases the resistance to impact load increases. Hence, the specimens with $[0°]_6$ type exhibited the maximum impact strength and absorbed maximum energy. The specimens with [0°/-45°/+30°/-30°/+45°/0°] type exhibited the least impact strength and absorbed minimum energy among GFRP impact specimens.

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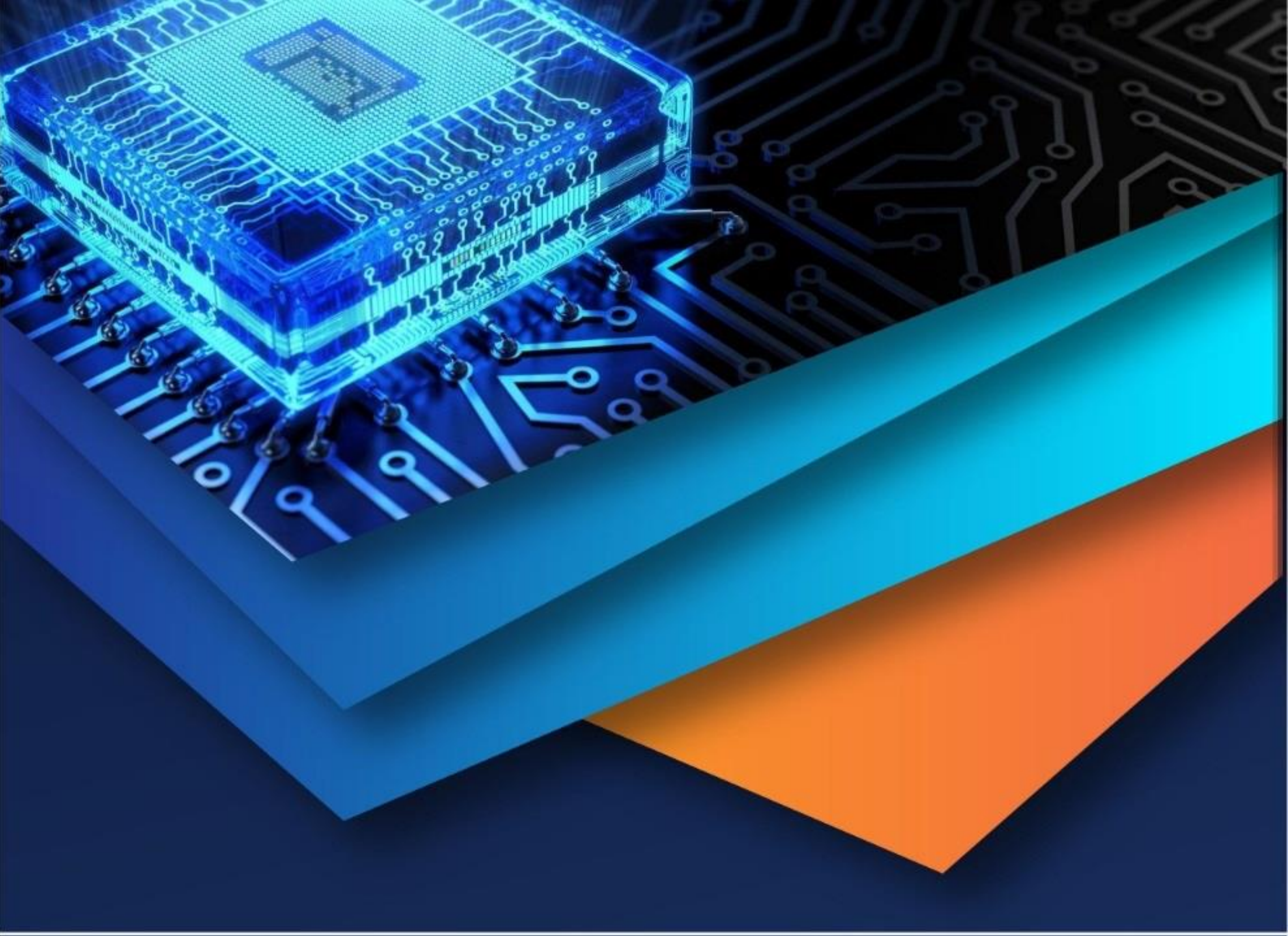

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