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Investigation on Mechanical Behaviour of Fiber-Reinforced Advanced Polymer Composite Materials

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Abstract: Fiber Reinforced Polymer composites materials are replacing traditional composite materials practical applications for some years due to characteristics such as high durability, resistance to corrosion, flexural strength, in addition to outstanding mechanical properties specific towards the substance. Thus, the objective of current work is to investigate the manufacturing of multi natural fibre reinforced polymer composites, as well as study their mechanical characteristics, and set side by side them to those produced with a single natural fibre reinforced composite. Fiber-reinforced polymer composite's density and hardness were determined to be within acceptable levels by conducting flexural and tensile strength tests on the composites. The ASTM standards samples method were utilised to produce the specimens of composite with varying fibre weight percentages using the hand-lay-up technique. Carbon fiber reinforced plastics (CFRP) composite material has a maximum tensile strength of 240 MPa and can sustain that strength. The maximal impact strength of the CFRP composite is 69.21 KJ/m2. The performance of Fiber-Reinforced Polymer composites is found promising.

Keywords: Carbon fibers reinforced composites; Mechanical properties; Composite materials; Tensile Test

1. Introduction and Background

Polymer composites may be found in a wide variety of everyday items[1]. In recent years, fiber reinforced materials have attracted attention due to the pursuit of light, strong, and hard materials. As a result, the determination of mechanical properties, especially for unidirectional composites, becomes essential. Composites have several uses in the automotive and marine sectors. Excellent corrosion resistance, as well as high stiffness-to-weight ratios, all contribute to the robustness and creep resistance of these applications[2–5]. Asia's developing countries are currently dealing with problems including growing urbanisation and the need for more secure and opulent travel in order to maintain a normal way of living by introducing composite materials[6]. The production of aluminum-based composites has been made possible by the increasing demand for aluminum-metal matrix composites in the automotive and aerospace industries[7]. The high-priced cost of synthetic fibres for employ in aviation and military uses has sparked academic and scientific interest in using natural fibres, counting but not restricted to banana, coconut husk, hemp, in consumer items and public constructions. Natural fibres offer a number of payback over standard fibres, together with biodegradability, renewable energy, nontoxicity, combustibility, and high specific mechanical properties [8,9]. When compared to synthetic fibre composites, natural fibre composites have poorer mechanical properties. Traditional composites with only one type of reinforcement are known as nano-composites. Utilizing a single matrix material, hybrid composites are built utilising many types of fibre. Because of their unique features, hybrid composites are more cost-effective than regular composites. A lot of researchers have gone in this route. Using banana fibre reinforced polypropylene composites, the mechanical characteristics of hybrid polypropylene-banana-glass-fibre composites were assessed. The findings showed that 30 weight percent of fibre loading provided the maximum improvement in features [10].

Due to characteristics like high strength-to-weight and stiffness-to-weight ratios, high damping, low thermal expansion capacity, and good corrosion resistance, carbon fibre reinforced plastic (CFRP) materials have been displacing stainless steel and other resources of a similar nature in the aeronautical and aerospace industries in recent years[11]. Carbon fibre reinforced plastic (CFRP), which offers qualities including a high strength-to-weight ratio, stiffness-to-weight ratio, good damping, and low heat, has recently replaced stainless steel and other related materials in the aerospace sector[12]. A metal that has been strengthened with two or more components which may be made of metal or non-metal materials. It is known as a metal matrix composite[19]. In present investigation it was intended to investigate manufacturing of fibre reinforced polymer composites, as well as their mechanical characteristics, Metal matrix composites (MMCs), which are intrinsically intelligent, are a class of high-performance, lightweight materials that are constantly evolving [17, 20]. The density of composites, which is based on the proportion of matrix to reinforcing components, is one of their key characteristics.

The usage of natural fiber-reinforced polymers (NFRPs), which have lately emerged as essential materials in a range of technical applications, necessitates a number of final industrial processes, including trimming, cutting, and drilling. Due to the heterogeneous nature of NFRPs, as opposed to homogenous materials like metals and polymers; various defects have been discovered while processing NFRPs using conventional cutting procedures, such as increased surface roughness and considerable damage at the cutting zone. Different weight percentages of 5, 10, 15, 20, 25, and 30 wt% were used to strengthen PA6 with aluminium. Aluminum Reinforced PA6 Tensile, flexural, impact, and hardness tests have been used to examine the mechanical characteristics of PA6 polymer composites [2,12]. The three state characteristics of solid, liquid, and gas are what determine how metal matrix composites were made. Estimates based on the distribution of appropriate metals are analysed using the system setup[13]. The liquid state improves the performance level of the infiltration method strategy. Matrix systems create features according to the needs of metals used to alter the way different particles are made. In liquid phase processes, the bandwidth of the system delivers material according to the appropriate aspect [14].

The carbon fibre reinforced plastic strands are filled by Lapox L – 12 epoxy resin, which may be utilised with a variety of hardeners to create fibre reinforced composites that are hand laid up[12]. To make complicated components for the automotive, aerospace, marine, chemical, and power plant sectors, contemporary machining techniques like AWJM are essential.

Natural fiber-reinforced polymers (NFRPs) have recently grown in importance as materials in several technical applications; as a result, using these materials requires various final industrial operations including drilling, trimming, and cutting. Because NFRP is a heterogeneous composition that distinguishes it from homogeneous natural materials such as polymers and metals, processing NFRP with conventional cutting techniques can lead to problems such as excessive surface roughness and material damage in the typical cutting zone, with various defects. Unconventional editing techniques were considered as a solution to these problems. The special effects of the cutting forces, which are the primary source of cutting errors in conventional cutting procedures, were not taken into consideration by unconventional cutting techniques[3].

In the some work, researchers investigate results about compressive and impact strengths. Modifications in the compressive and impact strengths of sisal/glass hybrid composites made of unsaturated polyester with fibre loading. They suggested that these treatments did not significantly improve the impact strength of the sisal-glass hybrid composites, but they did noticeably raise the compressive strength of these composites[16, 18].

Ashik et al. studied properties of composite materials with tensile, flexural strength. The composite laminates used in this study were manufactured using a manual lamination process. Hybrid laminates are produced by incorporating natural and glass fibers in different lamination sequences. The results of this study showed that the hybrid composite laminates could improve strength and be used as an alternative material for automotive applications, and the finite element analysis results confirmed the experimental results[16,19, 20].

The available literature shows that Fiber-Reinforced Polymer Composite Materials has wide applications and trending research area now a day. The extensive research is required to find the amount of fibre by weight, as well as assessment of the mechanical behaviour of GFRP and CFRP composites. The properties need to be studied for selection of composites. Therefore, the aim of this work is the development of carbon along with glass fiber reinforced epoxy resins. Further, the present investigation was also aimed towards finding manufacturing of fibre reinforced polymer composites, as well as their mechanical characteristics, and compares them to those produced using a single natural fibre reinforced composite and

The remainder of this article is organized as follows: Section 2 describes the material and methods that were used to prepare the model and composite fabrication of given materials. Section 3 provides results from mechanical characteristics of Fiber-Reinforced Polymer Composite Materials. The findings, a thorough description of a systemic study, and interpretations of the observations based on methodological outlooks are all provided in Section 4. In Section 5, the conclusion is reached through observations and evaluations in a variety of plausible scenarios.

2. Data Collection

The selection of proper concentration of materials in case of composites plays a great role for properties. Epoxy Resin (LY566) with hardener (HY951) are utilised as the matrix material. The composite slabs are constructed using a manual construction technique with mild compaction[17]. Epoxy Resin (LY566) with hardener (HY951) are utilised as the matrix material, and bi-directional E-glass in addition to carbon fibres by a thickness of 0.2 mm are employed as the ply direction of 0/90 reinforcements. HY951 seems to be a room-temperature drying, low viscosity epoxy casting resin. The reason for selecting these materials is a lot of room for filler here. Mechanical toughness is an important benefit for the same. Atmospheric and chemical degradation resistance is excellent [18)].

The procedure for the production of polymer composite includes in the subsequent steps. The hardener (HY951) with epoxy resin (LY566) was heterogeneously mixed in a 10:1 weight ratio before being cured at room temperature. After full mixing, the fibre layers in the matrix body were strengthened. The composites are created using the hand-lay-up process and gentle compression moulding. A cast mould with specifications of 250 mm x 250 mm x 5 mm has been used. After the composite had dried, a releasing handler was used to speed its release from the mould. Each composite is cured for twenty four hours in a tightening mould before being post-cured in air for yet another five hours. Specimens were produced in accordance with ASME guidelines. Table 1 highlights the Mechanical, Chemical and Physical Composition of Epoxy Resin.

Table 1: Mechanical, Chemical and Physical Composition of Epoxy Resin

Properties	**Epoxy Resin**	**Hardener (HY 951)**
Density (g/cm3)	1.1	0.95
Melting point	50 C	120 C (lit.)
Water solubility	Soluble	Soluble

Flat specimens are frequently used while conducting a tension test. The most common specimen geometries to date have been the dog-bone specimen along with through experiment by means of terminal tab. The tensile test in this investigation uses a specimen that is straight-sided. The D3039-14 ASTM standard test measures the tensile properties of fiber-reinforced composites. This test method analyzes the in-plane tensile properties of polymer matrix composites using high modulus fiber reinforcement. Composites reinforced with continuous or discontinuous fibers are acceptable composite geometries only if the laminate is balanced and symmetrical with respect to the test direction. The specimen's transverse and longitudinal measurements are given below in millimetres and millimetres, respectively. Using common diagnostic equipment and a rotating head speed of 2 millimetres per second, the ductility of the composite samples was determined. Three comparable composites' mean values were recorded as a composite property, and the outcomes were compared. Using a universal testing machine (UTM), tensile and compression tests are performed in line with ASTM standard test procedures. The tensile test is performed on a 250mm x 25mm x 4mm specimen as shown in figure 1, whereas the compression test is performed on a 140mm x 25mm x 4mm specimen as revealed in figure 2.

Fig. 1: Tensile test carried out on specimen

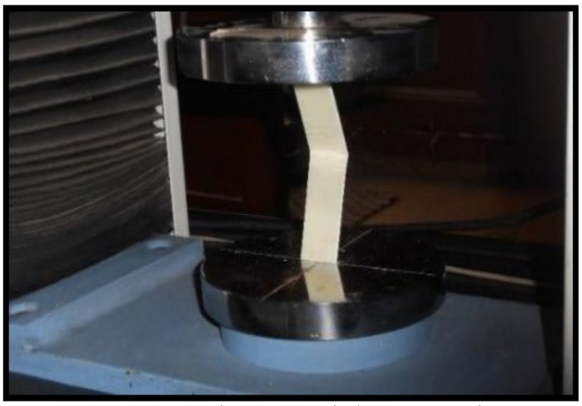

Fig. 2: Compression test carried out on specimen

The level of tensile stress that composites can sustain before breaking when bent is known as their flexural strength. The sample bends and cracks as pressure increases toward the centre of the frame. Rectangular composite sample specimens were subjected to the flexural test using Instron 1195 multifunction equipment and the ASTM D790 technique. The flexural test is performed on a 100 mm x 25 mm x 4 mm rectangular specimen compliant with ASTM D790 using a universal tester with a 3-roller deflection with a crosshead speed of 2 mm / min as exposed in figure 3.

Fig. 3: Flexural test carried out on specimen

Low-speed impact testing with instruments is performed on the composite samples. The energy used to break the V-notched specimen with a pendulum hammer is measured using the pendulum impact testing apparatus. This energy is related to its magnitude using the specimen's cross-section. Izod Impact strength tests are performed on 63.5 mm x 12.7 mm x 4 mm notched specimens according to ASTM D256-56.

3. Results

The density of composites, which is based on the proportion of matrix to reinforcing elements, is one of their key characteristics. Therefore, it is intended to employ Epoxy Resin (LY566) with hardener (HY951). The difference between anticipated and experimental densities is mostly caused by the presence of voids in the composite.

3.1 Tensile Test

A basic test called a tensile test involves placing a specimen under uniaxial stress until the material breaks. Uniaxial stress describes forces that are directed in different directions across the same axis and acting on opposite sides of a material. The tensile strength capabilities of glass fibre and carbon fibre are shown in Figure 4. It was observed that maximum stress handling capability is present in case of carbon fibre in every trial conducted during experimentation. Although both materials are much stronger than steel, industrial carbon fibre is almost 20% stronger than the finest fibreglass.

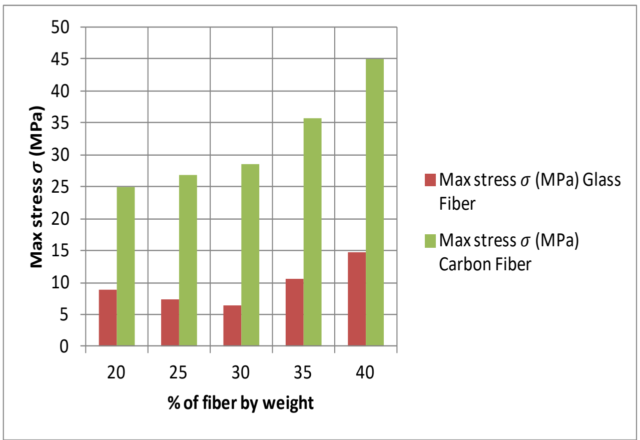

Fig. 4: Results of tensile test

3.2 Compression Test

In comparison to conventional composites, composites built from a mixture of materials offer higher levels of compatibility and dispersion, enabling greater stress transmission. Figure 5 reveals the results from compression test carried out with different specimens with varying percentages of fiber by weight. It was realized that carbon fiber is better than glass fiber considering the compression test. Carbon fibre is the preferable material for situations where stiffness and rigidity are critical since it is substantially less flexible than fibreglass. Tensile modulus of carbon fibre is four times that of fibreglass.

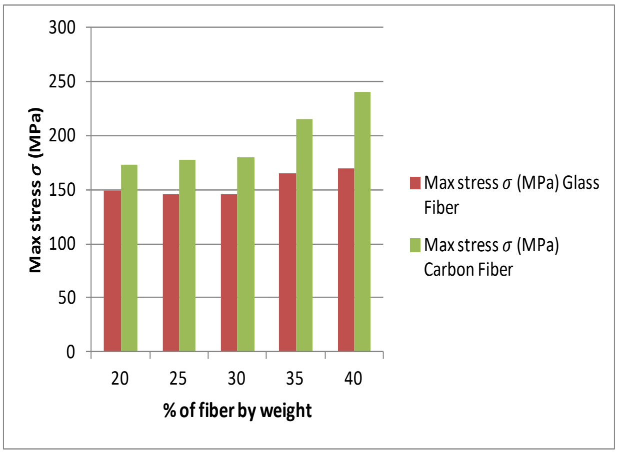

Fig. 5: Results of compression test

3.3 Flexural Test

Flexural strength, which can withstand a certain amount of tensile stress before breaking when bent, is a property of composite materials. The sample bends and cracks as pressure increases toward the centre of the frame. Rectangular sample specimens for the flexural test were collected using Instron 1195 standard equipment and the ASTM D790 technique. Results of the flexural test are shown in Figure 6. Further, It was predicted that as the percentage of fiber by weight increases, the carbon fiber shows better results as compared with glass fiber.

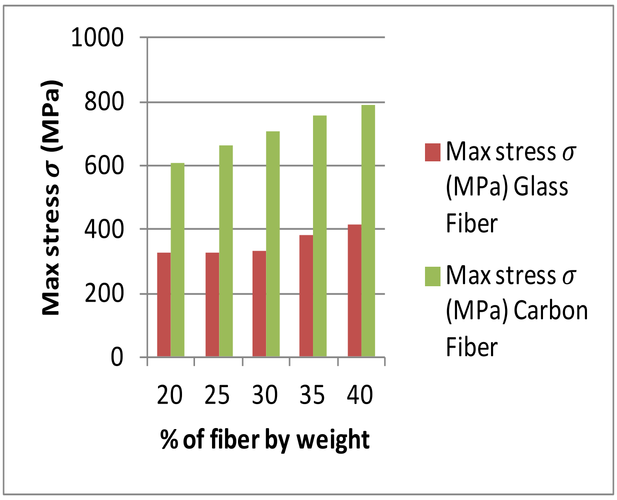

Fig. 6: Results of flexural test

3.4 Hardness Test

Hardness testing may be used to evaluate a properties of materials, such as strength, ductility, and wear resistance, as well as determine whether a material or material treatment is suitable for the purpose you need[16]. The results of hardness testing (BHN) are mentioned in figure 7. It was observed that carbon fiber are better than glass fiber and further, its hardness properties gets increased with increase in percentage of fiber as shown in figure 7.

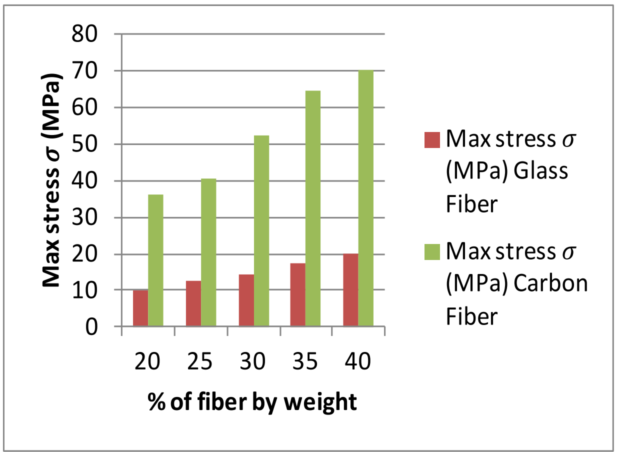

Fig. 7: Results of hardness test

4. SEM Analysis

An effective analytical method that studies a range of materials at high magnification and generates high-resolution pictures is scanning electron microscopy (SEM), often known as SEM analysis. SEM tests were performed on fabricated fiber-reinforced polymer composite samples. A tensile test was successfully accomplished, and the sample was examined using a scanning electron microscope. Fiber pull-out and poor interfacial adhesion to the composite cause sample failure. In order to better understand the failure process and adhesion at the fiber/matrix interface, impact fracture specimens are photographed using scanning electron microscopy[23]. SEM analysis with uneven fiber loading is as shown in figure 8.

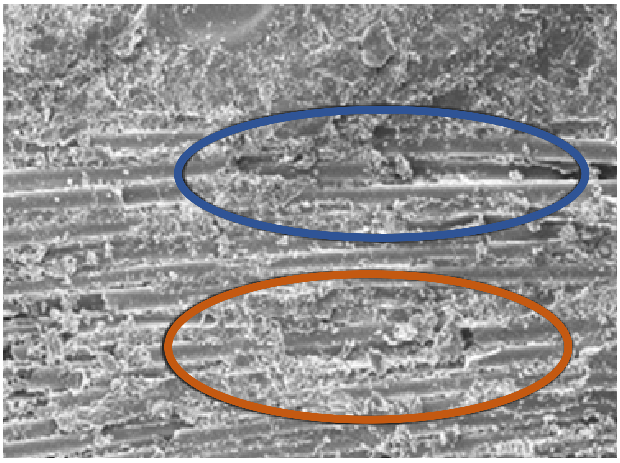

Fig. 8: SEM analysis with uneven fiber loading

Unmixed fibres were also detected and spread during testing owing to poor adhesion of fibres that were not effectively bound with the resin. Maximum resistive capacity is reached, resulting in enhanced fiber-to-fiber bonding and less fibre pull-out. SEM analysis with fiber pullout is shown in figure 9.

Furthermore, the strong stress field with indentation effects lead to fibre breakdown. Some fiber damage was noted in SEM analysis as shown in figure 10.

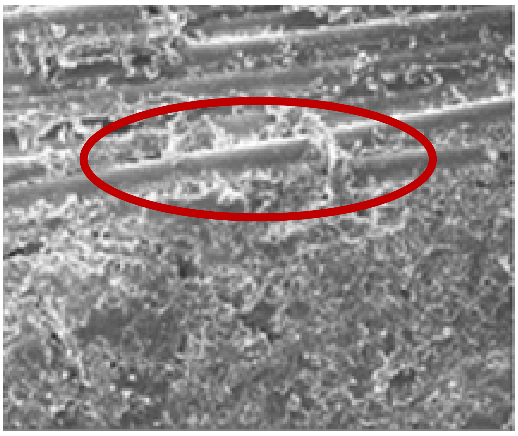

Fig. 9: SEM analysis with fiber pullout

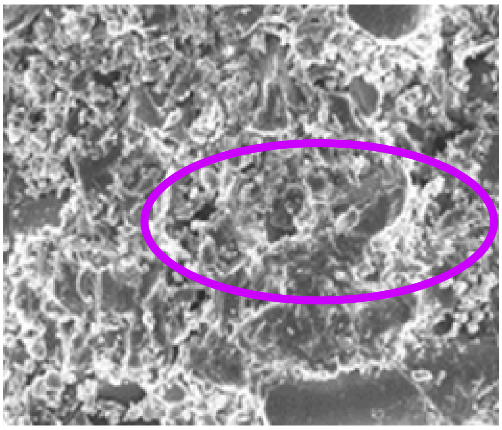

Fig. 10: SEM analysis with fiber damage

5. Discussions

The mechanical characteristics of the manufactured fiber-reinforced polymer composites, including impact strength, flexural strength, tensile strength, as well as hardness values, were experimentally evaluated. The purpose of this study is to compare the hardness of glass fiber reinforced composites with that of mesh fiber reinforced composites. Glass fibre is a commercial fibre that has been utilised in a variety of businesses, whereas nettle fibre is a natural fibre that is better for the environment. Due to their high specific strength and modulus, fiber-reinforced polymer composites have long dominated a wide range of applications. Natural fibres are the type of fibre used as reinforcement in reinforced polymers. With a rise in the fibre glass Vf of fibre weight fractions, the ultimate tensile and flexural strength of the fibre glass polyester composite improved[26]. The nature of material is very similar to the fibre glass material observed in case of our research.

The strong resistance to fracture propagation during the impact test is also attributable to the good adhesion between the fibre and matrix. If the fibres are properly impregnated into the resin, the increased fibre content will enhance the contact area between the fibre and matrix. The impact transfer should be more effective at increased fibre loading [10), 21)]. The most popular varieties of fibreglass typically only reach up to around 300 ksi in tensile strength, but carbon fibre may reach up to 500 ksi. The figure 11 shows comparative analysis of tensile strength for carbon fiber and glass fiber.

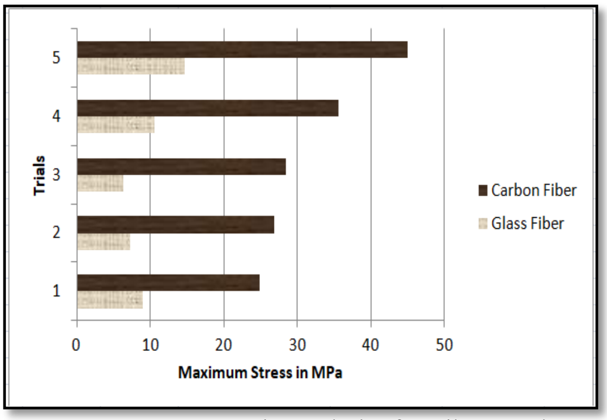

Fig. 11: Comparative analysis of tensile strength

However, industrial carbon fibre is more than 20% more robust than the best fibreglass, despite the fact that both materials are far more durable than steel. In comparison to fibreglass, carbon fibre has strength to weight ratio that is almost two times higher. Carbon fibre is a suitable material when a product has to be both strong and lightweight since it has similar stiffness and resistance to deformation as steel at a small fraction of the weight. For instance, in many aerospace applications, carbon fibre has taken the role of metal alloys, resulting in lighter and more fuel-efficient aircraft [9), 22)]. A popular choice for cycling and motorcycle helmets, carbon fibre provides steel-like protection in a lightweight compact. The comparative analysis of carbon fiber and glass fiber is shown in figure 12.

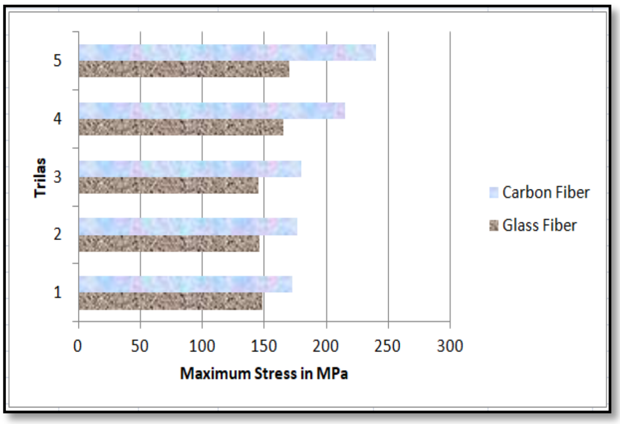

Fig. 12: Comparative analysis of compressive strength

Instron 1195 universality equipment and the ASTM D790 protocol were used to rectangular specimen materials for the flexural test. If the specimen is held transversely, the dimensions are 100 mm in length, 12.7 mm in breadth, and 4 mm in thickness. We loaded the cylinder at a rate of 2 millimetres per minute using a 10 kN load cell. Flexural tests, in which the specimen is exposed to compression, shear, and tensile stresses, are used to determine the materials' degree of flexibility. High flexural strength materials are brittle and rigid as shown in figure 13.

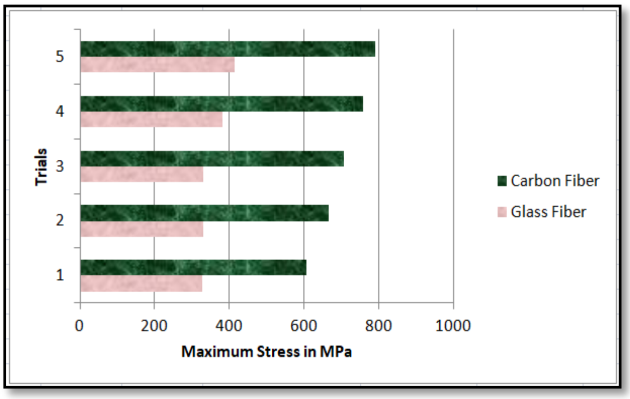

Fig. 13: Comparative analysis of flexural test

Some researchers looked at how the mechanical characteristics and morphology of bagasse meal/recycled polyethylene nanocomposites were affected by bagasse and nanoclay size[25]. Increasing the nanoclay concentration to 2% by weight increased the tensile and flexural strengths and modulus of the composites. They were then degraded by adding 4% by weight of nanoclay. On the other hand, the latter also reduces the notched impact strength of the composite. When compared to 60 percent glass fibre reinforced composites, the micro hardness of the 60 percent carbon fibre reinforced composites increases by 14.29 percent, while the micro hardness of the 30 percent glass fibre and 30 percent carbon fibre reinforced hybrid composite increases by 23 percent. The comparative results of carbon fiber and glass fiber are shown in figure 14.

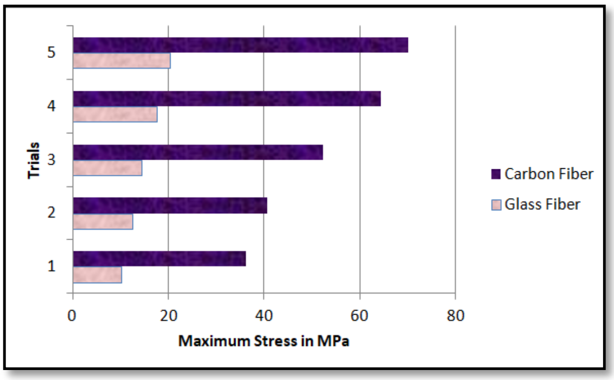

Fig. 14: Comparative analysis of hardness test

To achieve unique structural features, composite materials are created by mixing two or more components. The initial components of composites maintain some of their individuality[23]). It was found that the influence of fibre structure on mechanical characteristics during hybridization has great impact. The mechanical characteristics of hybrid composites differ according to the unique fibre structure as well as the weight/volume fractions of the component fibres [26]). In terms of the mechanics underlying the strength of carbon fibre, of course, we have only just begun to scratch the surface. With a remarkable strength-to-weight ratio and a wide range of practical uses, carbon fibre is a special and adaptable material. Strengthened with hybrid fibres Epoxy composite specimens with pure banana, pure glass, and hybrid fibres were created using different stacking sequences. On the mechanical characteristics, the effects of hybridization, stacking order, and alkali surface treatment were investigated[24]). The hybridization significantly improved the mechanical characteristics of the banana fibre composite, according to the experiment's findings. The stacking order had very little impact on the tensile strength; however positioning the woven glass fibre fabric at the extremities significantly increased its flexural strength and water absorption capabilities. The tensile strength of the banana fibre was increased by 27% as a result of chemical treatment [27]).

6. Conclusions

The hybridization significantly improved the mechanical characteristics of the fibre composite, according to the experiment's findings. By adjusting the amount of fibre by weight, a assessment of the mechanical behaviour of GFRP and CFRP composites is conducted in this work, and it is determined that the highest tensile strength of CFRP composite material is 240 MPa, and it can maintain that strength. The CFRP composite meets its maximum impact strength, which is 69.21 KJ/m2. The maximum flexural strength, as well as load-carrying capacity of the CFRP composite, is 796 MPa.

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