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Mechanical Characterization of Hybrid Bagasse/Eggshell/E-glass Fiber-based Polyester Composite

Dhaiwat N. Trivedi[1*], Fiona Munezero[1], Nikunj Rachchh[1]

[1] Department of Engineering, Faculty of Mechanical Engineering, Marwadi University, At & PO: Gauridad, Rajkot-Morbi Highway, Rajkot-360003, Gujarat, India
[*] Corresponding author, e-mail: dhaiwat.trivedi@marwadieducation.edu.in

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Abstract
Currently, numerous researchers, scientists, and industrialists are drawn towards utilizing natural fillers rather than synthetic ones because of their environmentally-friendly characteristics, lower density per unit volume and favorable mechanical attributes. Several studies have demonstrated that using organic filler in polyester matrix composites, instead of disposing of them in landfills, has various advantages. The current study focuses on the investigation of the mechanical characteristics of composite material made from a combination of bagasse, eggshell, and e-glass fibers exhibit characteristics such as strength under tension, strength under bending, resistance to indentation, and mass per unit volume. Different weight percentages of eggshell/bagasse were used to make the material using the hand lay-up technique (3wt%, 6wt%, 9wt%, and 12wt%), with 19wt% of glass fiber mixed in the resin. The use of inorganic fillers like calcium carbonate, a non-renewable mineral that may be expensive and environmentally hazardous to extract and process, is being reduced in favor of organic fillers like eggshell and bagasse, which are inexpensive and readily available. Specimens were generated by interposing fiber waste amidst chopped strand glass fiber mats, with variations in the bagasse, eggshell and polyester content, while keeping the amount of E-glass fiber constant. Afterward, the specimens were trimmed to the appropriate dimensions and subjected to analysis with a universal apparatus. The research showed that enhancing the quantity of bagasse/eggshell fiber within the hybrid composite resulted in an enhancement of its mechanical characteristics. The best reinforcement effect was observed in a hybrid composite with 6% bagasse/eggshell fiber.

Keywords
bagasse/eggshell waste, polyester matrix composite, e-glass fiber, mechanical properties, hybrid composite

1 Introduction

A composite material is composed of two or more components that are bonded together to create a single structural unit, where one component serves as a continuous matrix while the other acts as a reinforcement or filler [1]. A filler refers to a component that is added to the matrix material to improve certain properties. Using fillers in composites provides several advantages, including reduced costs due to lower resin requirements. Fillers can also improve the processing of the materials, as well as enhance their density control, optical properties, regulation of thermal expansion, prevention of flames, and properties related to electricity and magnetism. Additionally, the mechanical properties of the composites, properties like the ability to withstand fatigue, and durability against wear, can be improved by using fillers [2]. There are several inorganic filler materials that are commonly used comprising compounds such as calcium carbonate, aluminum silicate, calcium sulfate, and alumina trihydrate. However, Researchers are increasingly inclined towards substituting the aforementioned inorganic fillers with organic fillers, for instance, bagasse and chicken eggshells. This is because organic fillers offer several advantages like lower density increased filling capacity, non-abrasiveness, renewable sourcing, and cost-effectiveness. Eggshells are the protective outer layer of an egg that safeguards the contents inside. If not managed appropriately, they have the potential to become industrial waste that can harm the environment by encouraging microbiological activity [3]. Eggshell waste is typically left untreated and discarded in landfills, which incurs significant costs. The disposal of eggshell waste is a pressing issue since it is linked to the overall welfare of the public in terms of health. The

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responsibility for eggshell disposal in landfills lies with polluting the environment through the results of waste contamination and the consequent pollution of soil, and various hazardous consequences arises [3, 4]. [3], [4]. One potential solution to the current problem is to use eggshells as a filler in polyester matrix material. These eggshells consist of a protein fiber network intertwined with calcium carbonate crystals, which make up 96% of the shell's weight, along with Minor quantities of magnesium carbonate, calcium phosphate, as well as organic substance and water [5, 6].

Sugarcane bagasse, also known as cane chuff, is a readily available waste product derived from the processing of sugarcane in tropical countries like Brazil, India, Cuba, China, and others nations. It is the residue that remains after the extraction of juice in a sugar factory. The chemical compositions of pure bagasse fiber bundles are cellulose (45–55%), lignin (15–20%), and hemicelluloses (20–30%). In addition to these major components, bagasse fiber may also contain small amounts of other compounds such as pectin, ash, and extractives [7, 8]. As of 2021, the global production of bagasse amounts to approximately 540 million tons per year [9]. Bagasse fibers are known for their coarse and stiff nature and are utilized for various purposes such as energy generation, animal feed, and as a raw material for paper and other products. Despite its varied applications, bagasse is primarily valued as a renewable energy source in regions where sugarcane is a significant crop. Additionally, it can be utilized to produce non-woven products [10–12]. Due to its low cost and lightweight, it is contributing to mechanical characteristics as a natural fiber.

In general, the matrix material has lower strength compared to the reinforcements, and its primary function is to bind or adhere the reinforcements together [13]. This study involved the use of eggshell and bagasse powders as fillers, polyester as a resin, and e-glass fibers as a reinforcement in the development of composite materials. Composites made of polyester and e-glass fibre have been extensively utilized due to their greater specific power, stiffness, modulus, resistance to deformation, and fracture under stress in various applications. The fabrication process employed the hand lay-up technique to create various proportions of hybrid composites containing bagasse, eggshell, and e-glass fibers. Mechanical properties of the resulting hybrid composites were evaluated using standard ASTM tests.

1.1 Experimental methodology

The methodology utilized in this research is fully outlined and illustrated in Fig. 1.

The selection of the reinforcement and matrix was based on the intended use of the composite material. E-glass fiber and polyester matrix composites are commonly utilized in household applications. Eggshell and bagasse fillers were derived from waste materials of eggshells and sugarcane bagasse collected from different sources. These fillers were incorporated into the production of several composite variations. The fabricated composites underwent tests to evaluate their tensile and flexural properties. in accordance with ASTM standards D638 and D790, respectively [14].

1.2 Material choice

1.2.1 E-glass fibre

E-glass fibre is a lightweight material with high strength and lower stiffness. Nevertheless, glass fiber tends to be less brittle than other materials and is also more cost-effective. In this study, E-glass was utilized as the reinforcing component in the polyester resin matrix.

1.2.2 Polyester resin

Polyester resins are commonly manufactured by combining dibasic organic acids with dihydric alcohols. There are two main types of polyester resins: saturated polyesters, like polyethylene terephthalate, and unsaturated polyesters. The unsaturated polyester category requires a portion of the dibasic acid to contain double bonds, which contribute to the formation of the composite matrix network. Unsaturated polyester resin is in liquid form and solidifies when a hardener is introduced, specifically designed to cure at room temperature. The role of the hardener is to cure and solidify the resin.

1.2.3 Eggshell/bagasse filler

Eggshells and bagasse are two natural waste materials that can be used as fillers in composite materials.

1.2.4 Eggshells

The main constituent of eggshells is calcium carbonate, which provides excellent thermal insulation and a high strength-to-weight ratio. To create a composite material with enhanced mechanical aspects such as increased stiffness, strength, and impact resistance eggshell were used.

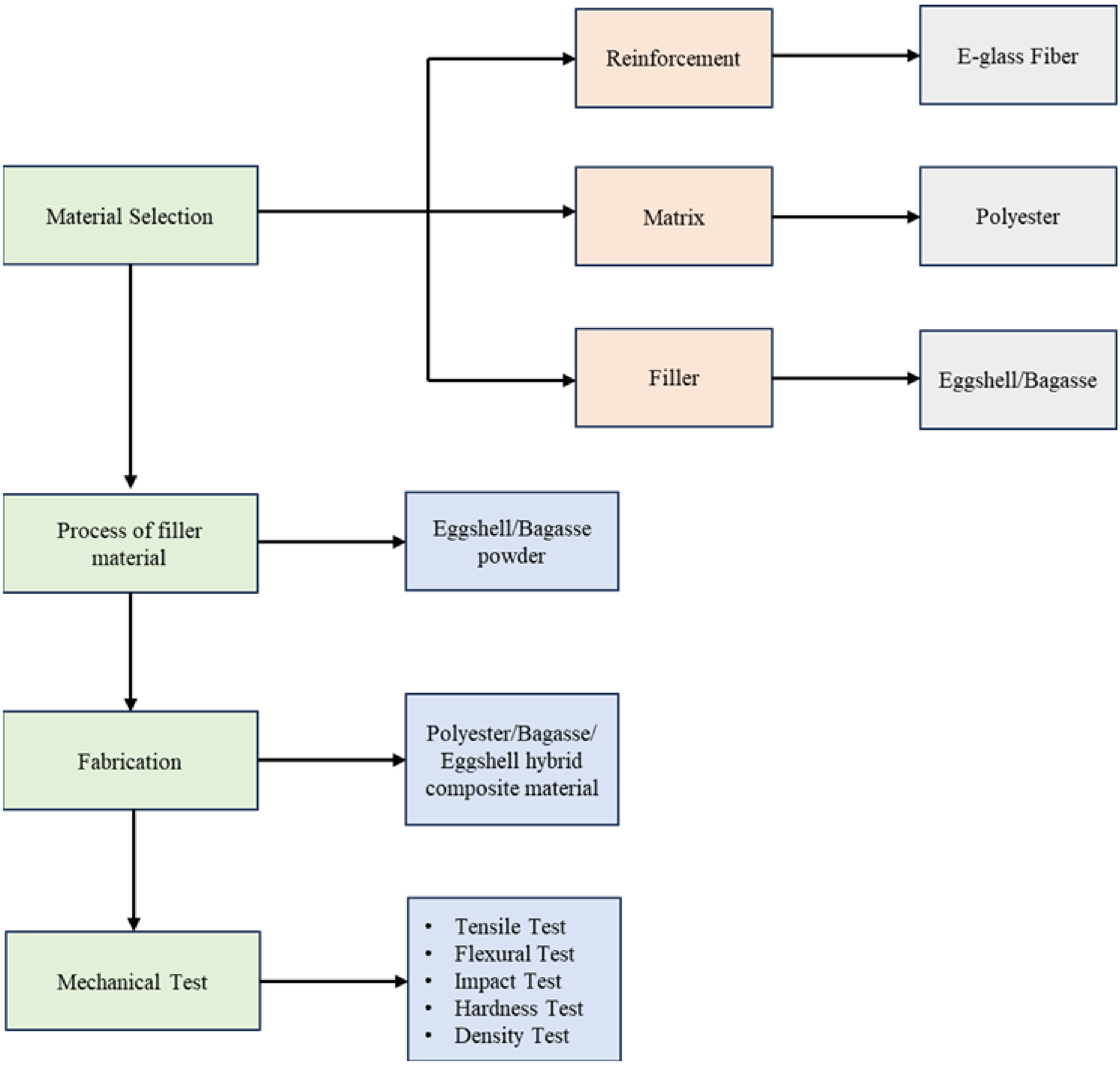

Fig. 1 Methodology

Eggshells were finely ground using a blender and combined with a polyester matrix. In addition, eggshells are renewable and biodegradable, making them a sustainable choice for composite materials filler.

1.2.5 Bagasse

Bagasse is a residue of fibrous material that remains after processing sugarcane. It primarily comprises cellulose, hemicellulose, and lignin, which provide it with favorable strength and stiffness characteristics. The bagasse was crushed in a ball mill to produce small fiber pieces and incorporated into a polyester matrix to form a composite material that has better mechanical properties, such as greater stiffness, strength, and impact resistance. Bagasse is also renewable and widely available.

1.3 Chemical treatment of filler material

The process of curing aids in achieving a material's final mechanical and chemical qualities. Incomplete curing lowers the material's performance. Eggshells and bagasse underwent a pre-treatment process involving immersion in NaOH for 24 hours, as illustrated in Figs. 2 and 3, followed by a 72-hour drying period. The eggshells were transformed into powder, whereas the bagasse underwent grinding in a ball mill to produce finely segmented fibers, as depicted in Fig. 4.

Fig. 2 Bagasse in NaOH

Fig. 3 Eggshell in NaOH

Fig. 4 Bagasse and Eggshell powder

2 Fabrication process

The fabrication of a hybrid eggshell/bagasse/e-glass-based polyester matrix composite was done by hand lay-up method. Eggshells and bagasse were prepared and soaked in NaOH for 24 h for the pre-treatment purpose and dried for 72 h. The eggshell was blended into powder and the bagasse was then ground in a ball mill to convert into small pieces of fiber. A mold of dimension 300mm×300mm was constructed with bolts and a piece of wood. To facilitate the easy removal of the solidified casting, a cellulose acetate layer was applied to the mold. Four plates were made with different weight percentages (3%, 6%, 9%, 12%) and the same weight percentage was taken on both bagasse and eggshell. 7.4 wt% of e-glass fibre was kept constant. 2% of Hardener and 0.1% of cobalt were mixed with the resin for hardening the resin and for a quick solution. The initial step involved positioning a fibre reinforcing fabric within an open mold, followed by saturating the fabric with resin through pouring and meticulous integration into both the fabric and the mold. polyester resin is rolled or squeezed into the fabric, Bagasse and eggshell fillers were spread all over the surface on the top of the first layer as shown in Fig. 5, then a second layer of

Fig. 5 Spread of bagasse/eggshell

glass fiber was added and resin was applied again with the help of brush as shown in Fig. 6. The resin was allowed to chemically react, commonly referred to as "curing", in order to obtain a solid and rigid matrix. Subsequently, the mold was left undisturbed for a duration of 30 hours to complete the curing process. The prepared Laminates of hybrid bagasse/eggshell/ E-glass fiber-reinforced polyester composite slabs were removed from the mold as shown in Fig. 7, and the identical process and procedures were applied to the remaining plates.

3 Mechanical testing

3.1 Tensile test

The HIECO electromechanical Universal Testing Machine (UTM) was employed to conduct tensile tests. For a tensile test, flat dog bone-shaped specimens were prepared in accordance with the ASTM D638 standard, with dimensions of 165 mm in length, 19 mm in width at the center, and 4 mm in thickness as shown in Figs. 8 and 9. For every weight percentage of composites, four samples underwent testing, and the resulting average value was computed.

3.2 Flexural test

Rectangular-shaped specimens of dimensions 165 mm in length, 15 mm in width, and 4 mm in thickness were prepared for bending tests, in accordance with ASTM D790 as shown in Figs. 10 and 11. The three-point bending test employed a three-point bending fixture. Four samples were subjected to testing for each weight percentage of composites, and the average value was determined.

Fig. 6 Applying resin by brush

Fig. 7 Plates after solidification

Fig. 8 Specimens for tensile test

Fig. 9 UTM for tensile testing

Fig. 10 Specimen for flexural test

Fig. 11 UTM for flexural testing

3.3 Hardness and density test

As depicted in Fig. 12, the Barcol hardness tester was used for the hardness test and square-shaped specimens of dimensions 20 mm × 20 mm × 4 mm were prepared for this test. In order to get the average hardness value for composites, four specimens were examined for each weight percentage. Square-shaped specimens measuring 20 mm × 20 mm × 4 mm were employed for density testing, as illustrated in Figs. 13 and 14. Tests were conducted both in air and water, with subsequent calculation of average values.

3.4 Impact test

The toughness of the composite specimens was evaluated using an Izod impact tester (PIT Series) featuring a U-shaped pendulum with a maximum energy capacity of 150 J as depicted in Fig. 15. The ASTM D-256 standard was followed to measure the impact energy required to fracture the composite material. The un-notched specimen was positioned as a cantilever as shown in Fig. 16, and the pendulum has swung to fracture it. A dial gauge connected to the machine was used to quantify the impact energy in joules (J).

Fig. 12 Hardness testing

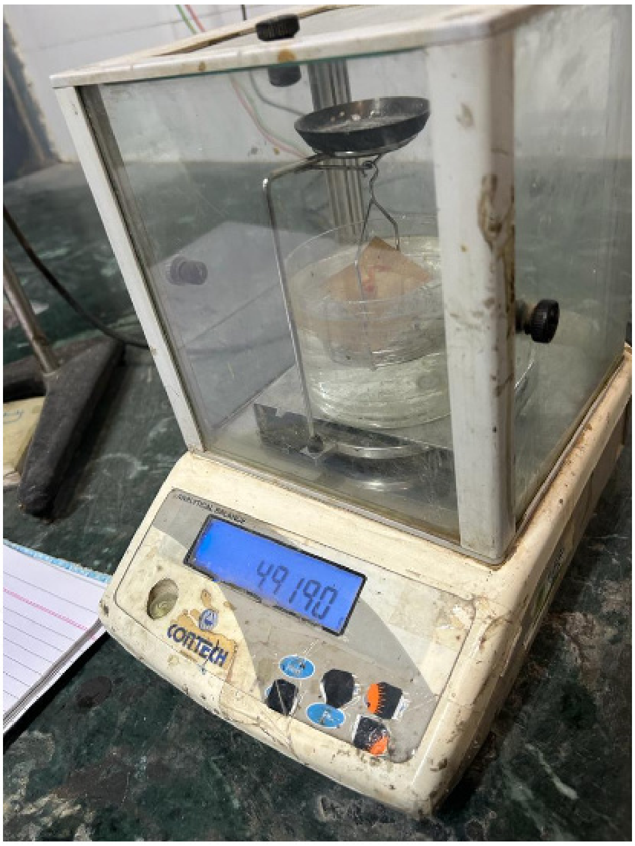

Fig. 13 Density testing both in water

Fig. 14 Density testing both in air

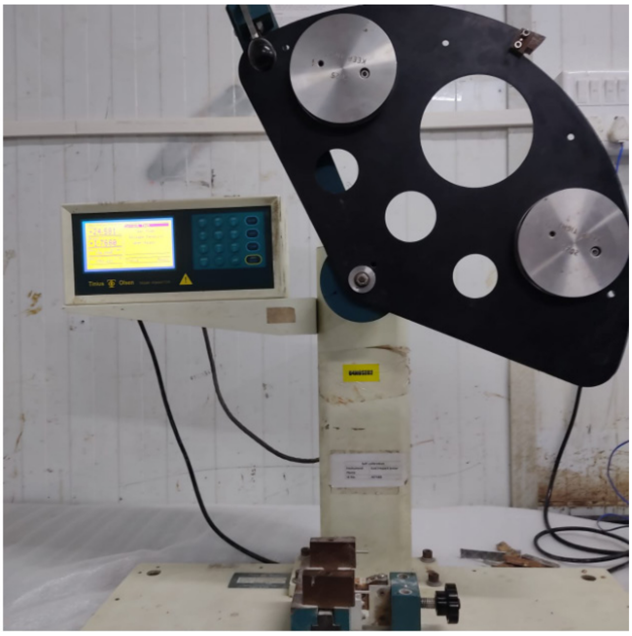

Fig. 15 Izod impact tester

Fig. 16 impact testing

4 Results and Discussion

4.1 Tensile strength

Reinforcement materials have an impact on the composites' characteristics. The fluctuation in tensile strength of the hybrid polyester matrix composite made of eggshells, bagasse, and e-glass fibers is shown in Fig. 17.

The table displays data on the tensile strength of composite laminates made from a combination of eggshell, bagasse, and e-glass fibers. It shows that the strength initially increased from 43.78 Mpa to 47.56 Mpa, but then began to decline at the 9% laminate composite level. The materials, method, specimen condition, and preparation, as well as the proportion of the reinforced material, all have a major impact on the tensile properties of composites. The data in Table 1 indicates that the maximum tensile strength was achieved with a composite of 6% of the hybrid eggshell/bagasse filler. The addition of this filler improved the mechanical characteristics of the composite, that is stiffness, and strength, which increase from 3% to 6% resulting in a significant improvement in tensile strength, as shown in Fig. 17. The 6% sample was found to withstand the maximum load and thus increase the overall strength of the composite material. Increasing the percentage of eggshell/bagasse filler led to a corresponding increase in tensile strength, as the filler was distributed over a larger area on the top of the fiber inside the mold and the resin was enough to bind them together which gave the best outcome compared to other samples.

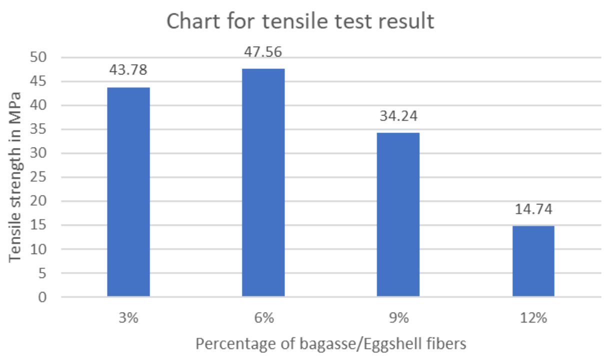

Fig. 17 The fluctuation in tensile strength hybrid eggshell/bagasse/e-glass fiber

Table 1 Effect of hybrid eggshell/bagasse/e-glass fibre on the tensile strength of the manufactured composites

No	Composite laminate (w%)	Width (mm)	Thickness (mm)	Ultimate tensile strength (Mpa)
1	3%	19	4	43.78
2	6%	19	4	47.56
3	9%	19	4	34.24
4	12%	19	4	14.74

4.2 Flexural strength

This experiment tested the flexural strength of polyester composites made from eggshell, bagasse, and e-glass fibers at various weight percentages. Table 2 lists the outcome of the bending strength and shows that addition hybrid eggshell/bagasse filler led to an increase in bending strength from 38.24 MPa to 58.5 MPa. The maximum bending strength value of 58.5 MPa was achieved at the 6% composite material level because the percentage of resin was sufficient for the percentage of filler provided, then the flexural strength started to decrease from 12.67 Mpa to 8.62 Mpa. As noted, the resin used in this experiment is brittle, which means that the flexural strength of the composite material will decrease as the weight percentage increases, as illustrated in Fig. 18.

The findings indicate that the type of reinforcements used in the 6% composite material demonstrated strong stiffness and bending strength. However, when more filler was

Table 2 Effect of hybrid eggshell/bagasse/e-glass fibre on the flexural strength the manufactured composites

No	Composite laminate (w%)	Width (mm)	Thickness (mm)	Ultimate flexural strength (Mpa)
1	3%	19	4	38.24
2	6%	19	4	58.50
3	9%	19	4	12.67
4	12%	19	4	8.62

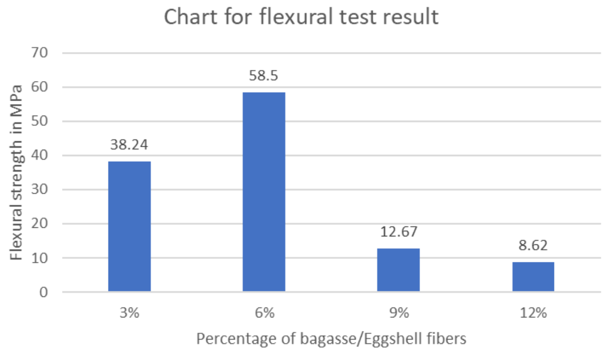

Fig. 18 The fluctuation in flexural strength with hybrid eggshell/bagasse/e-glass fiber

added, as in the case of the 9% and 12% composite materials, the resin was insufficient, resulting in weaker materials. The flexural strength started to decrease and dropped to as low as 8.62 Mpa for the 12% composite laminate.

4.3 Impact strength

Fig. 19 illustrates the impact strength changes of hybrid laminates composed of bagasse, eggshells, and e-glass fibre at room temperature. The impact energy decreases as the weight percentage increases. Table 3 provides the outcome of the impact strength conducted on fabricated composites, showcasing variations in weight percentage content.

The more the weight percentage of the filler increases, the lower the impact resistance becomes. The resin materials are considered brittle, resulting in low impact resistance. Insufficient resin content contributes to this effect. As the filler percentage increases, the impact strength continues to decline, as demonstrated in Table 3.

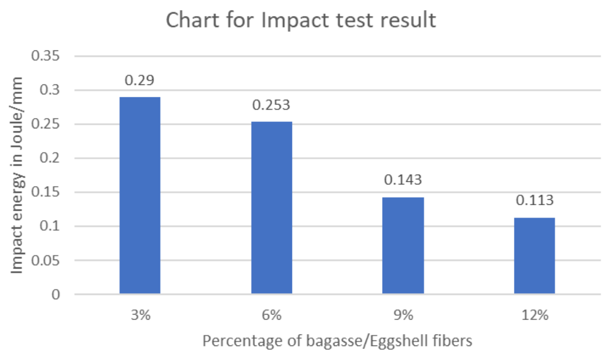

Fig. 19 The fluctuation in impact strength with hybrid eggshell/bagasse/e-glass fibre

Table 3 Effect of hybrid eggshell/bagasse/e-glass fibre on the impact of the manufactured composites

No	Composite laminate (w%)	Width (mm)	Depth (mm)	Impact energy (joule/mm)
1	3%	5.08	9.35	0.29
2	6%	6.97	12.14	0.253
3	9%	6.84	11.87	0.143
4	12%	6.82	11.25	0.113

4.4 Hardness

Fig. 20 illustrates the Barcol hardness values of the hybrid eggshell/bagasse/e-glass fiber/polyester composite, which increased from 13 BHU to 17 BHU with the addition of hybrid eggshell/bagasse filler. The maximum Barcol hardness of 17 BHU was obtained at the 12% weight percentage level. The hardness values plotted against the weight percentage fraction in Fig. 20 showed that the hardness increased with the addition of eggshell/bagasse filler content. However, the hardness value increased significantly as the wt% of eggshell/bagasse/e-glass fibre increased, as the pressing pressure applied by the Barcol hardness test on the sample reduced the indenter's insertion into the surface of the composite material that was created, leading to an increase in the hardness of the material. The addition of a combination of eggshell, bagasse, and e-glass fibers enhanced the modulus of the composite, resulting in an associated rise in its hardness. The findings from the hardness test, indicating the changes in hybrid eggshell/bagasse/e-glass fiber content of the manufactured composites, are presented in Table 4.

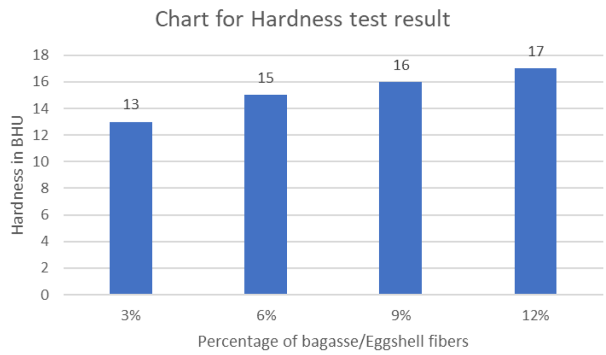

Fig. 20 The fluctuation in hardness test with hybrid eggshell/bagasse/e-glass fiber

Table 4 Effect of hybrid eggshell/bagasse/e-glass fibre on the hardness of the manufactured composites

No	Composite laminate (w%)	Width (mm)	Thickness (mm)	Hardness (BHU)
1	3%	20	4	13
2	6%	20	4	15
3	9%	20	4	16
4	12%	20	4	17

4.5 Density

In this experiment, the density of polyester composites was tested by combining eggshell, bagasse, and e-glass fibers at different weight percentages. Table 5 presents the findings of the density test, which indicate that the inclusion of hybrid eggshell/bagasse filler caused a reduction in density from 1.6 to 0.2 (g/cm^3). This decrease in density was attributed to the lower density of the eggshell/bagasse filler relative to that of the matrix, resulting in a reduction in the composite's overall density. Furthermore, as the weight percentage increased, the amount of resin available for each plate was insufficient, causing the bonding to weaken, thereby contributing to the density reduction. These results are shown in Fig. 21.

Table 5 Effect of hybrid eggshell/bagasse/e-glass fibre on the density of the manufactured composites

No	Composite laminate (w%)	Width (mm)	Thickness (mm)	Density (g/cm3)
1	3%	20	4	1.6
2	6%	20	4	1.2
3	9%	20	4	0.7
4	12%	20	4	0.2

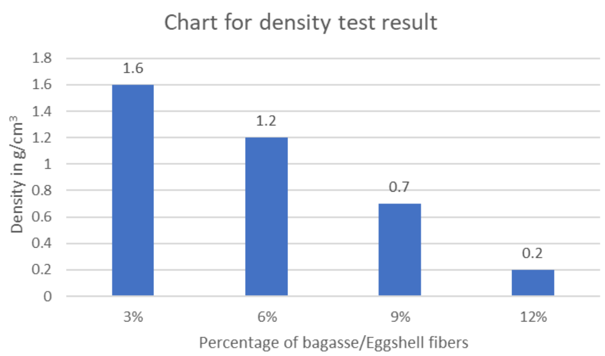

Fig. 21 The variation in hardness test with hybrid eggshell/bagasse/e-glass fiber

5 Conclusion

The mechanical behavior of a hybrid eggshell/bagasse/e-glass-based polyester composite was investigated in this experiment, and the following conclusions were drawn: The fabrication of hybrid composites with different percentages of eggshell/bagasse filler is feasible and economically efficient to accomplish using a straightforward hand lay-up method. The addition of eggshell/bagasse filler led to an increase in tensile from 43.78 to 47.56 (Mpa) and flexural strength varied from 37.24 MPa to 58.50 Mpa up to a certain limit, beyond which the strength decreased. The impact test decreased as the weight percentage were increasing due to insufficient resin from 0.290 to 0.113. The hardness value also significantly increased from 13 BHU to 17 BHU. The stress of the composite increased rapidly up to 6% content but then decreased as the eggshell/bagasse filler content increased and the resin content decreased. The addition of filler also resulted in a declination in the density of the composite. Overall, these hybrid composites possess good mechanical properties and are suitable for industrial applications, providing stiffness, hardness, abrasion resistance, heat resistance, breakage resistance, and chemical resistance.

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