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Evaluation of Impact Strength and Hardness for Polymer Matrix Composites with Steel, Carbon and Glass Reinforcements for Automotive Applications

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Abstract

Polymer matrix composites (PMCs) play a crucial role in a wide range of engineering submissions, owing to their impressive strength-to-weight ratio and customizable mechanical properties. This research focuses on examining how PMCs, enhanced with different materials, specifically carbon fibres, glass fibres, and steel fibres, behave when subjected to dynamic and static loading conditions. The study involves creating three distinct types of PMC specimens, each reinforced with one of the mentioned fibres. To comprehensively gauge their performance, Charpy impact tests was conducted to assess the material's resilience to sudden dynamic loading. Moreover, hardness tests, including Vickers and Rockwell hardness tests are carried out to evaluate the material's aptitude to withstand static loading and deformation. The findings of the experiment reveal that the carbon composite, as manufactured, displays promising characteristics with an impact resistance of 18 Joules and a hardness of 31 HV.

Keywords: Polymer matrix composite; carbon fibre; glass fibre; steel fibre; impact test; hardness test

INTRODUCTION

Composite materials play a crucial role in modern engineering, providing a distinct blend of qualities that may be tuned to specific applications. [1]. Among the myriad options available, carbon fibre, glass fibre, and steel fibre composites stand out as key contenders, each possessing distinct characteristics that cater to diverse needs [2]. The fabrication of these composites involves intricate processes, where fibres are strategically arranged and embedded within a matrix material to create a synergistic material with enhanced mechanical properties [3]. Carbon fibre composites are well-known for their remarkable strength-to-weight ratio and high rigidity, making them perfect for applications in aerospace, automotive, and sports equipment [4]. The fabrication typically involves impregnating carbon fibres with a polymer matrix, creating a material that exhibits superior tensile strength and resistance to corrosion [5].

Glass fibre composites, on the other hand, offer a more cost-effective solution with good strength and flexibility [6]. The fabrication process involves weaving or aligning glass fibres within a matrix, often composed of resin. This results in a composite that finds applications in the construction, marine, and automotive industries, where a balance between performance and cost is crucial [7]. Steel fibre composites, are characterized by their toughness and durability, and are manufactured by adding steel fibres to a matrix material such as

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concrete. This reinforcement enhances the material's resistance to cracking and impact, making it suitable for applications in infrastructure, such as bridges and buildings [8].

Following the meticulous fabrication processes, it is imperative to assess the performance of these composite materials through hardness and impact tests. Hardness tests gauge the material's resistance to indentation or penetration, providing insights into its strength and durability [9]. Impact tests, on the other hand, simulate real-world scenarios where the material may experience sudden forces [10]. By subjecting the fabricated composites to such tests, engineers can evaluate their ability to withstand external forces and make informed decisions about their suitability for specific applications.

Thus, in this research, the fabrication and comparison of carbon fibre, glass fibre, and steel fibre composites represent a crucial aspect of materials engineering. Through a thorough understanding of their unique properties and performance under various tests, engineers can select the most appropriate composite material for a given application, ensuring optimal performance and longevity in diverse industries.

LITERATURE SURVEY

[11] Anurag Namdev employed manual layup techniques to assess the mechanical and physical characteristics of laminates made of graphene nanoplatelets (GNP)-filled carbon fibre/epoxy composites (A-1, A-2, and A-3) and plain carbon fibre/epoxy composite (A0). A-2 composites outperform A-0, A-1, and A-3 composites in terms of Rockwell hardness, tensile, flexural, shear, and impact strength. The composite samples A-2 and A-0 exhibited an 18% increase in flexural strength, while the highest tensile strength was reached at 0.5 weight per cent of GNP (A-2), 11% higher than a-0. Using field emission scanning electron microscopy (FE-SEM) to assess morphological features, A-2 composites showed lower void content than other hybrid composites.

[12] T. Varun Kumarsay Composite materials consist of becoming progressively essential in a variety of industries, including automotive and aerospace. Because of their lightweight and similar strength-to-weight ratio, carbon fibre powdered reinforced polymer composites are ideal for pump impellers. Researchers discovered that carbon fibre has superior corrosion resistance and is an excellent material for certain applications. A die is used to create the composite plate, a weight ratio calculation is performed, and specimens are cut by ASTM requirements for tensile, flexural, and impact tests. Liquid penetrates non-destructive testing and ultrasonic non-destructive testing are used to anticipate crack formation and thickness variation. The composite material outperforms iron, metals, and physical steel in terms of ductile, flexural, and impact strength. The finished product is intended for use on pumps and Impellers.

[13] Flaviana CalignanoIn recent years, 3D printing has grown in popularity, with researchers concentrating on in-house filaments for fused filament fabrication FFF. Printed polymer pieces, on the other hand, have limited mechanical qualities and utility. This research looks at the mechanical characteristics of items made from carbon fibre-reinforced nylon filament using a low-cost printer. The outcomes demonstrate that the obtained values differ significantly from those on the datasheets of the filament providers. Thermal strains, infill percentage, and structure orientation all affect the tensile strength and durability. while building direction influences resilience. Mechanical characteristics and filling factors have a nonlinear connection.

[14] K Gajalakshmi The mechanical, corrosion, and fatigue properties of an aluminium metal matrix composite—which is made by reinforcing 4% carbon fibre (CF) coated in nickel and copper—are examined in this work. The composite is contrasted with coated CF-reinforced composites and cast alloy composites; the CF-coated composite exhibits better properties. The tensile strength of the Cu-coated CF composite was found to be 15.36% greater than that of the as-cast alloy and 2.55% higher

than that of the Ni-coated CF-reinforced composite. Additionally improved were Micro-Vickers impact strength and hardness. In comparison to as-cast and Ni-coated CF reinforced compositions, the corrosion rate was reduced by 59.72% and 23.23%, respectively, when 4%Cu coated CFs were added to AA6026.

[15] Ali Sinan Dike This study looked into the mechanical characteristics of composites containing polyamide (PA), isocyanate, and jeffamine coatings on short carbon fibres (CF). Using infrared spectroscopy, the CF samples were verified. We next used a melt-compounding technique to integrate the CFs into PA6. Tests were performed for shore hardness, tensile strength, dynamic mechanical analysis, and melt flow rate. The CF's robust adherence to the polymer matrix was validated by SEM examination. According to the study, the Surface-coated carbide fillers increased the tensile strength, tensile modulus, per cent elongation, and shore hardness of unfilled PA. The glass transition temperatures of the composites containing CF were found to be higher than those of the unfilled PA. The addition of CF had no negative effects on the MFR of PA.

[16] K. Umanath in this paper, carbon fibre and pineapple leaf fibre composite materials are used to create and analyse parabolic leaf spring plates. Because of its high strength-to-weight ratio, resistance to corrosion, and adaptable qualities, composite springs are being considered by the automotive industry as a potential replacement for steel spring plates. Three layers—carbon fibre mat, epoxy or polyepoxide, and pineapple fibre mat—are used in the open moulding process to create the spring plates. Carbon fibre and pineapple leaf fibre composites are stronger and lighter than epoxy glass springs, according to comparisons between glass fibre reinforced leaf spring plates and composite fibre leaf spring plates. Without sacrificing strength or structural weight, viable substitutes for metallic leaf spring plates are found.

[17] M. Ajay Kumar The objective of this study is to optimize machine parameters and assess the mechanical strength of PETG thermoplastics reinforced with carbon fibre. Nine pairs of flexural and tensile specimens were produced by ASTM standards, using variables including layer height, print speed, and infill density that were chosen for 3D printing. The outcomes were optimized using the Taguchi L9 experimental methodology. The ideal values for hardness, flexural strength, and tensile strength were 67.0011 BHN,

31.567 MPa, and 35.045 MPa, respectively. The machine's ideal settings were 200 l layer height, 60 mm/sec, and 80% infill density. When choosing the occupied ranges for 3D printing PETG material for various requests, these optimal values might be helpful.

MATERIAL AND METHOD

A detailed study was carried out in selecting the material for the preparation of composite material. The process parameters were highlighted, which are major influencing parameters in the properties evaluation. From the study, the hand layup method is suitable for this material preparation for economic viability.

Hand Layup Method

Hand lay-up stands out as the fundamental method in composite processing, characterized by its minimal infrastructure demands. Fig. 1 below shows the of hand lay-up setup, the procedural steps are uncomplicated: initiating with the application of a release gel onto the mould surface to prevent polymer adhesion. Subsequently, reinforcement, as an example of woven before chopped strand mats tailored to mould size, is placed on a surface. Liquid next, a thermosetting polymer is thoroughly varied with a designated hardener, poured onto the mat-covered surface, and evenly spread with a brush. A subsequent layer of the mat is added, and a gentle rolling motion with a roller ensures the removal of trapped air and excess polymer. This process iterates for each layer until the required stack of polymer and mat layers is achieved. Following curing the formed composite component is taken out of the mould and sent for additional processing when it reaches room temperature or a predetermined temperature. In comparison to alternative methods, hand lay-up boasts lower capital and infrastructure requirements. However, it is acknowledged that the production rate in processed composites is slower, and achieving a significant volume proportion of reinforcement presents challenges. In this work, epoxy resin with 11,250 mPaS viscosity and 1.17 g/cm^3 density was used. Room temperature was maintained throughout the experiment and 24 hrs was given as curing time for each laminate.

Fabrication Process

This section employed the hand layout approach to delve into the production of composite materials. The diagrams illustrating the materials required are depicted in Figure 2 and Figure 3. The necessary materials for the fabrication procedure are outlined below:

1. Bi-Directional Carbon Fabric (420 gsm)
2. Bi-Directional Glass Fabric (420 gsm)
3. Bi-Directional Steel Mesh
4. Epoxy Resin (LY 556)
5. Epoxy Hardener (HY 951)
6. Wooden Mould
7. Wax Polish (Releasing Agent)

Fabrication of PMC

Workstation preparation

An essential practice in working with composites involves prepping all the necessary materials and tools in advance. This is primarily because, once the resin and hardener are mixed, the timeframe during which the mixture can be utilized before it starts to gel is limited by the speed at which the hardener undergoes a chemical reaction with the epoxy, resulting in an exothermic reaction [2]. Additionally, as part of the initial preparation, the woven fabric must be carefully cut to align with the shape of the intended part.

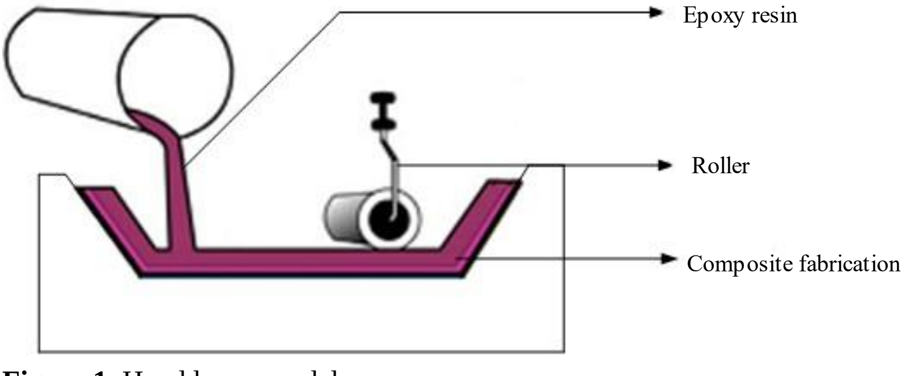

Figure 1. Hand layup model.

Figure 2. Steel, glass and carbon fibre.

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LY556 Resin HY951 Hardener Univax

Figure 3. Resins and hardener used in fabrication.

Mould preparation

Before commencing the lay-up procedure, it is crucial to properly prepare the mould. This preparation primarily involves cleaning the mould thoroughly and applying a release agent to its surface to prevent the resin from adhering. In the context of this experiment, the mould preparation involves securely taping plastic sheeting to the tabletop [3-4]. Alternatively, the mould can be cleaned using the techniques outlined below.

- Wipe the mould clean using a fresh cloth.
- Apply and evenly distribute the release agent on the mould's surface.
- Allow sufficient time for the release agent to set.
- Polish the surface with a clean cloth.

Lay-up process

The initial step involves combining the resin and hardener by the specified ratios provided by the supplier, which are usually indicated on the containers of the resin and hardener. This mixing process should be performed diligently with a mixing stick inside designated containers to prevent the introduction of excessive air bubbles into the resin. To ensure thorough mixing, take two minutes to mix slowly before applying the epoxy. Create the epoxy mixture using a 100:10 ratio, where 10% of the hardener, matched by the same weight of cloth as the resin, constitutes 100% of the mixture. Once the fabric is positioned at the base, apply the epoxy mixture onto the fibre layer and add a layer of fibre on top. Repeat this procedure until four layers of fibre sheet are securely in place [5]. Finally, apply weight to the produced material to facilitate solidification.

Curing

The curing process for the component can be accomplished either at room temperature or through the use of an oven set at high temperatures. The supplier usually provides information on the containers regarding the recommended working duration and curing time for each specific resin-hardener combination. In this experiment's context, using an epoxy resin system requires only room-temperature curing, making it a suitable and convenient option [6].

Cleaning

Once the component is ready for the curing process, it must be transported to the designated location. There are two options at this point: transfer it to a curing oven or allow it to cure in its current position until the following day. Following the curing process, a clean-up is essential. It involves wiping down the worktable using acetone and a towel after utilizing all the tools, such as brushes, rollers, mixing tools, and scissors [7].

MECHANICAL TESTING

Mechanical and physical testing of polymers and their composites is essential to guarantee the compatibility of materials for product design, quality control, application performance, and production processes. This testing is essential to verify whether the material meets the industry's performance standards, especially in aerospace, automotive, consumer goods, medical devices, and defence sectors. The evaluation process involves subjecting the material to various mechanical and physical tests. For polymer composites, mechanical testing focuses on key characteristics like strength and stiffness to assess their potential application in structural design. Standardised mechanical tests that are frequently performed on polymer composites include impact, flexural, tensile, and hardness testing.

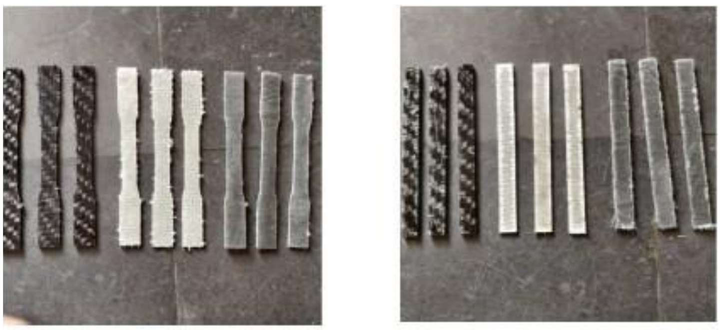
The fabricated composite material is cut into shapes that adhere to ASTM standards to perform these tests. The cutting process is executed using a CNC machine, as depicted in the accompanying Figure 4 showcasing an ASTM testing sample being prepared through CNC machine cutting. This rigorous testing and adherence to standards ensure that the materials used in various industries meet the required specifications and performance criteria.

Impact Test (ASTM D 256)

One technique for evaluating the toughness and impact resistance of materials, especially composite materials, is the Charpy impact test. Before it fractures, a notched specimen is subjected to a quick, high-force impact to gauge how much energy it has absorbed. This test is particularly useful for assessing materials' behaviour under sudden, dynamic loading conditions. The specimen size is crucial for obtaining meaningful results, with a common size being 10 mm in width, 10 mm in thickness, and 55 mm in length. As shown in Figure 5 a fluctuating pendulum is released from an exact height to strike the notched part of the specimen, causing it to fracture. The energy absorption during the fracture is recorded by Charpy impact test machine, which is a crucial indicator of the material's toughness. The notched part is intentionally introduced to create a stress concentration, simulating a real-world application where a flaw or notch might be present. An analysis of the fracture surfaces, including the presence and size of cracks, is used to determine the composite material's impact strength.

Hardness Test (ASTM D 785)

Hardness testing is a crucial method employed to assess the mechanical possessions of resources, and case of composite materials, Vickers Hardness machine is often utilized for this purpose. Composites, which consist of two or more distinct materials with different properties, present unique challenges in terms of evaluating their hardness. The Vickers Hardness test involves applying a controlled force through precisely shaped diamond indenter into surface of the material, creating a square-shaped impression. In the context of composite materials, the Vickers Hardness machine allows for a localized examination of specific regions within the composite, providing insights into variations in hardness across different constituents. This method is particularly valuable in assessing the homogeneity and integrity of the composite structure. Moreover, it aids in identifying potential weaknesses, discontinuities, or variations in hardness that could impact the overall performance of the composite material in real-world applications. By employing the Vickers Hardness machine, engineers and researchers can make informed decisions about the suitability and durability of composite materials in various industries, including aerospace, automotive, and construction. The figure 6 shows the impact testing of ASTM D 785.



Samples after machining

Figure 4. ASTM standard specimen for testing.

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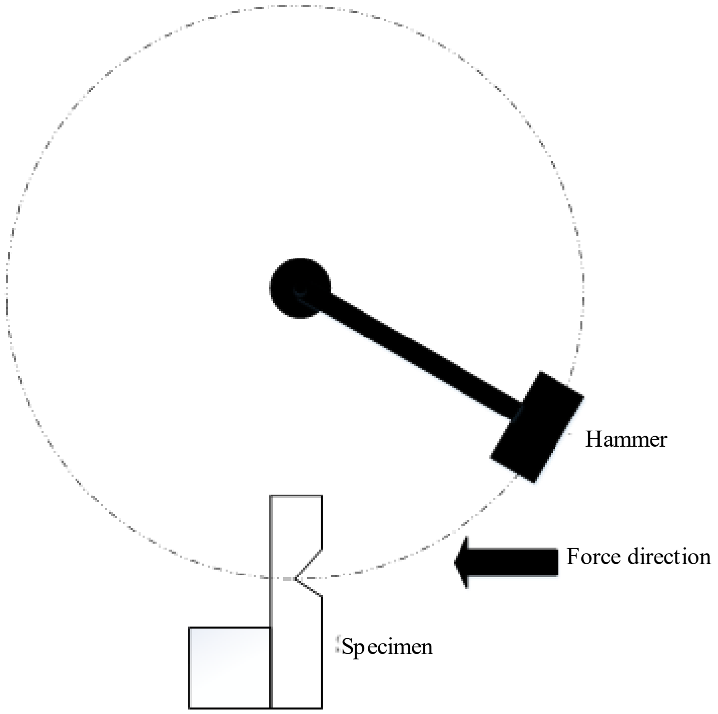

Figure 5. Impact testing.

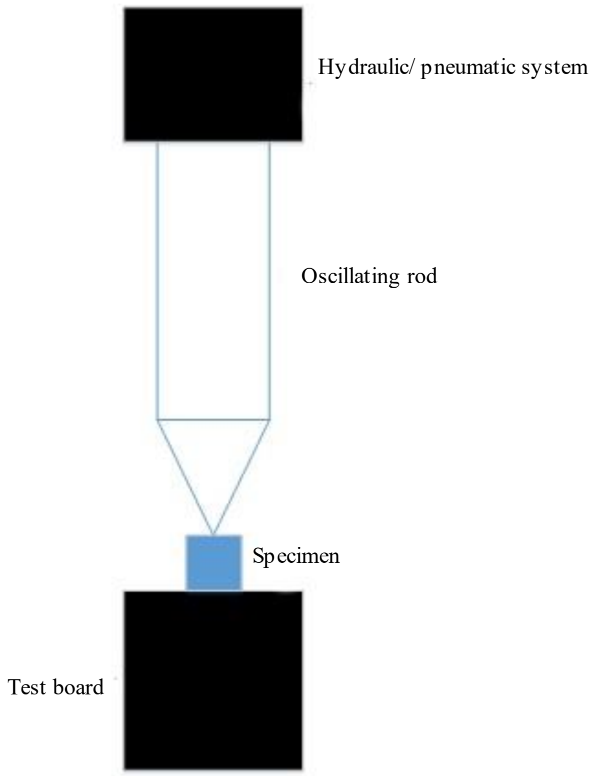

Figure 6. Hardness testing.

RESULTS AND DISCUSSION

Impact Test (ASTM D 256)

In this region, the Impact test was performed utilizing the Charpy impact equipment. The composite material was initially prepared by the ASTM standards specified to do the Impact test. The example was subsequently meticulously cut to the testing size, adhering to the guidelines outlined in ASTM Standards, as illustrated in figure 7.

Impact testing for carbon glass and steel PMC

The greatest impact stress that a material can withstand before failing, such as yielding (in the case of ductile) or breaking (Brittle) is impact strength [10]. Table1 displays the measured Impact strength of all the prepared samples (steel, glass, and carbon)

Three specimens for each material were tested, and the energy absorption (in joules) during the impact test was recorded. For carbon specimens, the energy absorption values were 14 J for Specimen 1, 18 J for Specimen 2, and 14 J for Specimen 3. On the other hand, glass specimens exhibited energy absorption values of 10 J for Specimen 1, 8 J for Specimen 2, and 10 J for Specimen 3. Lastly, all the three steel specimens recorded 4J energy absorption. The results highlight the varying impact resistance of the materials. Carbon specimens exhibited the highest energy absorption, with Specimen 2 showing the maximum value. Glass specimens displayed moderate energy absorption, while steel specimens consistently demonstrated the lowest impact resistance among the tested materials. These findings provide valuable insights into the materials' performance under impact conditions, aiding in the assessment and selection of materials for specific applications based on their impact-resistant characteristics. From the graph shown below it is been clear that the tensile strength of the carbon remains relatively advanced than glass and steel matrix composite. The Figure 8 shows the result of the impact testing for Carbon Glass and Steel PMC. This gives scope for attempting for hybrid composites, with carbon as one of the fibres to have more impact strength, for applications in automotive industries.

Hardness Test (ASTM E 384)

In this section, the Vickers Hardness test was conducted using the corresponding equipment. The composite material was initially fabricated in compliance with the specified ASTM standards for hardness testing. Subsequently, the specimen was carefully trimmed to the required testing dimensions, following the guidelines outlined in ASTM Standards, as depicted in Figure 9.

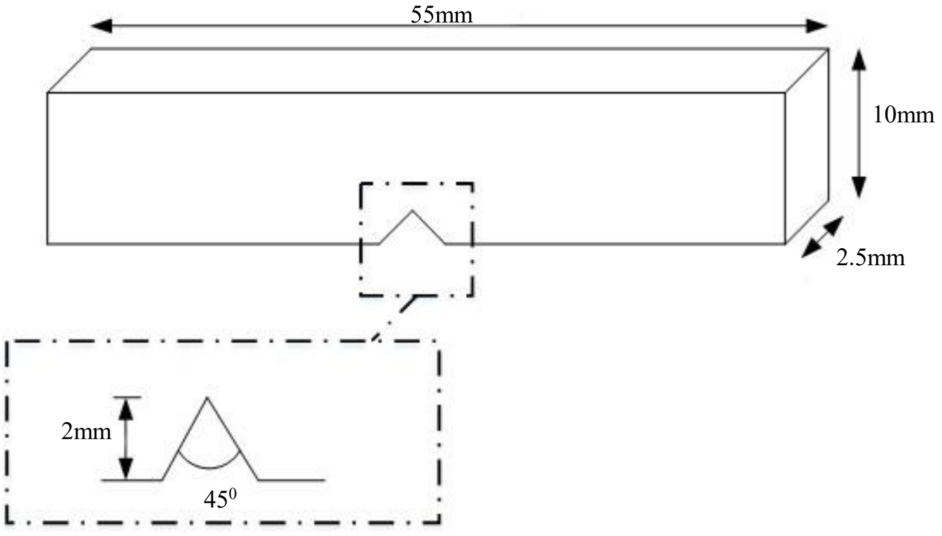

Figure 7. Impact test specimen ASTM standard.

Table1. Comparison of Impact Strength Carbon, Glass and Steel Matrix composite materials.

	Carbon (J)	**Glass (J)**	**Steel (J)**
Specimen 1	14	10	4
Specimen 2	18	8	4
Specimen 3	14	10	4

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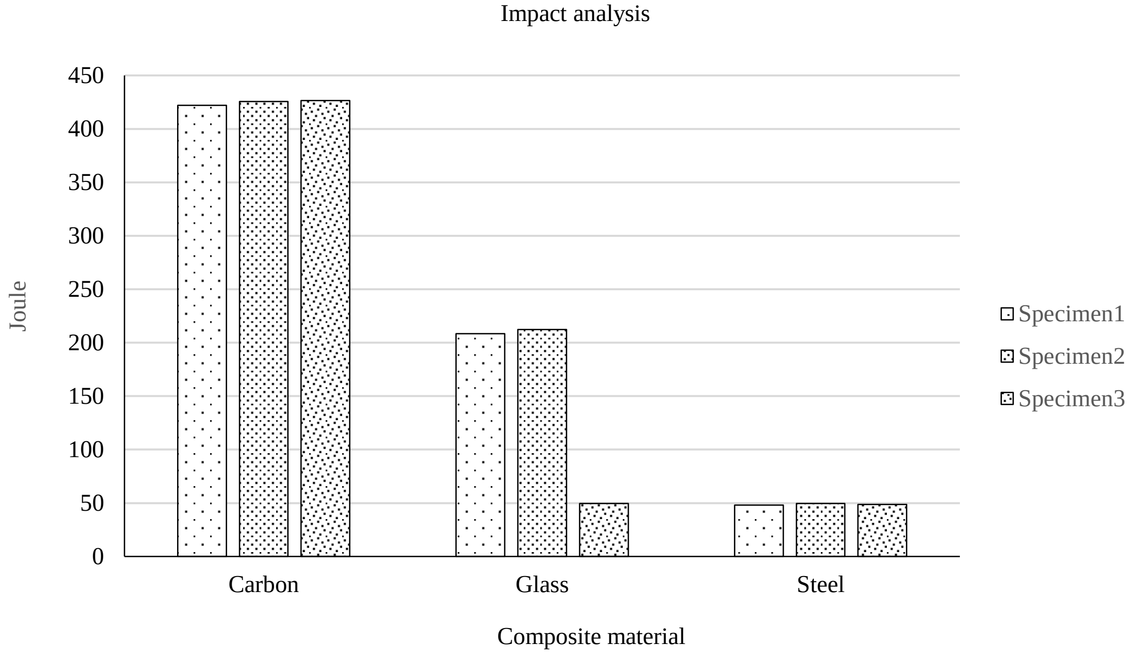

Figure 8. Impact Strength comparative result.

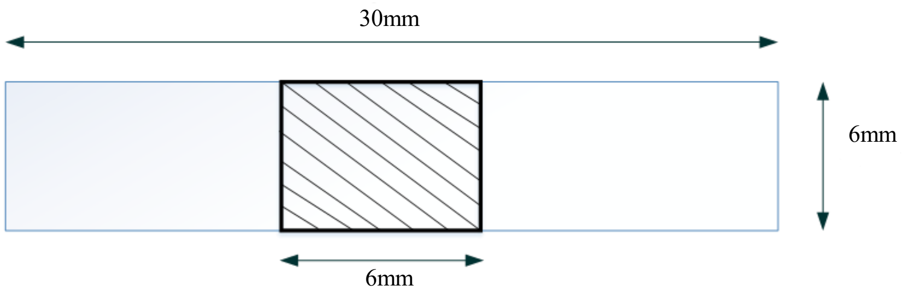

Figure 9. Hardness test specimen ASTM standard.

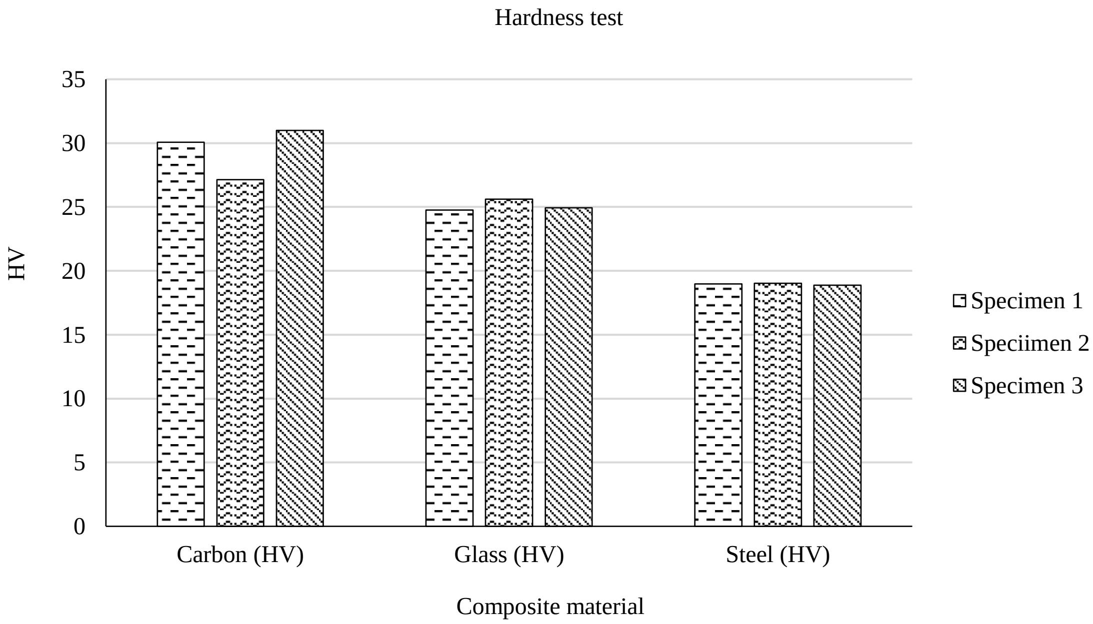

Figure 10. Hardness comparative results.

Table 2. Hardness Strength Comparative result of Carbon, Glass and Steel Matrix composite material.

S.N.	Carbon (HV)	Glass (HV)	Steel (HV)
Specimen 1	30.08	24.75	18.97
Specimen 2	27.13	25.6	19.02
Specimen 3	31	24.93	18.88

Hardness testing for carbon glass and steel PMC

The greatest hardness that a material can withstand before failing, such as yielding (in the case of ductile) or breaking (Brittle). Table .2 displays the measured Hardness strength of all the prepared samples (steel, glass, and carbon).

The hardness test results for three different specimens, namely Carbon, Glass, and Steel, are presented in the table. Each specimen underwent testing to measure its hardness strength, and the results are expressed in HV. Among the three composites Carbon has higher hardness than the other two composites. Specimen 1 has shown a value of 30.08 HV, followed by 27.13 HV for Specimen 2 and 31 HV for Specimen 3. In case of Glass fibre the Specimens1, 2 and 3 have shown values of 24.75 HV, 25.6HV and 24.93 HV respectively. It is observed that composites prepared by Steel resulted in comparatively less values among the three materials. Specimen 1 exhibited has shown 18.97 HV, where as Specimen 2 and 3 yielded 19.02 HV, 18.88 HV. The values of impact strength and hardness are on par with other research papers and hence the lamina with best results among the observed values can be applied in automobile field [8-9]. These results provide insights into the materials' abilities to withstand hardness resilience, with the recorded values serving as indicators of their respective hardness and resistance. Analysing and comparing these hardness test results can aid in evaluating the suitability of each material for specific applications where hardness resistance is a crucial factor. The graph in figure 10 compares the hardness of steel, glass, and carbon straightforwardly and concisely. It is evident from the graph below that carbon matrix composite has a substantially greater hardness than glass and steel matrix composite.

CONCLUSION

In conclusion, this research delves into the critical role of Polymer Matrix Composites (PMCs) in diverse engineering applications, leveraging their remarkable strength-to-weight ratio and customizable mechanical properties. The focus narrows down to an investigation of PMCs, reinforced with various materials such as carbon fibres, glass fibres, and steel fibres, under both dynamic and static loading conditions. Three distinct types of PMC specimens are created, each incorporating one of the mentioned fibres. The study employs a comprehensive approach, utilizing impact tests like Charpy and Izod to assess dynamic loading resilience, along with hardness tests such as Vickers and Rockwell to evaluate static loading and deformation resistance. The experimental findings highlight the promising characteristics of the carbon composite, showcasing an impact resistance of 18 Joules and a hardness of 31 HV.

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