Mechanical Properties Evaluation of PMC's With Hybrid Reinforcement

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Abstract

To enhance the properties of composites composed of steel, ceramic, or polymeric elements, they can be reinforced with fibers, particles, or whiskers that serve the same purpose. Natural reinforcement has been proven to be the most efficient usage of the minimal quantity of effort required in PMC, which is required in lightweight applications. The presence and influence of the unidirectional fiber in the composites manufactured with an epoxy matrix have been the subject of a limited number of research that is being carried out. The purpose of this research is to create, evaluate, and assess a polymer compound composed of both natural and synthetic elements in various proportions by hand layup process. The hand-laying process is used to process the materials and several mechanical parameters are being evaluated to establish the fabric's capacity under various loads and operating situations. A blend of glass fibers, jute, and basalt fibers combination is selected for the polymer preparation.

Keywords: Lightweight Materials, Micro Hardness, Hand Lay-Up Process, Hybrid Reinforcement.

1. Introduction

A polymer is a material composed of large molecules connected by covalent chemical bonds that are composed of repeated structural pieces called monomers. Poly means "many" and mer means "parts" in Greek. Excellent resistance to corrosion, fatigue, impact damage, high strength/stiffness-to-weight ratios, and improved torsional stiffness are some advantages of PMC composite materials. One of the most basic and widely used polymers, polyethylene, has a typical polymer chain structure depicted in Figure 1.1. Polymers have a more complicated structure than ceramic or metal. They have a reduced modulus and strength which can withstand temperatures up to 250°C and are cheap and easy to process. Fibrous composites are frequently divided into two categories: single-layer and multilayer composites. Since uni-layer composites are actually made up of many layers, each with the same orientation and qualities, the entire laminate might be considered a uni-layer composite. Most fiber composites that are utilized in structural packages are multilayered, meaning they are made up of multiple layers [1-2].

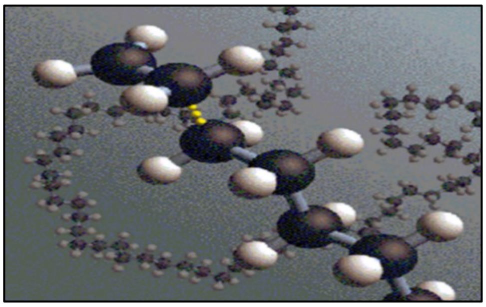


Figure 1.1. Typical Polymer Chain Structure

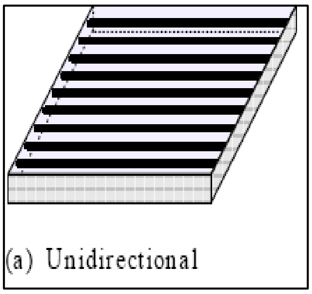


Figure 1.2. Fiber Orientation (Unidirectional)

The majority of the fibers in a unidirectional fabric, like the one shown in Figure 1.2, run in a single direction. The benefits of adopting unidirectional fiber fabric include high tensile strength and excellent impregnation qualities. Unidirectional fibers offer the best strength and stiffness along that axis since they are aligned in only one direction. Because of this, they are perfect for uses like aeronautical and automotive structures where the main load is anticipated to be directed in a certain direction [3].

Hybrid reinforcement in Polymer Matrix Composites (PMCs) refers to the use of more than one type of reinforcement material (fibers or fillers) in a single composite system to combine the benefits of each type of reinforcement. By combining different materials, hybrid composites aim to optimize the overall performance of the composite for specific applications, improving properties like strength, toughness, stiffness, or impact resistance [4]. Based on the review carried out, the following research gaps are identified:

- The mechanical properties of a thermoset matrix supplemented with natural fibers have been the subject of very few studies.
- There has been little research published on hybrid composites that blend glass and jute fibers.
- Researchers have done very little to examine how the mechanical characteristics of composites are affected by unidirectional fiber with epoxy matrix.
- The mechanical behavior of a thermoset matrix reinforced with unidirectional natural or synthetic fibers, has been the subject of minimal research.

2. Literature Review

Composites can now be produced utilizing techniques similar to those employed in traditional processing because of innovative composites processing. However, greater caution is needed when producing composites because different manufacturing processes can yield varying characteristics. Consequently, every composite that is created has distinct mechanical, chemical, and physical characteristics [5-6]. Because natural fibers may take the role of synthetic fibers, particularly in load-bearing applications. The profits of mutual forms of reinforcement are integrated into hybrid composites that have the joint qualities of synthetic and natural fibers [7].

The capacity of composites to combine contrasting elements that traditional materials cannot establish is one of their main advantages over conventional materials. Furthermore, lightweight materials with exceptional strength, thermal characteristics, and corrosion and wear resistance are needed for high-tech applications. These factors have inspired modern designers to create novel composite materials that adhere to stringent requirements for mass manufacturing. Numerous composite materials can be altered based on the intended use [8-9].

The kind of composite materials most frequently utilized in the automobile sector are polymer composites. Natural fiber-reinforced polymer composites are specifically used in passenger car door panels, instrument panels, headrests, armrests, seat shells, window frames, molded panel panels, bumpers, and floor protection [10]. Nameplates, rearview mirror panels, bicycle visors, seat coverings, indicator covers, and L-side covers have also been made from sisal and rosell fibers. In addition to load-bearing components like beams, roofs, multipurpose panels, water tanks, footbridges, mirror covers, paperweights, projector covers, mobile covers, helmets, and roofs are constructed from natural fibers and polyester composites. Transportation, economical military housing, interior housing components, temporary outdoor uses, and rehabilitation all make use of natural fiber composites [11].

Researchers have been motivated to create polymer matrix composites reinforced with natural fibers due to the abundance of natural fibers. The effective use of resources, especially natural materials, and their byproducts, is essential to global progress. Conversely, mechanical qualities like strength, flexibility, and resistance are absent from natural materials [12-13].

Natural fiber integration has also significantly improved material properties; as a result, the automotive industry is more interested in using the combined material. The methods used to process these materials are given more consideration. There are several techniques to create these composite materials, however the precise technique selected is mostly determined by the components selected. "Wet molding" techniques are frequently used in the production of polymer composites that are made in this manner using liquid resin. Pressure and climatic conditions typically speed up the curing process of produced composite in the hand layup process [14-15].

The goals of this study are to process, test, and analyze mechanical qualities that are assessed to determine how well they can tolerate different loads and operating circumstances. A composite material is created by combining polymer components with glass fibers, jute fibers, and basalt filler.

2.1 Objectives

Objectives of the present study which are taken from the literature review are listed below:

- Selection of matrix material and reinforcement with natural and synthetic fibres by hand layup process.
- Selection of composites are processed according by varying proportions of basalt and jute fibres (20%B + 10%J & 10%B + 20J).

- To create polymer composites with varying percentages of glass and jute fibres (20%G + 10%J & 10%G + 20J) are used.
- Sample preparation in accordance with ASTM standards and assessment of MP-processed composites under varied load conditions.
- Selection of best percentage of the material based on the mechanical properties results.

3. Experimental Work

This section explains the experimental work that will be done to accomplish the aforementioned goals after outlining the current study's goal.

3.1 Composite Processing

Composites strength and other characteristics, particularly their mechanical, chemical, and physical qualities, are determined by the materials (matrix and reinforcement) employed in their creation. The chosen materials must be easy to work with and possess acceptable machinability qualities. The following components (Figure. 3.1) were used for the current work's hybrid composite preparation: basalt fiber, epoxy, LY-556, Jute fiber and Hardner HY-951. Basalt is an environmentally acceptable bio-inert material that can be used at temperatures ranging from -269°C to 650°C. Its resistance to oxidation, radiation, compressive strength, and shear strength are enhanced. In the industry, fiberglass is a widely recognized and accessible material. It was created from silicon dioxide-containing chemicals.

Figure 3.1. Reinforcing Materials

3.2 Preparing the Sample

The composite laminate samples are prepared for mechanical property evaluation following manufacture. Experiments are prepared in accordance with a number of standard prescribed by American Society for Testing and Materials (ASTM).

3.3 Test of Hardness

It can be defined as the ability of a material to withstand indentation. Vickers hardness micro tester is being used to determine the hardness of the processed material as per ASTM D2583 standard (Figure 3.2). All tests assess the fibre-reinforced plastic composites' resistance under continuous pressure.

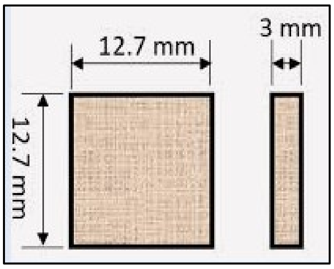


Figure 3.2. Hardness Test Sample

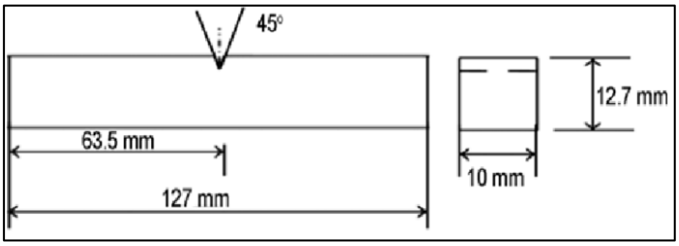


Figure 3.3. Hardness Test Sample for ASTM D256 Standard

For ASTM D2583 standard

3.4 Test of Impact

Impact tests aid in evaluating the material's behavior and toughness under increased strain rates. Crash testing comes in two varieties: drop weight and pendulum. Charpy and Izod are the two most widely utilized assessment methods. The Charpy impact test is employed in this investigation to ascertain the impact strength of a complicated material in accordance with ASTM D256 (Figure 3.3) [16].

3.5 Tensile Examination

Tensile testing evaluates a material's performance and behavior after it has been strained beneath load. The UTS, fracture strength, and fracture strength of the material are all included in the tensile test data. The manufactured sample material measures comply with ASTM D638-04 (Figure 3.4). The tensile strength of the material is evaluated on samples, and typical findings are found.

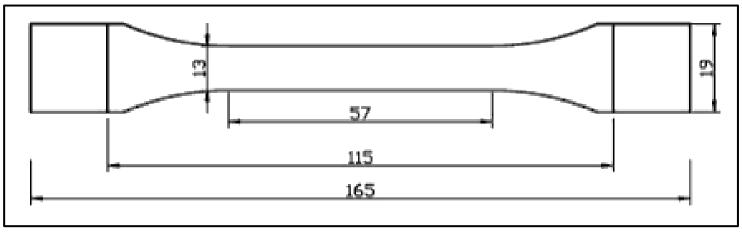


Figure 3.4. ASTM D638-04 Tensile Sample Dimension

3.6 Weight Percentage Calculation

The weight percentage (wt %) in PMCs refers to the proportion of each material (fibres, matrix, and any other reinforcements or fillers) in the composite, expressed as a percentage of the total weight of the composite. The weight percentage of each component in a composite is calculated using the following formula:

$$\text{Weight Percentage (Wt \%)} = \frac{\text{Weight of component}}{\text{Total weight of composite}} * 100$$

Total weight of the composite selected is 120g, for the 1st laminate L_1, 12g Basalt, 24g Jute and 84g epoxy is selected (12+24+84 = 120g). Converting the weight percentage to volume percentage, Basalt is 10% (12/120 =10%), Jute is 20% (24/120=20) and Epoxy is 70% (84/120). Similar weight percentage was calculated for the other composite laminates also.

3.7 Composite Material Processing Steps: The Detailed Procedure is as Follows

- Initially, a Teflon sheet is placed over a glass plate that serves as an open mold on a smooth table. In order to keep the laminate from adhering to the mold.
- The Teflon sheet was covered with a thin coating of wax polish, which serves as a releasing agent. The resin was made by combining epoxy (LY556) and hardener (HY951) in a 10:1 weight ratio.
- The bottom layer of fibre, cut to the proper ply angle and dimension is laid over the thin coating of matrix material (resin) that was applied with a brush to the mold surface.
- To eliminate air bubbles and voids, a suitable metal roller is rolled over the fibre layer to evenly distribute and sweep off the surplus resin.
- The fibre is sufficiently wetted by the resin coating before the subsequent layer is applied.

- Until the top layer of the laminate was piled, the previous two stages were repeated.
- The top surface of the laminate was covered with a glass plate (top mold) and another Teflon sheet that had been wax-polished.
- The laminate undergoes gelation and solidifies after being left to cure in ambient conditions for a full day.

4. Results

Testing is done on the processed materials to assess their mechanical and microstructural characteristics. The results of testing the glass-jute hybrid composite with a various test are discussed in this section.

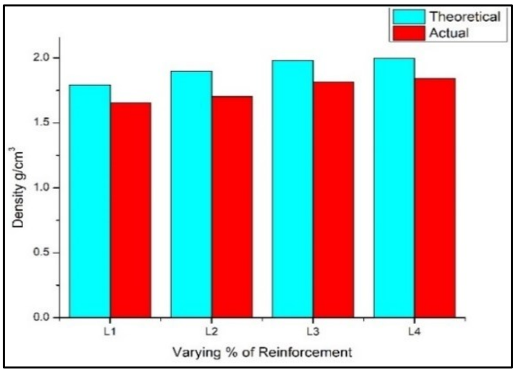


Figure 4.1. Density of Various Laminates

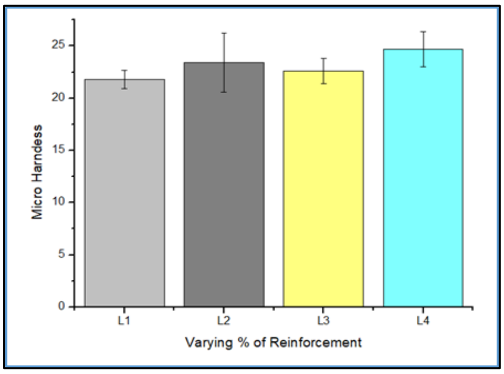


Figure 4.2. Hardness of Various Laminates.

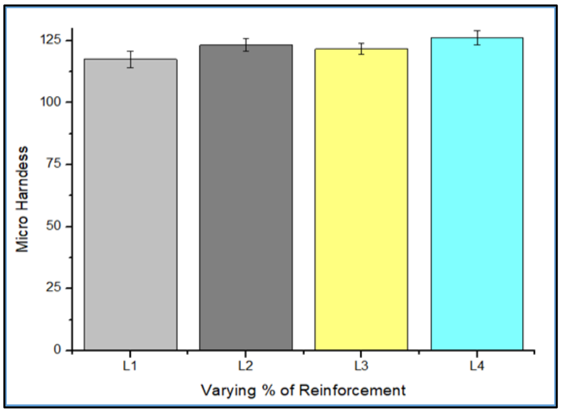


Figure 4.3. Impact Strength of Various Laminates

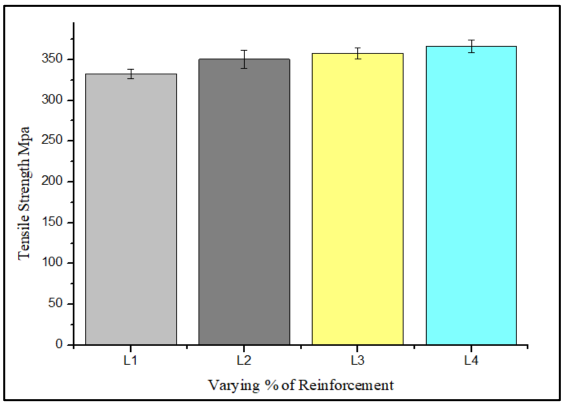


Figure 4.4. Tensile Impact Strength of Various Laminates.

4.1 Density Test

Table 4.1. Matrix and Reinforcement Weight Percentage

Sl.No	Laminates	Hybrid	Basalt (B) Wt %	Jute (J) Wt %	Glass (G) Wt%	Epoxy Wt%
1	L1	Bsalat+Jute	10	20	-	70
2	L1	Bsalat+Jute	20	10	-	70
3	L3	Basalt+Glass	10	-	20	70
4	L4	Basalt+Glass	20	-	10	70

Table 4.2. Porosity measurement

Sl.No	Laminates	Theoretical Density g/cm3	Actual Density g/cm3	Porosity
1	L1	1.792	1.654	7.70
2	L1	1.897	1.702	10.28
3	L3	1.981	1.813	8.48
4	L4	1.998	1.844	7.71

Trials are conducted to ascertain the material's actual density by comparing the weights of the samples of size 1inch which are placed in air and water. The difference in their weights are used to calculate the actual density of the material and rule of mixture is used to determine the theoretical density. Table 4.1 shows the materials percentage selected for processing; Table 4.2 indicates the porosity details obtained during processing. Figure 4.1 shows the variation in the density of the materials. The theoretical and the actual density are similar in nature but the actual density is found to be less compared to theoretical density due the presence of the porosity which evolves during the processing of the material. Because of the difference between the theoretical and real densities, the results show that a very little amount of porosity does present throughout the processing of the polymer material. The entrapment of gas bubbles during processing or an incorrect distribution of fibres inside the matrix material are the cause of the porosity. Because of the weak areas at the agglomerated spots, the porosity affects the material's strength. A weak spot caused by the development of a porous structure or agglomerated points causes the material to break under light loads and has a short lifespan. If the ratio of basalt to jute is high, the density of the composite will tend to be higher, as the heavier basalt takes precedence over the lightweight jute. Therefore, depending on the amount of basalt in the composite, the resulting material's density can be higher than that of pure jute but still lighter than pure basalt. Similarly, the higher density of basalt usually outweighs the slightly lower density of glass. As a result, the overall density of the composite material will be higher than that of pure glass but could still be slightly lower than pure basalt, depending on the specific proportions of each material in the mixture.

4.2 Micro Hardness Test

Hardness can be measured through indentation resistance. Hardness is frequently assessed using a constant indentation depth. Fiber arrangement and volume fractions are frequently the main factors that determine the quality of a composite. There is a clear correlation between volume fraction and hardness, High volume fraction and high hardness are correlated and vice versa. The matching hardness values for the same quantity of epoxy and reinforcing components are displayed in Table 4.3. Hardness of processed materials were measured using Shore-D, Barcol and Vicker's micro hardness tests. A load of 10 kgf is applied gradually during the test on the surface of the sample.

Table 4.3. Micro Hardness with SD

Sl.No	Laminates	Micro Hardness	Standard Deviation
1	L_1	21.82	0.87
2	L_1	23.39	2.82
3	L_3	22.62	1.21
4	L_4	24.67	1.69

The hardness features of the various composites are displayed in Figure 4.2. It is evident that as the percentage of the reinforcing component increases, so does the composites' hardness. Combining glass and jute fibres increases the material's strength and hardness by distributing the test load among the fibres and minimizing the test indenter's penetration through the composite material's surface. Since epoxy's low hardness will result in decreased strength, so glass fibres are added to composite materials to increase their resistance to indentation. Jute fibres follows the same pattern of strength enhancement but are little bit lesser due to their lower density compared to glass.

4.3 Impact Test

The capacity of a material to absorb energy is measured by its toughness. The samples were first cut from the composite panels and then they were completed to size. The samples were secured vertically and then broken by a single pendulum swing.

Table 4.4. Impact Strength with SD

Sl.No	Laminates	Impact Strength (J)	Standard Deviation
1	L1	117.50	3.41
2	L1	123.25	2.5
3	L3	121.75	2.21
4	L4	126.25	2.75

Impact test helps to evaluate the toughness of the material behavior at higher deformation speed. The material's toughness is being measured using impact tester, the impact strength values of glass fibre and jute fibre composites are displayed in Figure 4.3 and Table 4.4. Compared to glass and basalt fibres, the impact strength rate of the material which includes jute and basalt fibres are lower. Basalt and glass fibres are stronger and more rigid, which increases their capacity to absorb impact energy. The primary cause of the strength decreases which results in less energy absorption is the jute fibre's decreased stiffness and strength. However, because of their greater resistance to the spread of stress, the basal fibres demonstrated resilience to the impact. One may see a discernible increase in strength as the amount of basalt fibre increases.

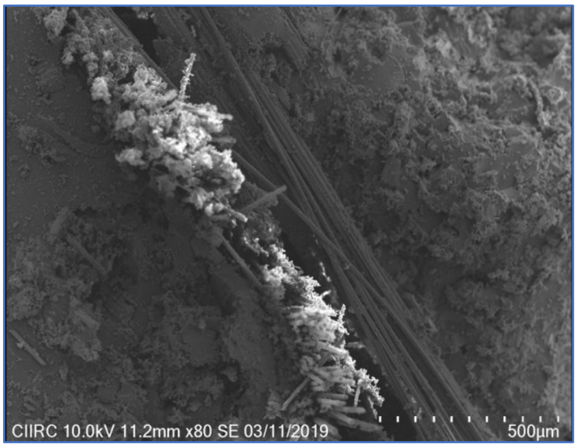
4.4 Tensile Test

Ultimate tensile strength, breaking strength and maximum elongation strength are among the details provided by a tensile test. The produced specimen material has dimensions of 165 x 19 x 3 mm and is made in accordance with ASTM standard D638-04. Specimens are tested and average values are taken to measure the tensile strength of the material, the two main factors that determine a composite material's tensile strength are its fibre content and strength. Thus, it is evident that variations in fibre loading affect the strength of composites. Tensile test findings indicate that the composite material's tensile strength increases with the number of fibres. The impact of fiber loading on modulus and tensile strength is displayed in Table 4.5.

Table 4.5. Tensile Strength with SD

Sl.No	Laminates	Tensile Strength (Mpa)	Standard Deviation
1	L1	332.85	5.80
2	L1	350.29	11.08
3	L3	357.95	6.71
4	L4	365.85	7.78

The UTS of the materials is displayed in Figure 4.4, it can be noted from the results that as the fibre content increases, and the tensile strength also increases correspondingly. It's evident that adding fibres improves the tensile strength of basalt/glass hybrid composites because the densities of glass and basalt fibres are substantially higher than those of jute and basalt fibres. Because the two types of fibres adhere to the matrix properly, the tensile strength of the composite grows steadily as the weight % of fibres increases. Fibre hybridization, which is primarily caused by shear and stress transmission between fibres, greatly boosted the tensile strength as compared to individual reinforcement. Shearing and load transmission between the fibres are the primary causes of this. This demonstrates that having more fibres along the load's path prevents the material from deforming and gives it the strength to withstand the load before failing. The results of the SEM analysis of the tensile samples performed both before to and during the tensile test are shown in Figure 4.5. These microstructural characteristics are the crucial component that shows that the presence of reinforcement materials is improving the materials' qualities. It is clear that the reinforcing elements are affixed to the matrix material and that the fibre alignment is parallel to the loading direction. The fibreglass-basalt composite's tensile strength was enhanced by the stiff fibrous material in the matrix. The fibre



pull out, voids are also specified in the SEM images which proves the justification given.

(a) Before Failure (b) After Failure

Figure 4.5. SEM of Tensile Sample (Basalt+Glass)

5. Conclusion

The conclusions of the present investigation carried out on the processing and testing of hybrid polymer composites are listed below:

The laminate processing technique of hand lay-up is being used to successfully process polymer composites with Glass, jute and basalt with different percentages of reinforcement. The presence of fibre components that aid in obtaining strength along the fibre direction is indicated by the SEM of the composite with basalt and glass. According to the density test, the existence of porosity weakens the material because of the weak spots at the agglomerated points. A weak spot caused by the development of a porous structure or agglomerated points causes the material to break under light loads and have a short lifespan. The strength is increased because the test load is divided among the glass and basalt fibres. This also raises the material's hardness and decreases the test indenter's penetration into the created composite material's surface. Reinforcement boosts a material's tensile strength in the same way that it raises its hardness. When there are more fibres pointing in the direction of the load, the material resists deformation and becomes stronger to support the load before failing. The strong interfacial contact between the fibres and the epoxy, which eliminates any spaces between the fibre and the matrix and functions as a mechanical bond between the glass, jute, or basalt fibre and the epoxy, is what causes the increase in tensile strength. Both the power and the coefficient of friction will rise as a result.

The future work can be carried out with varying the percentage of the composition, material and processing technique with reference to the specific applications.

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