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EFFECT OF FIBER ORIENTATIONS ON THE MECHANICAL BEHAVIOR OF GLASS FIBER EPOXY COMPOSITES

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Abstract

The tensile and flexural properties of glass fiber reinforced epoxy composites (GFEC) for use as a skin in a beam are the subject of this investigation, which examines the effects of various fiber orientations (0º, 15º, 30º and 45º). During the study, materials that are used for the preparation of composite are shown in Table 1. Epoxy (GY 250) and a binder (HY 951). The prepared GFEC samples were characterized using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), dynamic mechanical analysis (DMA), and thermo-gravimetric analysis (TGA). The mechanical properties of the composites were carried out and found to be superior at 0º orientation among all samples. Additionally, the thermal stability in terms of TGA and DMA analyses revealed a superior usage capability. The XRD analysis confirmed the amorphous nature of the composites, and the FTIR analysis demonstrated the chemical breakdown behavior. The prepared composites showed improved properties in stiffness, toughness, hardness, and heat distortion temperature and the ease of processing cost facilitates their uses in many applications.

Keywords: glass fiber orientation; mechanical property; epoxy composites; thermal stability

1. Introduction

Conventional materials are replaced by composites in various applications because of less production cost, strength to weight ratio as well as reduction in cost. The properties are modified by adopting different orientation of glass fiber orientation to suit the strength and modulus requirements. Apart from strength to weight factor, the thermal stability is also tuned for particular application by using different grades of epoxy binder combination. The elemental composition decides the uses of varied application which can be monitored depending on the situation. Besides the above properties, the nature of interfacial bonds and mechanisms play an important role. Specific fillers, additives are used to enhance and modify the quality of performance in many applications. Therefore, in the present work, an attempt has been made to study both mechanical and thermal behaviour of glass fiber reinforced composites having different orientations.

Torabizadeh [1] investigated the material properties, static and low temperature behavior of unidirectional glass fiber reinforced composites in which epoxy resin is considered as the matrix material. Srivastava [2] examined the impact behavior of sandwich constructions which are made of cross-piled, polyurethane foam-cured composites with E-glass fiber reinforced polymer matrix. Sathishkumar et al. [3] studied glass fiber reinforced polymer composites using various processing techniques and found that at 25% of fiber, flexural strength and tensile strength were found to be maximum. Adekomaya and Adama [4] investigated the effect of fiber orientation, and loading on

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the performance of composite polymeric materials and observed that loading with fiber improves the strength of the polymer composites. In this work, they prepared fiber reinforced composites by manually laying them out. For epoxy resin ampreg-21, woven E glass serves as reinforcement. El-Assal and Khashaba [5] investigated the GFRP composites fatigue behavior under combined torsion and bending stress and concluded that unidirectional GFRP composites had inferior torsional fatigue strength when compared to results. The number of stress cycles increases along with the volume of the fiber. Harizi et al. [6] used a passive infrared thermographs technique to record infrared radiation and the composite behavior at high temperatures. Pandav and Sawant [7] evaluated various mechanical properties experimentally. Sikarwar et al. [8] reviewed the impact of fiber orientation and thickness on the functionality of glass fiber reinforced polymer. Aiello et al. [9] observed that anisotropically behaved fiber reinforced polymer bar as well as elevated transverse coefficient of thermal expansion can create splitting cracks. Bhat et al. [10] studied the fatigue damage in composite materials. Bati et al. [11] looked at how two distinctive composite materials could strengthen masonry arches experimentally. El-Habak [12] did experiments on woven GFRC to determine the compressive behavior at different strain rates ranging from 10^2 to 10^3 s^{-1}. Using GFRP composite laminates and a static tensile test, Ferdous et al. [13] and Rad et al. [14] evaluated the fatigue life of GFRP composite. Harsha et al. [15] did experiments on fiber reinforced PAEK composite and observed that with the increase in fiber content in composite increases the wear rate.

Ganeshan et al. [16], Nagarajaganesh et al. [17], Raja et al. [18], Yoganandam et al. [19], Balasubramanian et al. [20] have taken natural fibers to fabricate the composite materials and carried out many experiments such as XRD, FTIR, and TGA to characterize the composite materials.

Morampudi et al. [21] determined the fiber strength, Young's modulus, the stability and matrix strength of the fiber reinforced composites. Somaiah et al. [22] stated that fiber particles, or flakes which are insoluble elements in structural composites creates significant role in development of composite materials. Biswas et al. [23] focused on monolithic materials as compared to fiber reinforced polymeric materials considering high specific strength, modulus, and other related properties such as erosion, fiber content and orientation for specific loading conditions. Stricker et al. [24] studied the toughness behavior of highly syndiotactic polypropylene for industrial applications. Kong et al. [25] experimented using natural fiber in both thermoplastic and thermoset matrix composites as reinforcing materials because of lower greenhouse gas emission, increased energy recovery and biodegradability. Reddy et al. [26] carried out analytical, numerical, and experimental studies for composites reinforced with fibers. Li and Lou [27] used 3D printing for fabrication of complex three-dimensional structures with composite materials. Zanuddin et al. [28] analyzed the attractive quality of epoxy resin matrices in strength, stiffness, temperature resistance, low creep and shrinkage properties over FRP composites and its degradation and failure caused by precursors.

From the above mentioned literature it is observed that very few experimental works are available on the study of GFRC with different fiber orientation. Hence in the present work an attempt has

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been made to study the effect of fiber orientation on the mechanical and thermal properties of GFRC experimentally. In the next session, the material and method used for different experiments are presented.

2. Materials and Methods:

2.1 Materials

During the study, materials that are used for the preparation of composite are shown in Table 1. Epoxy (GY 250) and a binder (HY 951) purchased from the Huntsman firm; Hyderabad are used during the preparation of composite. Glass fibers purchased from Perfect Trading company; Kolkata were used as reinforcement for the epoxy matrix.

Table 1. Materials used for composite

S. No.	Materials	Grade
1	Epoxy resin (Matrix)	GY 250
2	Epoxy Resin (Binder)	HY 951
3	Woven fiber glass (Reinforcement)	363.23 GSM

2.2 Fabrication of composite:

Glass fiber reinforced epoxy composite were prepared using the hand layup method. For this glass fiber mat is cut according to the specifications. For a certain direction of reinforcement, three sections measuring 30 cm x 60 cm are taken into account for 2 mm thick skin.

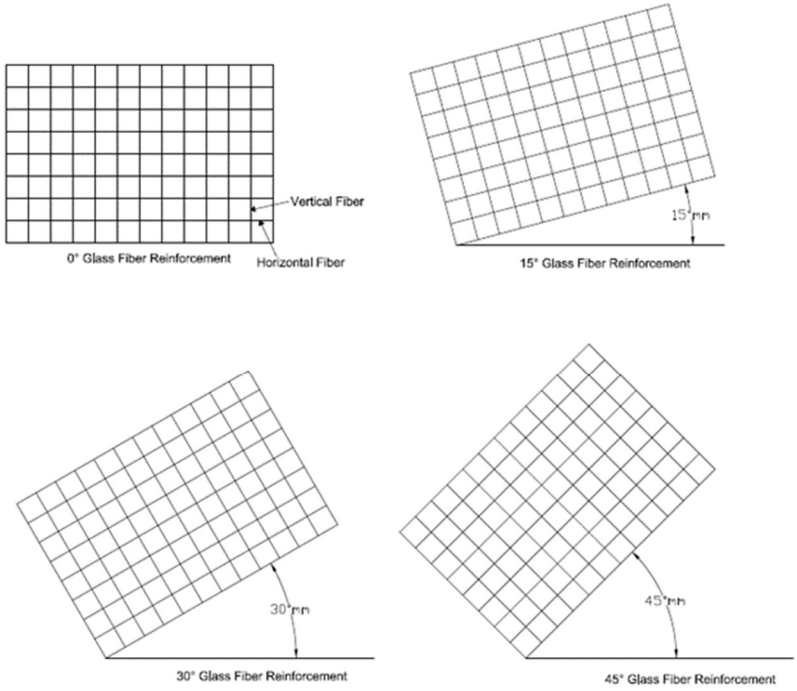

Figure 1: Fiber orientations in composite

The first three glass fiber mat pieces are weighed using a digital balance. Next, an equal amount of epoxy was placed in a plastic container. Three sheets of glass fiber mat weigh 184 gm for a composite that is 2 mm thick. The hardener is then mixed with the epoxy in the same container at a weight ratio of $1/10^{th}$ of the epoxy, or around 20 gm. Then, using a mixer stick, both components are well swirled and combined. On the surface of the wooden table, a coat of a 10:1 combination of epoxy (GY250) and binder (HY951) is applied first.

The coat is then covered with one sheet of glass fiber mat. Over the glass fiber mat, rolling is done using a hand roller. The glass fiber mat is then recoated again. The following two layers are constructed using a similar process to create the 2 mm composite. Glass fiber mats are oriented at 0^0,15^0,30^0 and 45^0 in a horizontal manner and cut into pieces to prepare the composite. The different orientations used in composite are shown in Figure 1.

3. Material and method:

3.1 Tensile strength

Composite specimens are prepared as per ASTM D3039 standards. The specimen has 250 mm in length (L), 25 m in width (W),3mm thickness, 55 mm in sleeve length , and 140 mm gauge length. Tensile tests were performed at a cross head speed of 1.5 mm/min on Instron UTM of 100 KN capacity.

Table 2 shows the fiber orientation effect on composites tensile characteristics. The GFEC composite with 0º and 15º fiber showed an ultimate stress of **300** MPa and **240** MPa respectively while the elongation was **5.17%** and **5.97%.** Whereas for 30º and 45º fiber orientation, the ultimate stress was found to be **220** MPa and **130** MPa respectively which are very low when compared to 0º and 15º fiber orientation. The stress versus strain curves of 0º, 15º, 30º and 45º fiber orientations are shown in Figure 3. Figure clearly shows that 0º orientation exhibits better performance in terms of tensile strength when compared to other orientations.

Table 2: Fiber orientation effect on tensile strength

Fiber orientation	Ultimate Stress (MPa)	Ultimate Strain (%)	Break Strain (%)
0º	300	5.17	5.18
15 º	240	5.88	5.97
30º	220	6.59	6.77
45º	130	7.47	8.25

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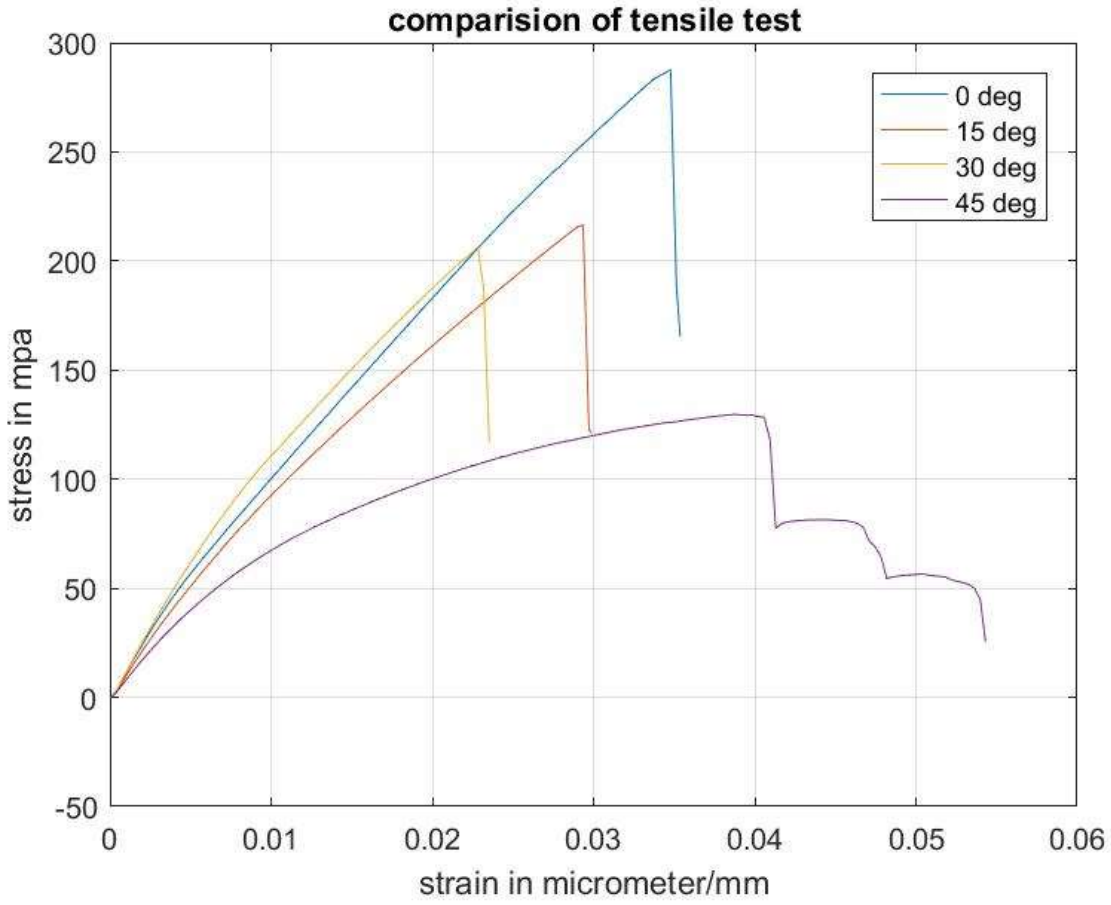

Figure 2: Stress strain variation for 0^0, 15^0, 30^0, 45^0 fiber orientations

3.2. Flexural strength:

Flexural characteristics of the prepared composite specimens was performed using a UTM machine (Instron UTM of 100 KN capacity) as per ASTM D790 standards at a crosshead speed of 1.5 mm/min on samples of 127(L) mm x 12.7(W) mm x 2 mm (Figure 4).

Table 3 shows the effect of fiber orientation on the flexural characteristics of GFRC composite. It was observed that with 0º and 15º fiber orientations showed an ultimate stress of **289** MPa and **251** MPa respectively. Whereas for 30º and 45º fiber orientation it was just 237 MPa and 218 MPa which are very low when compared to 0º and 15º fiber orientation. The stress vs strain curves of 0º, 15º, 30º and 45º are shown in Figure 5. Similar observations have been reported earlier by Harsha et al. [15] for fiber-reinforced thermoplastic composites such as polyaryletherketone composites, the tensile and flexural properties of any composite should be considered before proposing it as a possibility for construction materials, taking the fiber orientation angle into consideration. The figure highlights that the flexural strength is higher for 0º fiber orientation similar to tensile strength.

Table 3: Fiber orientation effect on flexural strength

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Fiber orientation	Ultimate Force (N)	Ultimate Stress (N/mm^2)	Ultimate Strain (%)
0º	122	289	3.26
15º	95.15	251	3.75
30º	68.3	237	4.25
45º	66.7	218	5.18

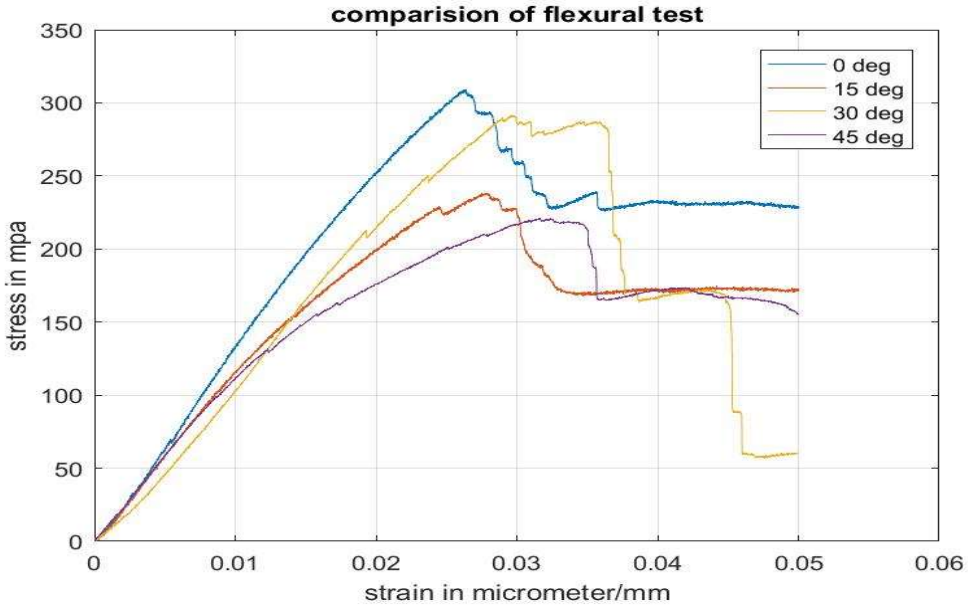

Figure 2: Stress strain variation for 0^0, 15^0, 30^0, 45^0 fiber orientations

3.3 Thermo-gravimetric analysis (TGA):

Thermogravimetric analysis (TGA) is method of analyzing material thermal stability and change of mass under specific controlled heating environment which is function of time or temperature. TGA was employed to investigate the GFRC composite thermal behavior ranging 3 - 12 mg (Universal V4 5A TA Instrument). The tests were

carried out between 20°C to 800°C at 20°C/min rate. As the specimen is heated at a constant rate to assess the degradation rate of the composite. The weighed sample of 10.2690 mg is taken from 0° orientation GFEC composite and is kept inside the electric furnace which is fitted with a thermocouple for measuring the temperature. When the specimen is heated up to 100°C inside the furnace shows no significant mass change but at 200°C the change occurs by 0.05%, with further more increase in temperature up to 300°C, the changes occur by 2.766%. At 373.85°C further decrease in mass is observed which is at 0.4716% per °C and at 424.85°C the decrease of mass is by 0.1618% per °C. The decrease of mass is 29.99% as shown by the curve in Figure 6. With further heating, the decrease of mass noticed as seen from the figure and when the temperature is 800°C.

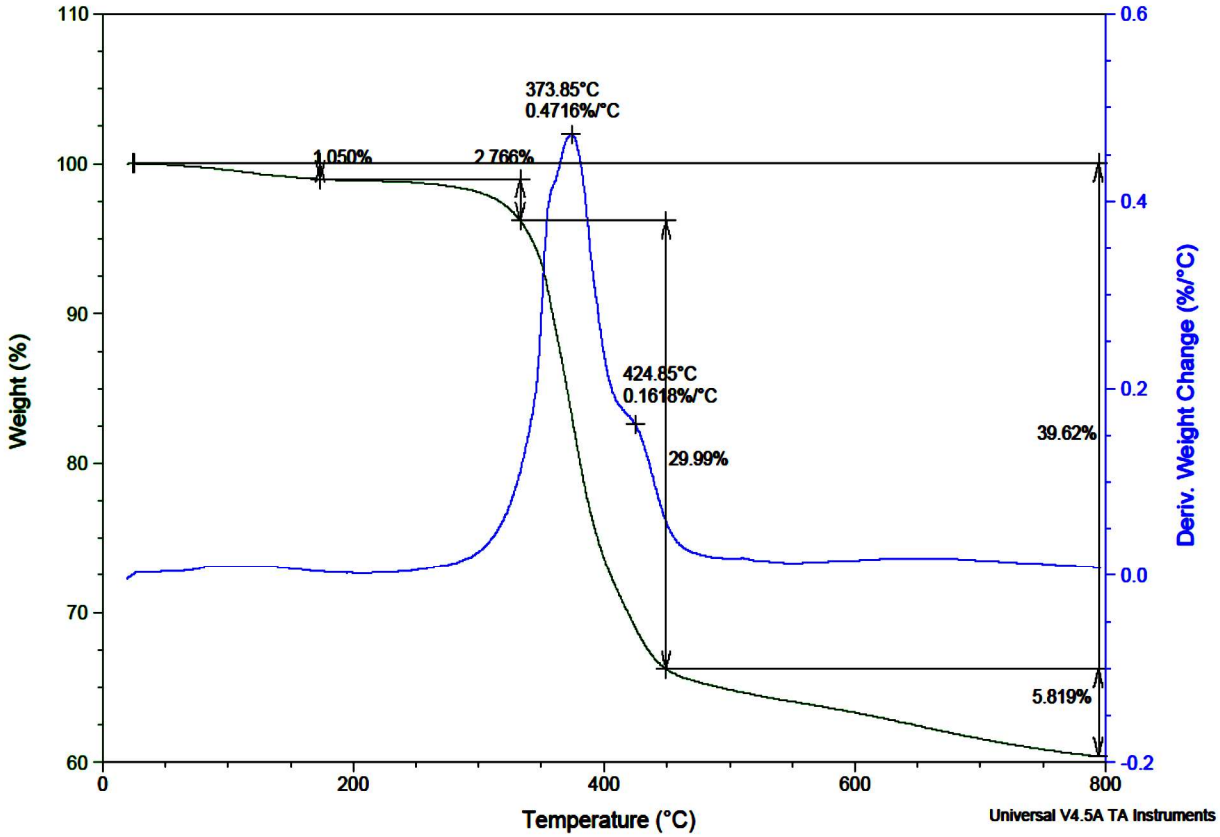

Figure 4: variation of temperature with mass

3.4 Dynamical mechanical analysis (DMA):

Dynamic mechanical analysis promising successful method to study relaxation in polymers and to understand the behavior of the materials under stress for uniaxial or biaxial , temperature, and phase composition of fiber composites with respective roles of determining the mechanical properties also used for studying the viscoelastic behavior of polymers. One can determine the complex modulus by applying sinusoidal stress **to measure strain of material .**DMA is used to characterize the composites property with heating rate up to 600°C, 0.01-200 Hz frequency and force range of 0.0001-18N amplitude using a Universal V4 5A TA Instrument. For the specimen with orientation 0° at temperature around 12.5°C, the storage modulus is 2500 MPa, the loss modulus is 250 MPa and tan Delta being 0.25. It was observed that with the increase in temperature, the storage modulus as well as loss modulus decreases and hence tan delta. This decrease is because of stiffness loss in GFEC composite. The blue curve represents storage modulus and temperature as shown in Figure 7. The grey curve represents tan Delta and temperature for the tested specimen. At 75°C, the storage modulus as well as loss modulus decreases gradually. Further with increase in temperature, the same change is remarkably noticed showing the complex modulus of specimen decreased over temperature range 50-100°C. After 100°C, the storage loss modulus remains almost constant thus the material is stable at 100-

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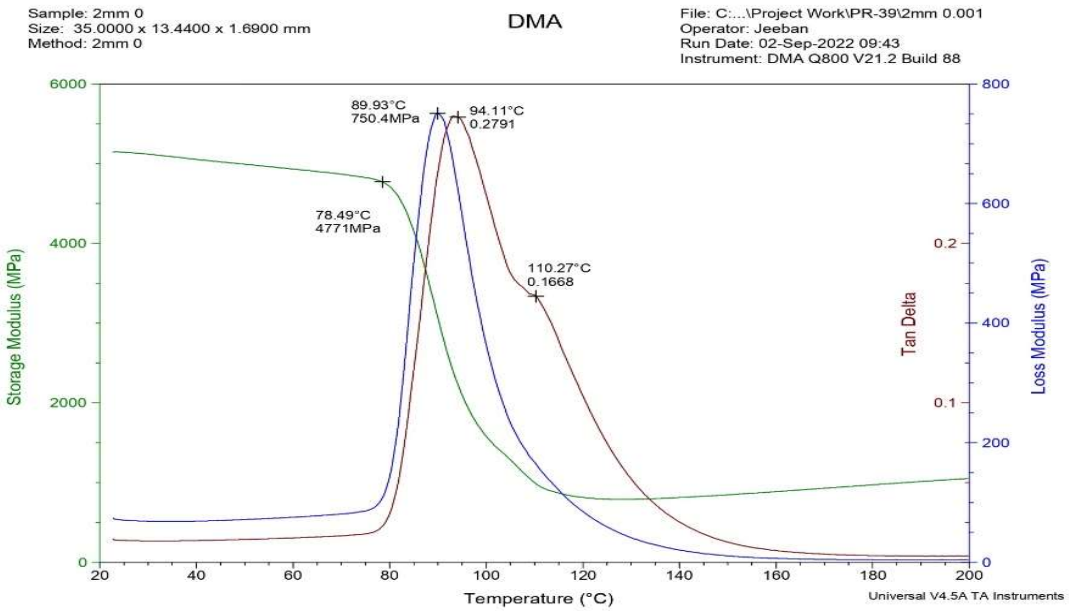
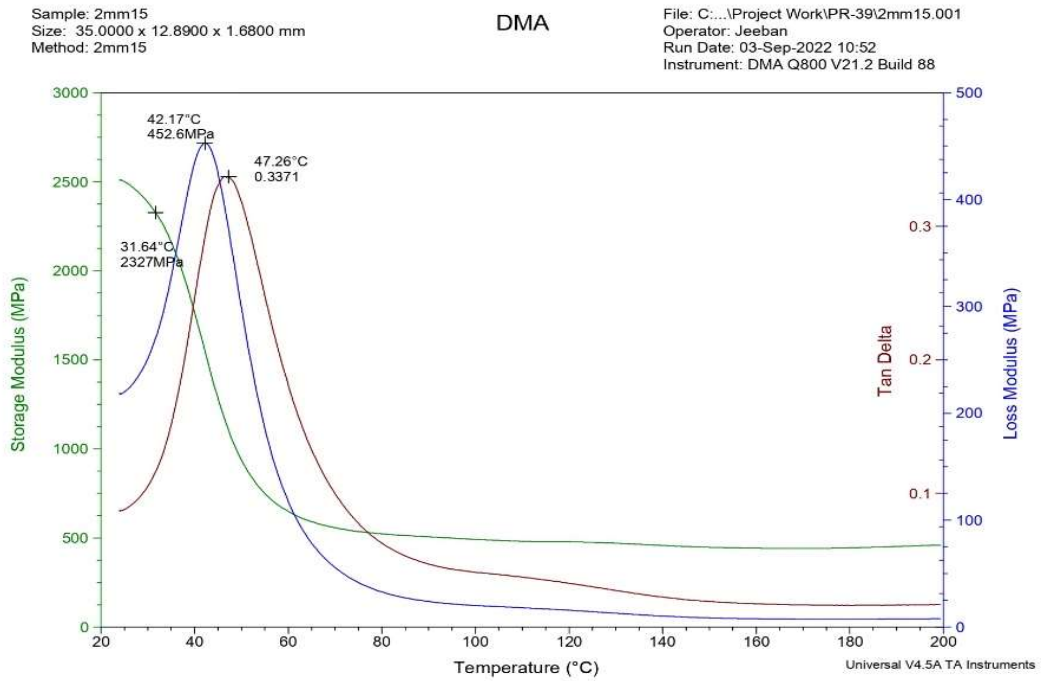
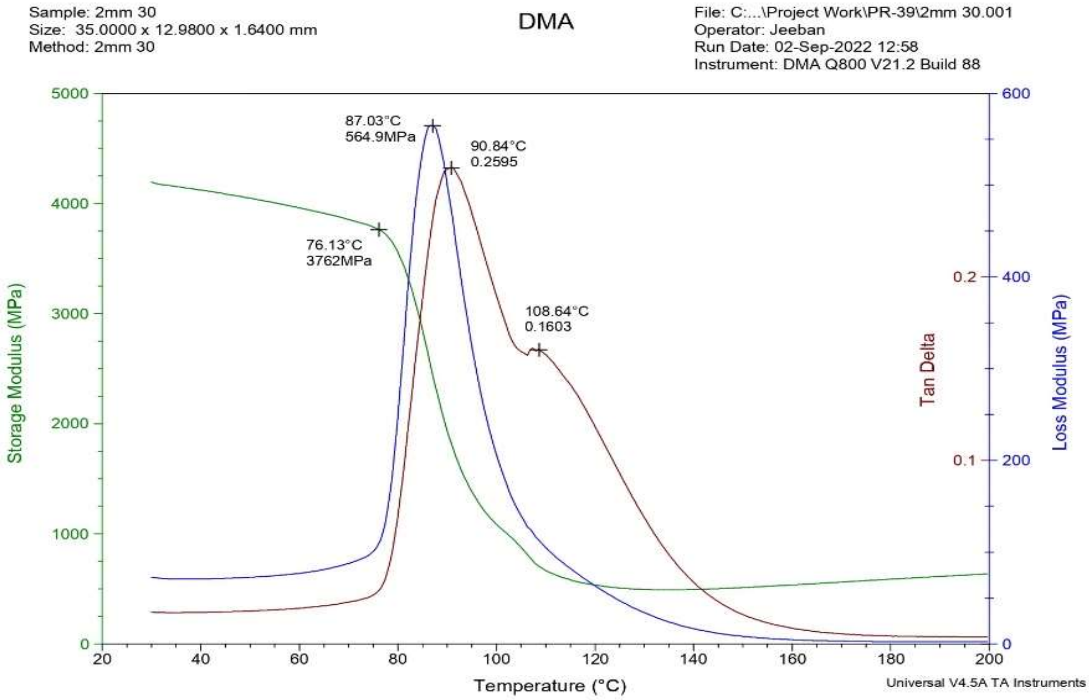
200°C temperature range. The inelastic deformation is remarkable for the specimen at temperature range 50-100°C. Beyond 100°C, the elastic and inelastic deformation remains almost constant. The specimen tested as per ASTM D5418 and specimen dimension 63mm(L)x12.7mm(W) with machine TA Instruments, model No. DMA Q800.



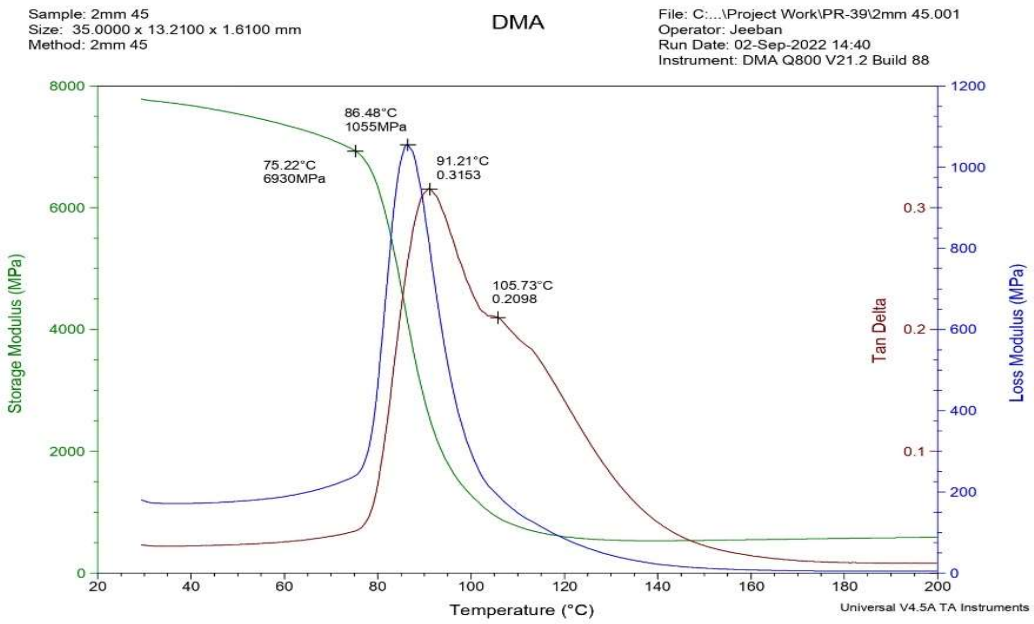
(a) for 0deg



(b) 15deg



(c) for 30deg



(d) for 45deg

Figure 5: variation of temperature with storage modulus (a) for 0^0 (b) for 15^0(c) for 30^0, and (d) for 45^0 GFRP composites.

3.5 Morphological analysis:

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SEM is a useful technique for determining the connection between the matrix and the micron level of additives. The composite failure can be analyzed using SEM allowed for the generation of a diverse quality of signals over the solid samples surface. SEM may also examine particular point locations on samples. The results of microstructure research are analyzed and compared to the physical and mechanical qualities that were measured. Additionally, each PFR mix's porosity was assessed using an optical microscope and then examined using the "Image J" programme.

SEM was used to examine the microstructure of the tested mixtures of glass fibre and epoxy in order to look into how glass fibers and epoxy changed the mechanical properties and failure modes. On the surface of the examined samples fracture, microscopic pictures were taken. Figure 6 shows the fracture of the glass fiber and epoxy, which is an indication of good contact between the glass fiber and epoxy. It also explains why the PFR mix is becoming more flexible despite losing strength.

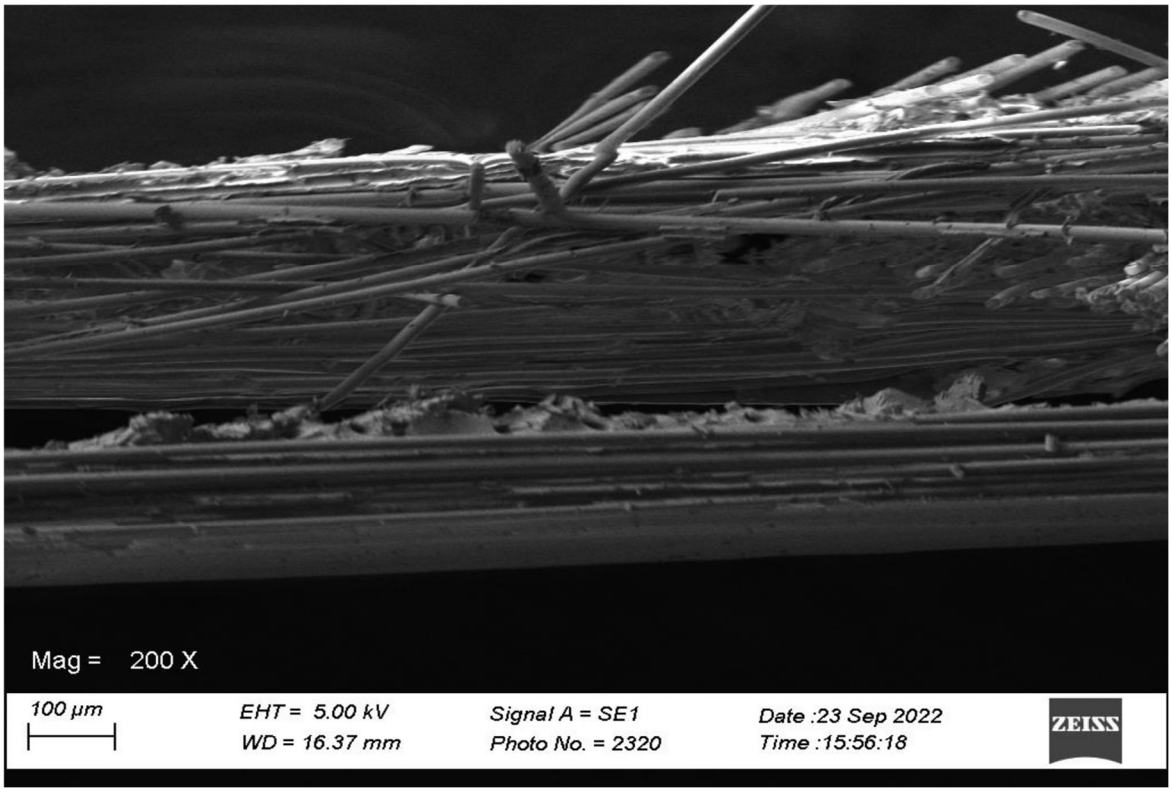

Figure 6: Morphological analysis of composites

3.6 XRD analysis:

Study of X-ray diffraction was conducted to ascertain the molecular structure of the composites under copper K-α radiation at 30 mA and 40 kV condition. Continuous measurements were taken with steps of 0.02° at continuous scan mode with a scan speed of 5°/min. A 2θ range between 2° and 80° is chosen for the analysis.

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The composites distinctive wide underlying peak, centered about 15°, is in good accord with other XRD tests as shown in Figure 7. This wide peak illustrates the amorphous character of the composite and demonstrates the homogeneous dispersion of the glass fibers inside the epoxy matrix. Silica, a marker of directed loading in the epoxy resin, was found in the majority of components in the X-ray diffractogram of oriented glass fiber. This confirms that the composite still contains crystalline silica. The absence of any further discernible XRD peaks in the composites, which can be detected, suggests the amorphous nature of composites.

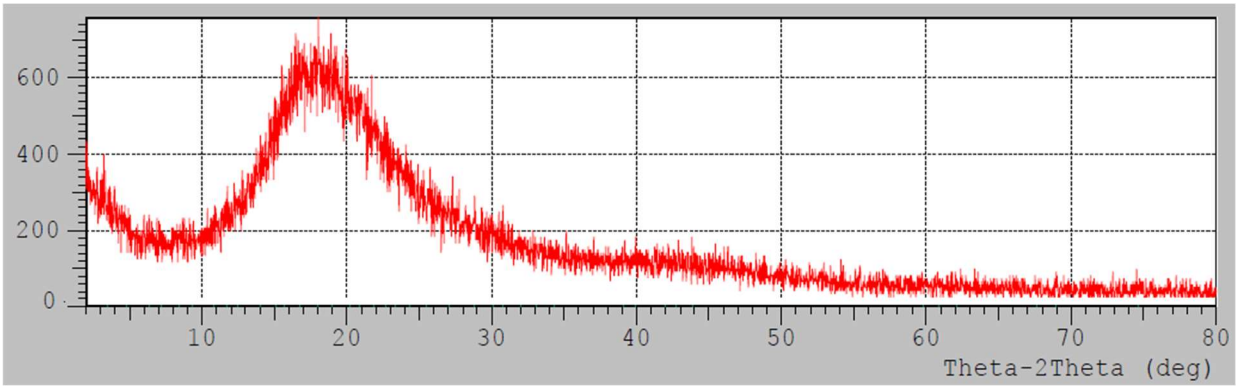

Figure 7 XRD pattern of composite

3.7 FTIR analysis:

Using a Bruker FTIR spectroscope, the produced composites are FTIR examined. The grinded powder of composite and potassium bromide with mixture of 1:10 to create a pellets for analysis. In the 500 to 4000 cm^{-1} wave range, the spectra is recorded at laboratory temperature at 30 scans per minute with a 3 cm^{-1} resolution.

Utilizing FTIR spectroscopy, the chemical breakdown of the epoxy matrix was also studied. The transmission of infrared light through the composite specimens is plotted as shown in figure 8. With the exception of two significant peaks, one at 3290 cm^{-1} and the other at 2922 cm^{-1}, both of which correspond to the ester carboxyl group. Additionally, a few minor peaks from 1652 to 1301 and from 1233 to 826 cm^{-1}, which stand for the flame retardant's OH bonds.

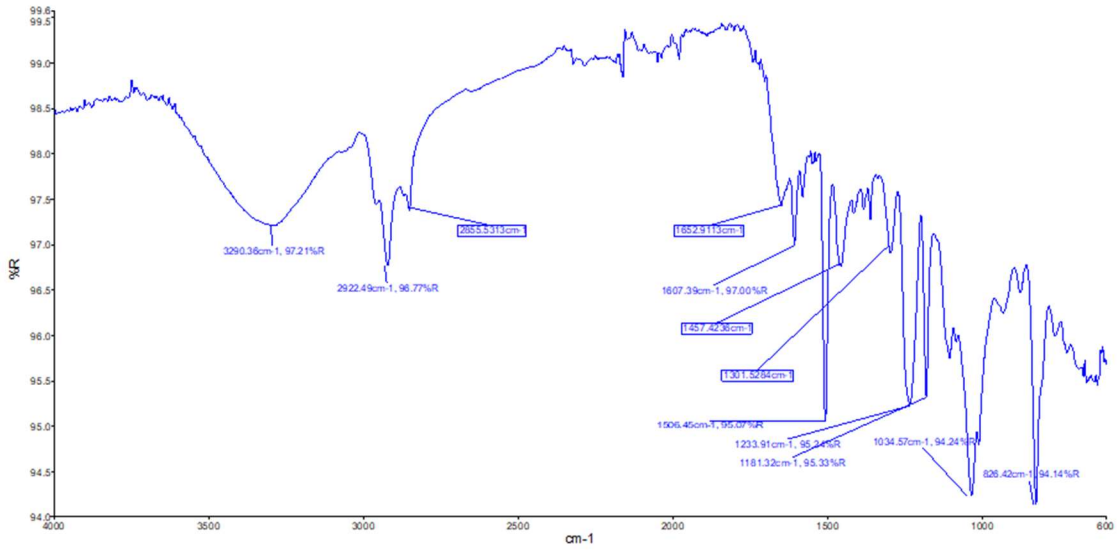

Figure 8. FTIR transmission of composite

4. Conclusions

The following results are drawn from the experiments on the impact of fiber loading and relative fiber orientation of GFRC composite that may be useful for the researchers to use as skin material of sandwich beam structures:

1. By using a straight forward hand lay-up process, glass fiber-reinforced epoxy composites (GFRC) with various fiber orientations ware successfully prepared.
2. Composite with 0º fiber orientation shows better tensile (**300** MPa) and flexural strength (**289** MPa) compared with other fiber orientations.
3. TGA results shows that around 200°C, the change in mass occurs by **0.05**%, with further increase in temperature up to 300°C the mass changes by **2.766**%. At 373.85°C further decrease in mass is observed which is **0.4716%**/ °C. Further, at 424.85°C the decrease of mass was by **0.1618%**/ °C.
4. DMA results show that at 75°C, the storage modulus and loss modulus decrease gradually. Further increase in temp., the same change is remarkably noticed showing the complex modulus of specimen decreased over temp δ range 50-100°C.
5. XRD peaks in the composite suggest that the materials were amorphous in nature.
6. FTIR spectrum prove the presence of OH and ester carboxyl group present in the composites.

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