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Abstract: In this study, the mechanical properties of hybrid composites reinforced with both Basalt fibers and Glass fibers are evaluated. The composites were fabricated through the use of a hand layup process followed by compression molding techniques. The composites in this study were prepared using traditional hand layup technique, with Lapox L-12 and K-6 epoxy serving as the matrix. Different fiber stacking sequences and thicknesses were used in the fabrication process. The mechanical properties of the composites and hybrid composites, such as flexural strength, impact strength, and tensile strength, were determined. The measurements were taken in accordance with ASTM standards. The results indicate that the addition of basalt and glass fibers as reinforcements has a substantial impact on the mechanical properties of the composites. It was found that the composites reinforced with basalt-glass fibers possess superior mechanical properties when compared to those reinforced with basalt and glass fibers alone.

Keywords: Hybrid Glass and basalt composites, Natural Basalt fibers, Lateral Fibers, Interfacial bonding

1. Introduction

Because of its unique combination of qualities, such as a high strength-to-weight ratio and exceptional corrosion resistance, composite materials have grown in popularity in recent years. Epoxy-based composites reinforced with basalt and glass fibers have been widely explored for their mechanical qualities among the numerous types of composite materials. Basalt fibers are made from natural volcanic rock, which is melted and extruded into fibers. These fibers have a high tensile strength and good chemical resistance, making them an attractive reinforcement option for composite materials[1-2)]. Glass fibers, on the other hand, are produced from silica and distinguished by their high modulus, low density, and superior chemical resistance.

When these fibers are combined with epoxy, a type of polymer matrix, the resulting composite material exhibits improved mechanical properties compared to the individual components. The high strength of the fibers and the toughness of the epoxy matrix work together to create a material with improved strength, stiffness, and impact resistance[2)].

Epoxy-basalt composites offer significant advantages, particularly in terms of their high flexural strength and modulus. These properties make them well-suited for various applications, including bridges, buildings, and aircraft structures[2),8)]. The high flexural strength ensures that the composites can withstand bending and loading forces without breaking or deforming, providing structural stability and integrity. Additionally, the high modulus of elasticity indicates that these composites exhibit minimal deformation under applied stress, contributing to their overall stiffness and resistance to deformation.

Furthermore, epoxy-basalt composites demonstrate excellent corrosion resistance and durability, making them highly suitable for use in harsh environments[3)]. The epoxy matrix acts as a protective barrier, shielding the basalt fibers from corrosive agents such as moisture, chemicals, and UV radiation. This corrosion resistance prevents degradation of the composite over time, ensuring its long-term performance and reliability. The durability of epoxy-basalt composites enables their application in environments where traditional materials may be susceptible to deterioration, such as marine, chemical processing, or offshore structures.

The combination of high flexural strength, modulus, corrosion resistance, and durability make epoxy-basalt composites a favorable choice for critical applications. Their ability to withstand significant loads and harsh conditions ensures the structural integrity and longevity of the components, providing enhanced safety and reliability.

These properties make epoxy-basalt composites an attractive option for various industries, where the performance of materials under demanding conditions is crucial. Epoxy-glass composites are known for their high compressive strength and modulus. These properties make them suitable for use in high-load-bearing applications, such as gears, bearings, and pressure vessels. Epoxy-glass composites' high compressive strength is especially advantageous for applications requiring high impact resistance, such as sports equipment and automobile parts. However, a variety of variables including fiber orientation, stacking method, thickness etc., decides the mechanical characteristics of composites. Researchers[4-8),19-20)] have examined how these factors affect the mechanical characteristics of these composites and developed strategies for enhancing the characteristics for certain applications.

One of the primary challenges associated with epoxy basalt and glass fiber composites lies in their inherent brittleness[26-27)]. These composites exhibit a tendency to fracture easily, which significantly restricts their utilization in scenarios necessitating flexibility. To address this limitation, researchers[28-30)] have focused their efforts on investigating methods to enhance the toughness of these composites through the integration of supplementary materials like carbon nanotubes or the exploration of alternative polymer matrices.

The allure of epoxy-basalt and glass fiber composites stems from their remarkable combination of properties, including exceptional strength, excellent resistance to corrosion, and impressive durability. Extensive research has been conducted to analyze the mechanical characteristics of these composites, confirming their suitability for a wide range of applications. Nonetheless, the persistent issue of brittleness necessitates further investigation in order to overcome this obstacle. This research focuses on preparing the hybrid composites using basal and glass fiber by varying the layers of fiber matts and examine the effect of thickness and composition on mechanical properties

2. Fabrication and testing.

The traditional hand layup technique is a widely used method to prepare polymer composites[4-6),25)]. In this method, layers of reinforcement fibers such as glass/ basalt fibers are placed in a 30X30-centimeter mould and then impregnated with a polymer matrix, typically a Lapox L-12 with K-6 epoxy resin procured from Atul Ltd., Gujarat (India). The layers are then consolidated by rolling the fibers to remove air bubbles and followed by hydraulic pressing to ensure proper wetting of the fibers. After that, the composite is cured at the proper temperature and pressure. For tensile, flexural, and impact testing, the cured specimens are machined in accordance with ASTM D638, ASTM D790, and ASTM D256 standards, respectively.

The composition of the prepared composite series has been designed in such a way that fiber constitutes 70% of the overall volume while the matrix portion makes up the remaining 30%. This 70:30 volume ratio has been chosen based on the desired properties and performance of the composite. The high fiber content is expected to result in improved mechanical properties, such as high stiffness and strength. Conversely, the matrix material is responsible for binding the fibers together and protecting them from environmental damage, ensuring that the composite retains its integrity over time. The volume ratio of 70:30 is a common ratio used in the preparation of composite materials and has been found to be effective in balancing the properties and performance of the final product. The layering strategy employed in the creation of basalt-glass hybrid composites involves stacking one layer of basalt with four consecutive layers of glass fibers [9)]. This particular stacking pattern has been specifically chosen in order to create a strong and durable composite material.

Fig. 1: Fabrication procedure followed during preparation of composites.

The combination of basalt and glass fibers in composite materials offers several advantages due to their complementary properties. Basalt fibers contribute to the overall strength and toughness of the composite, while glass fibers enhance dimensional stability. The stacking pattern chosen for these materials is expected to result in optimal mechanical and structural properties. The composition of each composite series, including the fiber and matrix content and their respective volume percentages, is outlined in Table 1. This table serves as a valuable reference for understanding the fiber-matrix ratio in each composite series, providing crucial insights into the material composition. Analyzing the information in Table 1 allows for a better comprehension of the structural characteristics of each composite series and enables predictions regarding their mechanical performance.

Table 1: Composition of Basalt, Glass fiber, and matrix and their code

Composites	Code	Matrix volume	Reinforcement volume	No of fiber mat layers		Thickness in mm
				B	G	
Epoxy + Basalt Composites	B6	30%	70%	57	-	6
	B8	30%	70%	77	-	8
	B10	30%	70%	96	-	10
Epoxy + Glass fiber composites	G6	30%	70%	-	57	6
	G8	30%	70%	-	77	8
	G10	30%	70%	-	96	10
Epoxy + Basalt + Glass fiber composites	BG6	30%	70%	12	48	6
	BG8	30%	70%	13	56	8
	BG10	30%	70%	17	68	10

The inclusion of basalt fibers in the composite imparts excellent strength and toughness properties. Basalt is a naturally occurring volcanic rock with high tensile strength, which allows it to withstand significant loads without fracturing. When incorporated into the composite, basalt fibers enhance its overall structural integrity, making it more resistant to deformation and failure. This is particularly advantageous in applications where mechanical strength is critical, such as structural components in construction or automotive industries.

On the other hand, glass fibers contribute to dimensional stability within the composite. Glass is an amorphous material with low thermal expansion coefficients, meaning it has minimal changes in size and shape with temperature variations. When embedded in the composite, glass fibers help to minimize dimensional changes caused by temperature fluctuations, reducing the risk of warping or distortion. This property is crucial in applications where precise dimensional control is required, such as aerospace or precision engineering.

By combining basalt and glass fibers in a specific stacking pattern, the composite takes advantage of the synergistic effects of their respective properties. The basalt fibers provide the necessary strength and toughness, while the glass fibers ensure dimensional stability. This combination results in a composite material with improved overall performance compared to using either fiber type alone.

Table 1 provides detailed information on the fiber-matrix ratio for each composite series. This data is essential for understanding the composition of the materials and their expected behavior. By examining the volume percentages of the fibers and matrix in each composite series, researchers and engineers can make informed decisions regarding material selection and tailoring the properties of the final product. The information presented in Table 1 serves as a valuable resource for designing and predicting the mechanical performance of the composite materials based on their specific fiber-matrix ratios..

3. Results and Discussion

Table 2 presents a comparative analysis and tabulation of the tensile, flexural, and impact strength of composite materials reinforced with mats of glass and basalt fibers, with increasing thickness. Tensile strength is a critical mechanical property of composite materials that quantifies their ability to withstand maximum tensile stress before fracturing[24)]. The tensile strength of composites is influenced by several technical factors, including the choice of reinforcement material, matrix composition, and overall thickness of the composite.

The ultimate tensile strength (UTS) of the epoxy-basalt composite demonstrates a gradual increase with thickness. Specifically, the UTS values are 200.876 N/mm^2 for a 6mm thickness, 234.480 N/mm^2 for an 8mm thickness, and 271.848 N/mm^2 for a 10mm thickness. This phenomenon aligns with a common trend observed in various composite materials, where an increase in thickness often leads to enhanced strength characteristics. The reasons behind this behavior can be attributed to several technical factors, such as improved load-bearing capacity, increased interfacial bonding between the reinforcement and matrix, and a greater volume of reinforcing material present in the composite structure.

Basalt fibers are a great reinforcement for epoxy composites because of their high tensile strength, good resistance to high temperatures, and resistance to abrasion. On the other hand, the tensile strength of the epoxy-glass fiber composite is 123.192 N/mm^2 for a 6mm thickness, 215.765 N/mm^2 for an 8mm thickness, and 243.36 N/mm^2 for a 10mm thickness. The graphical representation of the tensile properties of prepared composites are shown in figure 2. Glass fibers are also known for their high tensile strength, but they are generally lighter and cheaper than basalt fibers. Finally, the hybrid epoxy-basalt and glass fiber composites have tensile strength values of 277.377 N/mm^2 for a 6mm thickness, 351.517 N/mm^2 for an 8mm thickness, and 385.753 N/mm^2 for a 10mm thickness. When compared to composites formed with only one type of reinforcement, these composites, which integrate the strengths of both basalt and glass fibers, can provide superior mechanical qualities[12–14).]

When choosing materials for varied purposes, the tensile strength of composite materials is a crucial factor. The results indicate that the epoxy-basalt composite has a higher UTS than the epoxy-glass fiber composite, but that the hybrid epoxy-basalt and glass fiber composites have the highest tensile strength values of all. This highlights the importance of considering multiple factors, such as the type of reinforcement and the thickness of the composite.

Table 2: Composites' and hybrid composites' mechanical properties.

Composites	UTS N/mm^2	Flexural Strength N/mm^2	Impact Charpy J/mm^2
B6	200.876	352.62	14
B8	234.480	361.412	18
B10	271.848	389.443	24
G6	123.192	322.685	10
G8	215.765	325.215	14
G10	243.36	342.089	16
BG6	277.377	436.638	26
BG8	351.517	441.036	30
BG10	385.753	504.216	32

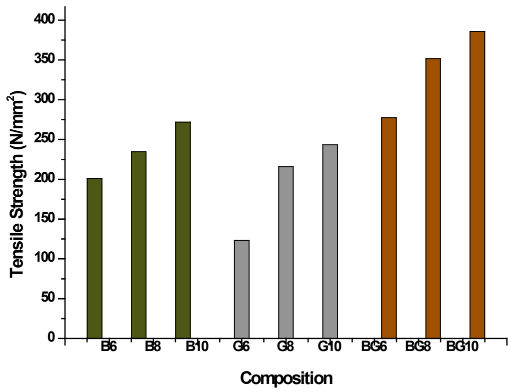
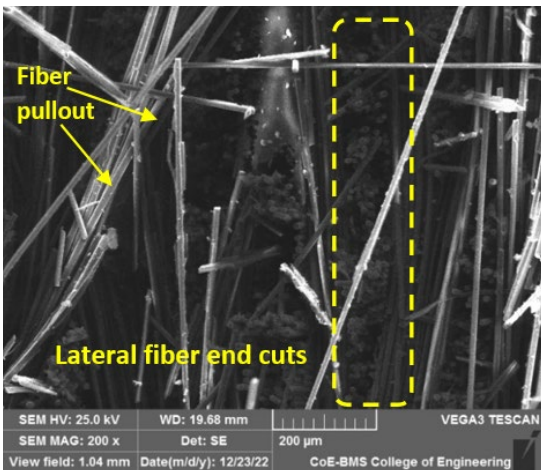


Fig. 2: UTS of Glass, Basalt fiber composites, and basalt-glass fiber hybrid composite.



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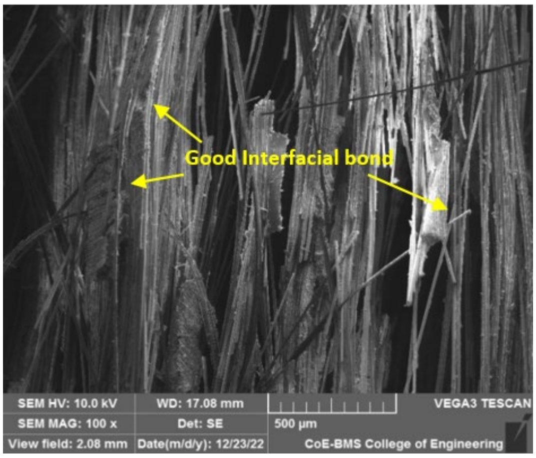

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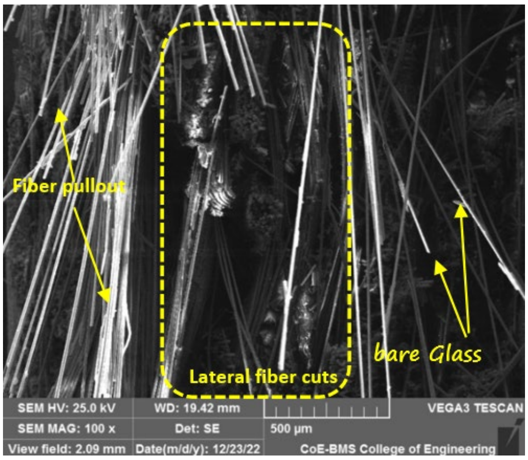

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Fig. 3: SEM images of Fractured Tensile specimens of (a)Glass fiber composite (b)Basalt fiber composite and (c) basalt-glass fiber hybrid composite

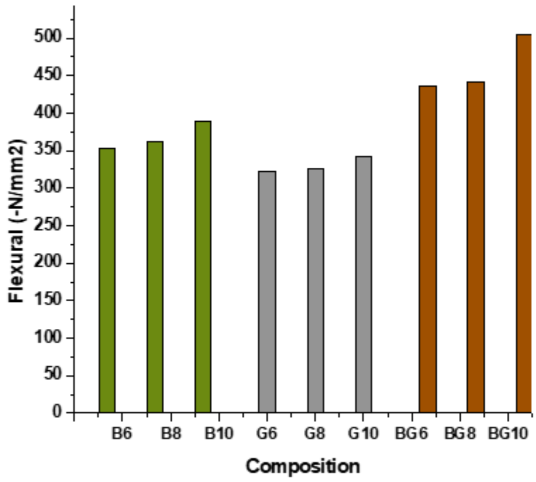


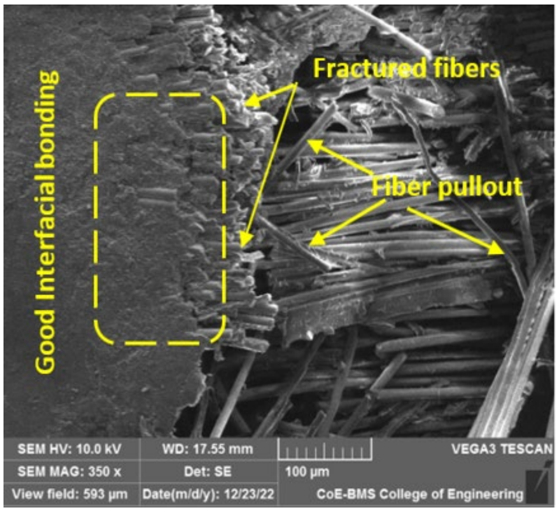
Fig. 4: Flexural strength of Glass, Basalt fiber composites, and basalt-glass fiber hybrid composite

Flexural strength is another important mechanical property of composite materials and is a measure of their ability to resist bending. Similar to tensile strength, flexural strength is influenced by several factors, including the type of reinforcement, the type of matrix, and the thickness of the composite.

The flexural strength of the basalt composite exhibits an upward trend as the thickness increases, indicating an enhanced resistance to bending and increased stiffness. In comparison, the flexural strength values of the epoxy-glass fiber composite are comparatively lower, suggesting that glass fibers are less effective in resisting bending compared to basalt fibers. This can be attributed to the inherent mechanical properties of basalt fibers, such as their high tensile strength and stiffness, which contribute to improved flexural strength in the composite. Conversely, glass fibers possess lower mechanical properties, resulting in reduced flexural strength in the composite material.

Moreover, the hybrid epoxy-basalt and glass fiber composites exhibit higher flexural strength values than their single-fiber counterparts. This suggests that the combination of basalt and glass fibers synergistically enhances the composite's resistance to bending. This improvement can be attributed to the interfacial bonding between the matrix and the two different types of reinforcements, as well as the superior mechanical properties of both basalt and glass fibers. The combined effect results in a composite material that exhibits improved overall performance, particularly in terms of flexural strength.

Epoxy-basalt composites have a higher impact strength than epoxy-glass fiber composites. This is due to the fact that basalt fibers outperform glass fibers in terms of tensile strength and modulus. Additionally, the interface between the epoxy and the basalt is stronger, leading better load transfer and energy absorption. When hybrid epoxy-basalt and glass fiber composites are used, the impact strength is further increased. This is because the basalt fibers provide high mechanical properties, while the glass fibers improve the toughness of the composite. The combination of these two fibers results in a hybrid composite that has a balance of strength and toughness, leading to improved impact resistance. It is also observed that the impact strength increases with the increasing thickness of the composite. This can be attributed to the fact that a thicker composite has a higher number of fibers, which enhances the mechanical properties and toughness of the composite. Furthermore, a thicker composite can absorb more energy before fracture, leading to improved impact strength.



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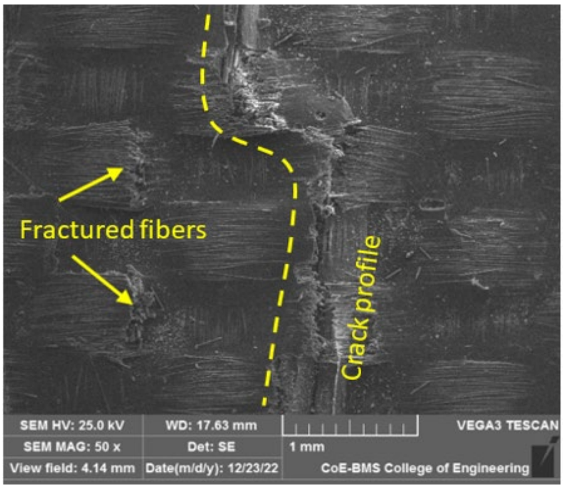

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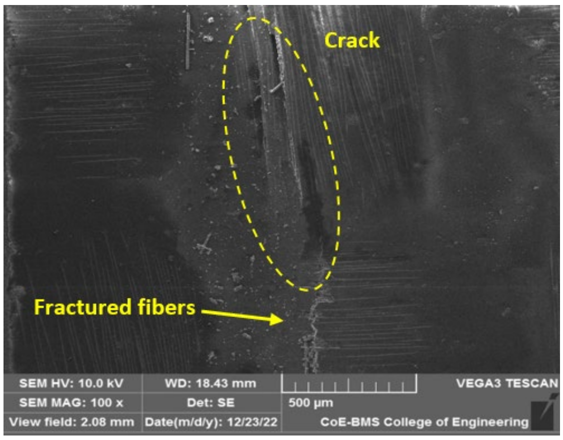

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Fig. 5: SEM images of Fractured Flexural specimens of (a) Glass fiber composite (b) Basalt fiber composite and (c) basalt-glass fiber hybrid composite

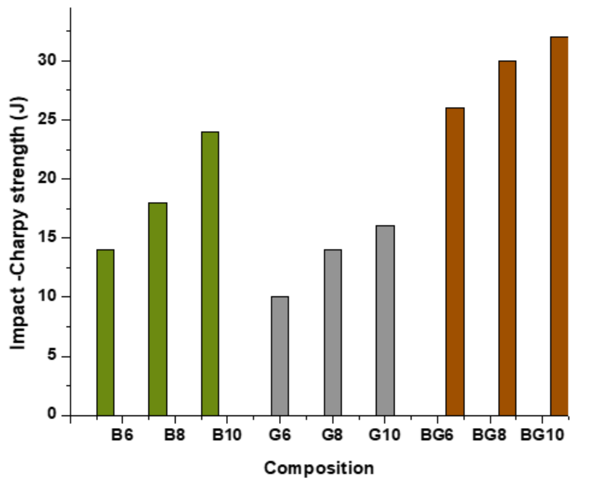
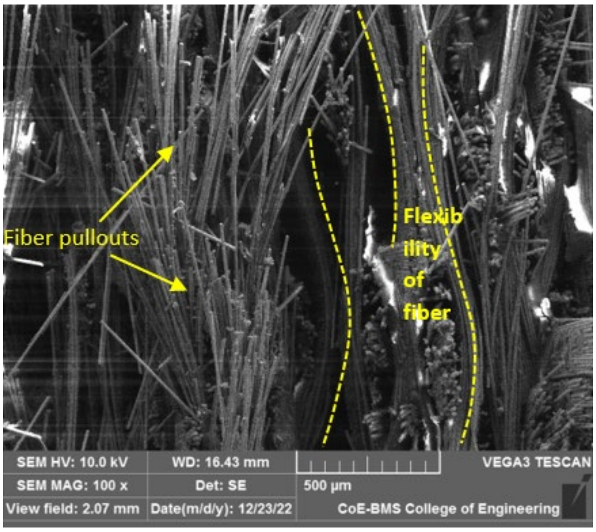
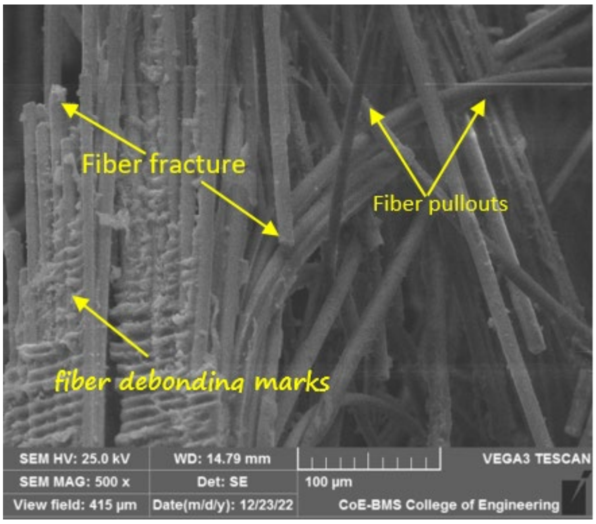


Fig. 6: Impact strength of Glass, Basalt fiber composites, and basalt-glass fiber hybrid composite



(a)



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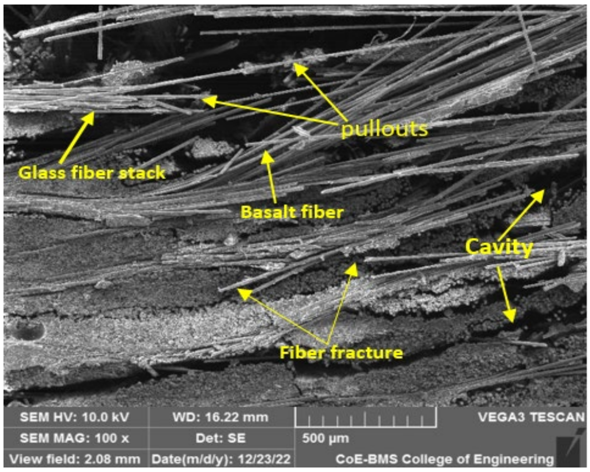

(c)

Fig. 7: SEM images of Fractured impact specimens of (a)Glass fiber composite (b)Basalt fiber composite and (c) basalt-glass fiber hybrid composite

The SEM images in the figure 3, 5 and 7 shows the fractured surfaces of tensile, flexural, and impact specimens of all composite series. The fracture of fibers in composite materials occurs when the applied stress surpasses the fibers strength and the boundary between the matrix and fibers lacks adequate bonding also due to loading conditions, the process used to prepare a composite.

The fibers aligned perpendicular to the applied force, known as lateral fibers, experience higher loads and are more prone to breaking compared to fibers aligned in the direction of the applied force[19-23]. This phenomenon can be observed in figures 3(a), (c), and 7. The increased load on lateral fibers can be attributed to several technical reasons namely load transfer, fiber orientation, matrix properties, interface bonding, etc. The orientation of the fibers greatly affects their mechanical behaviour[24]. Lateral fibers are subjected to more bending and shear stress compared to fibers aligned in the direction of the applied force, causing increased stress on the lateral fibers. Inadequate interface bonding is the reason for fiber pull out in composite and the same is visible in figures 3,5 and 7. SEM of flexural specimens of hybrid composite shows Higher mechanical values among the composite series are the result of superior interfacial bonding between matrix and fibers as compared to single fiber reinforced composites. The flexibility of the fibers can also be witnessed in figure 7(a), this shows the prepared composite will observe the impact load to a certain value and if the interface bonding is strong, the fibers are less likely to pull out of the matrix under impact loads, increasing the overall flexibility of the composite.

4. Conclusions

This study involves the characterization of a high-performance glass and basalt composite material through mechanical and microstructural analysis. The composite consists of glass and basalt fibers with varying densities, intertwined within a matrix. The mechanical properties of the composite were evaluated through tensile, flexural, and impact tests conducted at room temperature and perpendicular to the primary fiber direction. The findings from the experiments are as follows:

- Scanning electron microscope (SEM) imaging revealed that the hand layup approach, which improves the contact between the fibers and the matrix, is the most promising method for fabricating glass and basalt fiber composites.
- When compared to composites composed of a single type of fiber, hybrid composites combining glass and basalt fibers exhibited greater resistance to tensile, bending, and impact forces.
- The basalt polymer composite outperformed the glass fiber composite in terms of mechanical characteristics, regardless of the measured thicknesses. This superior performance can be attributed to the exceptional strength and stiffness of basalt fibers.
- As the thickness of the composite increased, the mechanical strengths improved due to enhanced interfacial bonding between the matrix and the reinforcements. This observation suggests that the overall mechanical properties of the composite can be significantly influenced by its thickness.

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