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Research Article

Mechanical properties of hybrid banana fibre, rice husk, and eggshell reinforced epoxy composite

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Abstract

The hybridization of natural fibres improves composite development by compensating the drawbacks of single fibre reinforcement in a polymer matrix. This study examined the influence of rice husks, eggshells, and banana fibres on the mechanical properties of an epoxy polymer composite with the aim of developing a sustainable composite material with improved mechanical properties from agricultural wastes. The composites were developed from varied proportions of banana fibre (BF) and eggshell (ES) with constant rice husks (RH) in an epoxy polymer matrix; 5:20:20, 10:15:20, 15:10:20, and 20:5:20 respectively. The BF and RH were treated with 5% NaOH before its usage as a reinforcement. The mechanical properties; flexural, tensile, and impact strength of the cured samples were investigated and the test results revealed that hybridized BF/ES/RH enhanced the mechanical properties of the epoxy polymer matrix composite. The best flexural, tensile, and impact strength was obtained at composition 15:10:20 BF/ES/RH. The flexural, tensile, impact strength, flexural modulus, and tensile modulus ranged from 3.66 to 25.06 MPa, 11.35 to 17.42 MPa, 14.98 to 28.61 J/mm^2, 133.80 to 850.75 MPa, and 469.18 to 1872.09 MPa respectively. The composite exhibited 64.7%, 9.3%, and 39.84% improvements in flexural, tensile, and impact strength, respectively, over the control sample. The BF, ES, and RH contribute to the composite's tensile strength, impact resistance, and rigidity respectively. The result showed that the composite is suitable for various applications in engineering such as car door panels due to its improved mechanical strength while causing a reduction of waste circulation in the environment.

1. Introduction

Research on composites is growing rapidly due to the rising demand for environmentally friendly materials with improved properties Raju *et al.* and Jain *et al.* [1,2]. Traditionally, composites have been produced via the use of carbon or glass fibres (synthetic) for reinforcement in a polymer matrix. Synthetic fibres like glass fibres have good mechanical properties such as increased tensile, flexural, and impact strength but they pose health risks during processing or disposal, introduce pollution into the environment, lack sustainability, and cause an overall increase in production cost Mahir *et al.* [3]. Now, there is an increment in opposition to the use of synthetic fibres due to their negative effects on the ecosystem. Finding alternative methods that are eco-friendly and

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sustainable for polymeric composites development is therefore necessary. As a result, the emphasis has turned to the use of natural fibres for composite production due to their advantages such as availability, affordability, environmental friendliness Arjmandi *et al.* [4], recyclability, renewability, and biodegradability Bisht & Gope [5].

Natural fibres and fillers are plant and animal base which are mostly agricultural wastes. The plant-based natural fibres including jute, sisal, banana fibre, coir, rice husk, and so on, can be obtained from different parts of the plant. The animal-based natural fibres or fillers include eggshells, feathers, hair (wool), bone, etc. The wastes obtained from plants and animals can be utilized as a reinforcing material for composite production that is light in weight, cost-effective, sustainable Adediran *et al*. [6], nonabrasive, nonhazardous, and biodegradable Alkaron *et al*. [7]. In light of waste usage for composite development, rice husks (RH), eggshells (ES), and banana fibre (BF) are used in an epoxy polymer matrix to improve the epoxy matrix polymer matrix. Rice husk is mostly used as a reinforcing material due to its abrasiveness [8] and stiffness Ogundipe *et al*. [9]. Bisht and Gope investigated the impact of rice husk reinforcement loading on the bio composite's ability to withstand fracture, using epoxy resin filler loadings 10 to 40% by weight. The study revealed an increase in fracture toughness from 1.072 to 2.876 MPa√mm as the filler loading rises from 10 to 20% RH Bisht & Gope [10] which is in support of Premnath & Nivedhitha [11] Studies.

Eggshell as a filler material has been used instead of the commercial $CaCO_3$ fillers because they contain 95% $CaCO_3$. Its use in composite formation improves the properties of the composite [12-14]. Petrasek and Muller investigated the use of eggshell particles as reinforcement in an epoxy matrix with 10, 20, 30, and 40% weight. The properties of the pure epoxy matrix were improved with a 22% increase in the tensile strength at 10% eggshell reinforcement Petrasek & Muller [15]. Banana fibre is used as reinforcement in composite production due to its high tensile strength [16] and good surface adhesion [17] with epoxy resins. Ramesh *et al*. developed a composite using banana fibres as reinforcing material with an epoxy matrix. The composite materials of 50:50 banana fibre and epoxy resin gave better properties of 112.58 MPa tensile, 76.53 MPa flexural, and 9.48 Joules impact energy [18].

According to Sahoo *et al*. [19], composite obtained from reinforced natural fibres such as banana fibre hybrid produces better material properties when subjected to physical (ultraviolent, corona, etc.) [20], chemical (alkalinity, acetylation, etc.) [21] and biological treatments Birniwa *et al*. [22]. Fibre treatment for better properties was affirmed by [23] for it increases the surface roughness of the fibres and promotes adhesion capability with the polymer matrix. Composite materials produced from treated fibres are used by different industries such as the automotive vehicle interiors - front and rear door lining, foot mats, etc. Mohammed *et al*. [24] construction industry such as the manufacture of particle boards and roofing sheets [1] aerospace industry (flaps, aircraft wings, ice protection panels covering the fuselage, etc.).

There are different studies on the utilization of BF and RH Deepan *et al*. [25], BF and ES Ganesan *et al*. [26], RH and ES Lokesh *et al*. [27] for composite development but there are limited studies on the combination of the three reinforcing materials. Eggshell is a good reinforcing material because it causes an increase in the strength of the material due to its higher concentration of calcium carbonates and surface area Ganesan *et al*. [26]. Rice husk is a lightweight material with good refractory properties due to its high silica content [5] while banana fibre has a higher tensile strength which RH and ES are deficient Deepan *et al*. [25]. Epoxy is a thermoset polymer used as a matrix for reinforcement because of its high tensile strength, temperature-resistant capability, and effective wetting of natural fibres for proper adhesion [12,22]. According to [28,29], hybridization of the fibres improves the mechanical properties of the composite compared to the utilization of single fibres, therefore, this study aims to study the mechanical properties of banana fibre, rice husks, and eggshells as reinforcing material for composite production useful for the production of the interior components of an automobile such as door panels and dashboard.

2. Materials and Method

The materials used for this study were; epoxy, hardener, banana fibre, rice husk, and eggshells. They were locally sourced i.e., the rice husk was obtained from a rice mill, eggshells from the

Landmark University Cafeteria, and banana fibre from Opeyemi farm; all in Omu-Aran, Kwara State, Nigeria. The epoxy and hardener of density 1.169 g/cm^3 and 1.0195 g/cm^3 respectively were obtained at Lagos from Tony International Enterprise, Ojota, Lagos.

2.1 Material Properties

The physical properties of rice husk, eggshell, and banana fibre are shown in Table 1, the chemical properties are illustrated in Table 2, and Table 3 shows the mechanical properties of the fibres.

Table 1. Physical properties of rice husk, eggshell, and banana fibre

Fibre/filler	Particle size/ fibre length	Density g/cm^3	Specific surface area (m^2/g)	Porosity (%)
Rice husk	125 μm	1.12	1.45	87
Eggshell	75 μm	2.42	2.61	60
Banana fibre	4 mm	0.91	-	-

Table 2. Chemical properties of rice husk, eggshell, and banana fibre

Fibre/filler	Elemental composition
Rice husk	C (39.02%), O (28.73%), Si (16.23%), Rb (16.02%)
Eggshell	Ca (47.15%), O (34.52%), C (13.14%), Sb (2.52%), I (1.44%), and Mg (1.23%)
Banana fibre	C (37.05%), O (36.60%), Al (12.28%), Ca (7.90%), Si (3.09%), and K (3.08%)

Table 3. Mechanical properties of the fibres

Fibres	Tensile strength (MPa)	Young modulus (GPa)	References
Banana fibre	400 – 650	25 - 36	[30]
Rice husk	25 to 75	2.5 to 3.7	[31]

2.2 Material Preparation

2.2.1 Rice Husk Preparation

The rice husks obtained from the rice mill were washed with distilled water to remove impurities and contaminants and then dried in the sun for 3 days. The rice husk sample was thereafter ball-milled to obtain smaller rice husk particles. The screened rice husk particles of 125 µm particle size [32] were used. The rice husks were oven-dried at 40 – 60°C for a full day to get rid of the inherent moisture content [33]. After that, the dried fibres were treated with 5% NaOH for 4 hours to remove the foreign matter that can prevent the effective combination of the fibres in the epoxy polymer matrix [20]. Then, the fibres were washed to remove the alkalinity solution and dried at 60°C for 10 hours to obtain moisture-free fibres. Figures 1 (a), and (b) show the obtained rice husks and the treated milled rice husks.

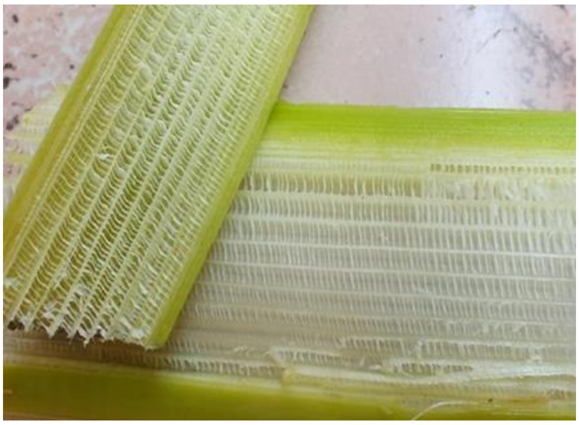
2.2.2 Banana Fibre Extraction and Preparation

Banana fibre was extracted from the pseudo-stem of banana trees through water and mechanical retting. The stem was cut and separated into strips. The banana strips were then soaked in water for 6 hours to reduce the lignin content, soften it and make the fibre extraction easy. The strips were removed from the water after 6 hours and placed on a smooth, clean, and hard surface for the fibre extraction using a knife. A knife was used to remove the gum, wax, and remaining lignin contents to obtain the banana fibre content [34]. The banana fibres obtained were cut into 40 mm lengths with scissors [35] oven-dried at 40 – 60°C for a full day to get rid of the inherent moisture content [33]. The dried banana fibres were then treated with 5% NaOH to remove impurities and non-cellulosic material that can hinder the adhesion of the fibres with the polymer matrix [20]. Then, the fibres were washed to remove the alkalinity solution and dried at 60°C for 10 hours to obtain moisture-free fibres. Figures 1 (c), (d), (e), and (f) show the banana stem, stripped banana stem, extracted banana fibre, and chopped treated banana fibre respectively.

(a)

(b)

(c)



(d)

(e)

(f)

Fig.1. (a) rice husk, (b) milled treated rice husk (c) banana stem, (d) stripped banana stem, (e) extracted BF, and (f) chopped treated BF

2.2.3 Eggshell Preparation

The eggshell waste was soaked in water for 24 hours and washed severally to remove the organic residue and membrane secretion [36]. The washed eggshells were sun-dried for three days and then ball-milled to obtain eggshell powder. The eggshell powder was collected and stored in an air-tight container. Figures 2 (a) and (b) show the dried chicken eggshell and the milled eggshells.

(a) (b)

Fig. 2. (a) dried chicken eggshells and (b) milled chicken eggshell

2.3 Method

The polymer composite was developed using an open mould hand lay-up method and the experiment was carried out under laboratory room temperature (20 – 25°C) and 40 - 60% humidity. The epoxy resin was mixed with the hardener in a ratio of 2:1 to obtain the matrix. The eggshell (ES), rice husk (RH), and banana fibre (BF) at different proportions as shown in Table 4 were then mixed for each test to form a homogenous mixture. The selection of the materials with fibre contents was based on previous research. Thereafter, the mould was placed properly on a polythene bag and taped with a cellotape to enable the stability of the various moulds. A petroleum gel was used as a lubricant to lubricate the mould before pouring the mixture inside the mould. The uniform mixtures were poured into tensile, flexural, and impact moulds as shown in Figure 3 (a), (b), and (c) respectively. The polymer matrix was cured at room temperature for a full day before its removal from the mould [37] as illustrated in Figure 3 (d), (e), and (f) respectively. The cured samples were subjected to tensile, flexural, and impact tests, and the fractured samples are shown in Figure 5 (a), (b), and (c).

Table 4. Composite composition

Samples	Sample designation	BF (%)	ES (%)	RH (%)	EPOXY (%)
A	$BF_5ES_{20}RH_{20}$	5	20	20	55
B	$BF_{10}ES_{15}RH_{20}$	10	15	20	55
C	$BF_{15}ES_{10}RH_{20}$	15	10	20	55
D	$BF_{20}ES_5RH_{20}$	20	5	20	55
Control	$BF_0ES_0RH_0$	0	0	0	100

ES: Eggshell, RH: Rice husk, BF: Banana fibre

(a) (b) (c)

(d) (e) (f)

Fig. 3. (a) tensile mould, (b) flexural mould, (c) impact mould, (d) cured tensile samples, (e) cured flexural sample, and (f) cured impact samples

The epoxy polymer composite without reinforcement was produced as a control. The epoxy polymer matrix was then reinforced with the various fibres at different mixing ratios as shown in Table 4, and then compared with the Control. The different material composition was used to obtain an improved epoxy natural fibre-reinforced composite [38].

2.4 Mechanical Test on Composite Samples

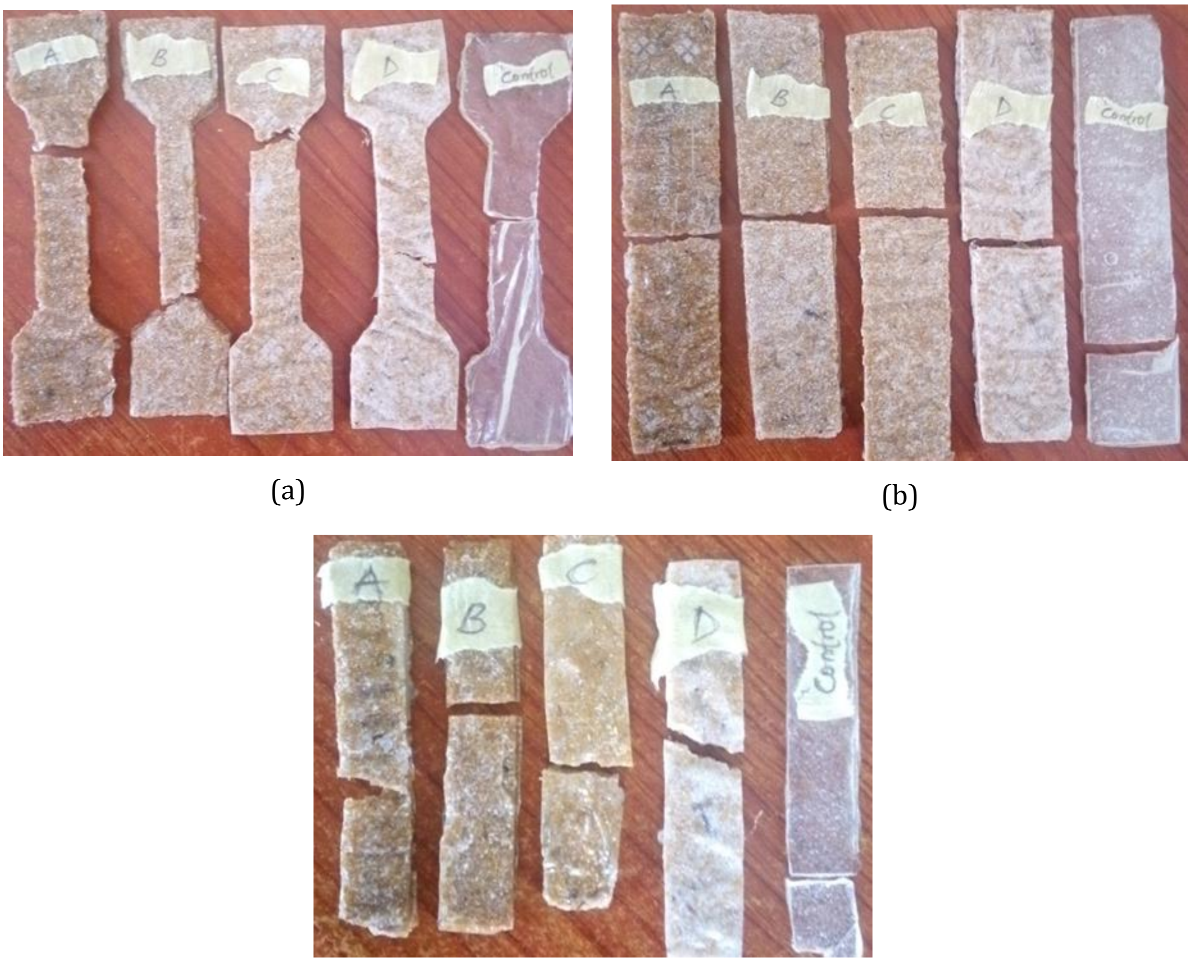
2.4.1 Tensile Test

The composite material sample was produced according to Tensile (ASTM D3039-17) standards [17,39] with a gauge length of 55 mm, width of 14 mm, and thickness of 3 mm as shown in Figure 3 (a). The tensile strength was done using an Instron-3369 Universal Testing Machine (UTM) as shown in Figure 4, with 50 kN applied load at 5 mm/min crosshead speed. The test was done in triplicates and the average was reported. Figure 3 (a) and (d) refer to the ASTM standard mould for the production of the composites for tensile test and cured composite respectively. The tensile fractured sample is shown in Figure 5 (a)

Fig. 4. Universal testing machine (Instron-3369)

2.4.2 Flexural Test

The material's ability to bear bending applied forces that are perpendicular to the object's longitudinal axis is referred to as its flexural strength. A 3-point flexural bending test was conducted for the flexural samples using ASTM D790-17 standards [40] with dimensions 127 mm × 24 mm × 3 mm as shown in Figure 3 (b). The crosshead position was used to calculate the specimen deflection. The Universal Testing Machine utilized, has a consistent rate of crosshead motion throughout the entire range and the load measurement systems error wasn't greater than 1% of the maximum load that was anticipated. The test was done in triplicates and the average value for the flexural strength and displacement were reported. Figure 3 (b) and (e) show the flexural mould and the cured composite. The flexural fractured samples are shown in Figure 5 (b).



(a) (b)

(c)

Fig. 5. (a) fractured tensile samples, (b) fractured flexural samples, and (c) fractured impact samples

2.4.3 Impact Test

The impact test was carried out according to impact (ASTM D256-23e1) standards with the application of an impact testing machine. The samples were prepared with mould size 65 x 12 x 3 mm as shown in Figure 3 (c) and the cured samples as shown in Figure 3 (f). A V-groove was cut on the longer side of the sample at a depth of 2.5 mm and a distance of 31.73 mm to initiate cracks as the load was applied on the sample that was horizontally placed on the impact testing machine support. The V-notch sample faced outward and aligned to ensure a hammer struck the sample's centre. The hammer was released, causing the sample to fracture. The impact strength for each composite sample was carried out and an average energy absorbed result for the samples was recorded after the conduction of three (3) measurements [11]. The fractured sample is shown in Figure 5(c).

2.4.4 Morphological Examination of Composite Sample

The morphological test investigation revealed the interfacial interaction of banana fibres, rice husks, eggshells, and epoxy resin. The unfractured and fractured samples were examined using a scanning electron microscope (SEM). The samples were layered with a small coating of gold to allow sample conductivity with minimum electrostatic charges. The photographs of the samples were taken to understand the morphological properties of the polymer composite.

3. Results and Discussion

The mechanical properties of the produced epoxy polymer composite obtained from reinforced rice husks, banana fibre, and eggshells were evaluated and the average value of each test was used.

3.1 Tensile Test Result of Produced Samples

3.1.1 Load and Displacement of Tensile Samples

Figure 6 shows the graph of tensile load versus displacement. There was an increase in displacement of all the samples from their original position when the load was continuously applied. A continuous increase was observed from the origin until a point when the load was constant but with increased displacement; the samples exhibited behaviour that is associated with Hooke's law. Sample C shows a higher load-bearing capacity compared to Sample A, B, D, and control because it was able to withstand much deformation of 895 N load before it fractures. The slope is the steepest; indicating that it can bear more load before it fails.

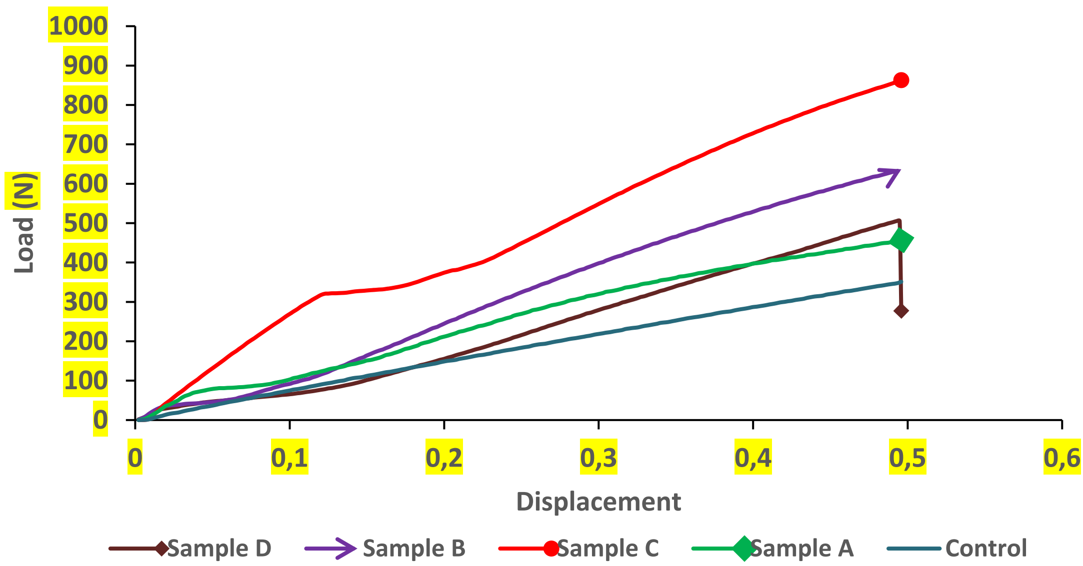


Fig. 6. Load vs displacement graph of tensile samples

An increase in the displacement of all the samples from their original position when the load was continuously applied was due to the strengthening of the matrix by the increase in the BF content. The reinforcing material in sample C was evenly dispersed in the epoxy matrix with better wettability as shown in Figure 13 (c) which leads to good interfacial bonding of the fibres with the matrix. A composite with good interfacial bonding will support more loads before it fractures [38]. As the banana fibre increased by more than 15%, agglomeration occurred, causing a reduction in the interfacial bonding in Sample D; making the material fail with the application of lesser loads compared to Sample C. Figure 6 shows that reinforcement of the epoxy matrix improves the properties of the composite; Sample C is better than the control sample which agrees with the studies of Oladele *et al.* and Amir *et al.* [37,40].

3.1.2 Tensile Strength

The tensile strength result according to Figure 7, shows that the epoxy polymer matrix, Control was improved when compared with the reinforced composites. Sample C of 15% BF, 20% RH, and 10% ES composition has the highest tensile strength with a 6.3% increase as compared with the pure matrix. The tensile strength of the composite increases with an increase in the banana fibre content from 5 to 15% and begins to decline after 15% banana fibre in the composite. The decline in the tensile after the 15% increment in banana fibre was due to the agglomeration of the fibres in the matrix. The interfacial bonding between the fibre and the matrix worsens with an increase in BF after 15% fibre loading. Also, irregularly shaped fibres decrease the strength of the composites due to the inability of the filler to enhance the stress transferred from the polymer matrix [5]. As the eggshell powder content begins to reduce with an increased banana fibre, the tensile strength increases. The findings from the current studies agree with previous studies by Panchal *et al.* and Fan [41,42]. The result shows that there is a limit at which better tensile strength can be obtained when hybridized with rice husks and eggshells are used as filler in polymer composite production. Therefore, with every increase in the BF% wt., there was an increase in the tensile strength according to [43]. The maximum tensile strength obtained from the hybridized sample is greater than the singular RH-reinforced composite as reported by [44].

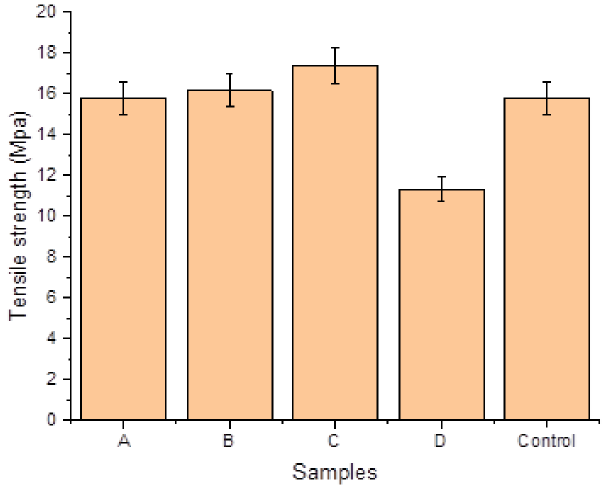


Fig. 7. Tensile strength of BF/RH/ES reinforced polymer matrix composite

3.1.3 Tensile Modulus

Figure 8 shows the tensile modulus of different samples; A, B, C, D, and Control. The tensile modulus signifies material stiffness which indicates how much such material can deform under stress application.

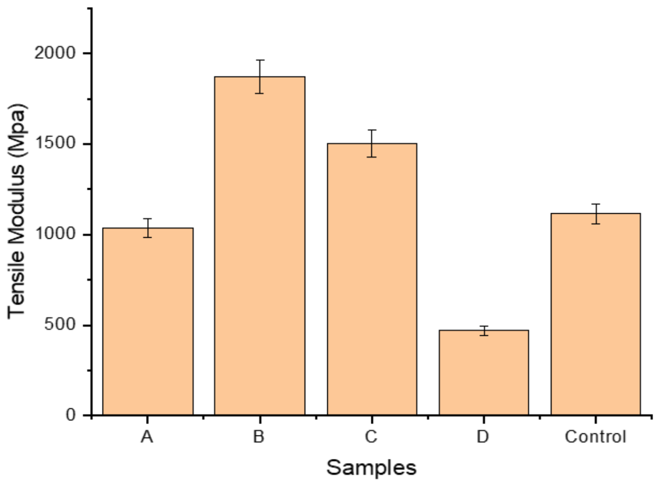


Fig. 8. Tensile modulus of BF/RH/ES reinforced polymer matrix composite

Sample B has the highest tensile modulus; making it the stiffest composite sample among all the samples. It is 40.45% better than the pure epoxy polymer matrix. Sample D is the least stiff composite due to its lower tensile modulus value. The tensile modulus of the composite increased from 5 to 10% Banana fibre and began to decrease after 10% BF as shown in Figure 8 due to agglomeration of the fibres which is in line with the findings reported by [17]. The behavior of increase in tensile modulus in Sample B was because of the fibre content increase without void formation which leads to the transfer of more load from the matrix to the filler. The decreases in the interfacial bonding due to the agglomeration of the fibre lead to poor adhesion between the filler and matrix which causes slippage and a decrease in the stiffness of the composite as observed in Sample D [5]. The tensile modulus of the composite developed from the hybrid reinforced BF/RH/ES yields better results than a single reinforced composite as reported by Bisht and Gope [5].

3.2. Flexural Test Result of Produced Samples

3.2.1 Load and Displacement of Flexural Samples

Figure 9 shows the load and displacement of the flexural samples. For every increase in load, there was an increase in displacement. Sample C exhibited higher displacement at a higher load compared with other samples. It was able to withstand 37 N of load before it fractured. The control sample was unable to withstand more than 12 N of load before it failed. Sample A has the lowest displacement when subjected to a load of 5.2 N. The control sample was able to withstand 11.5 N before it began to deform. However, it fails faster compared with the reinforced Sample C composite. This suggests that reinforcing the epoxy polymer matrix increases the flexural properties of the composite as shown in Thiagamani *et al.* study [45].

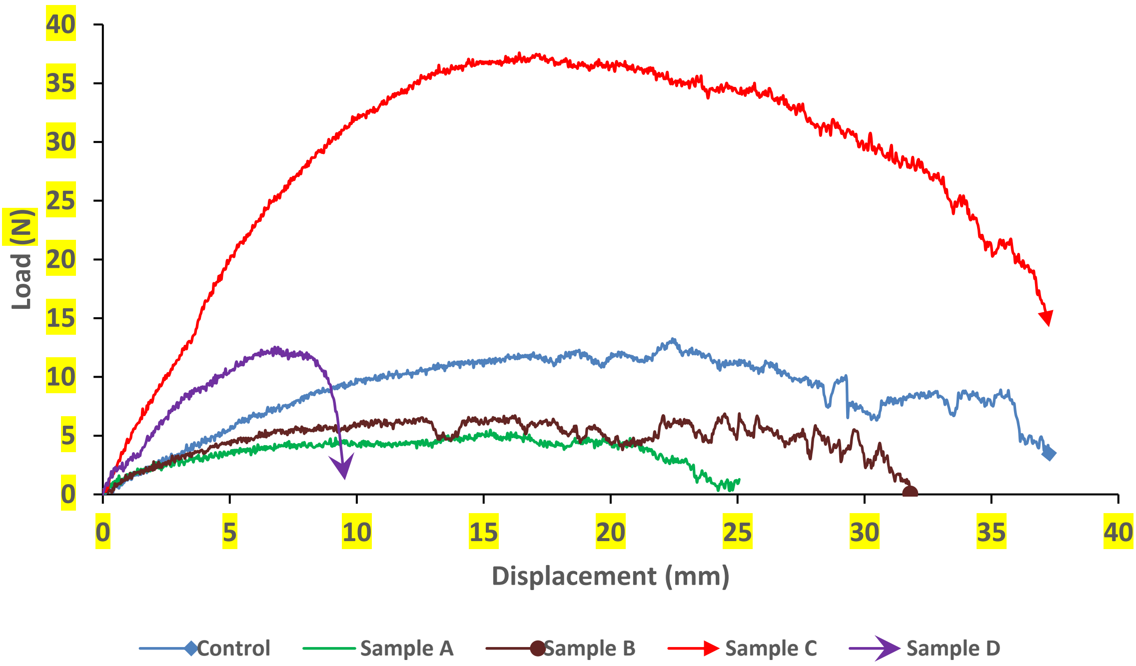


Fig. 9. Load vs displacement of flexural samples

3.2.2 Flexural Strength

Figure 10 shows different composite sample compositions for flexural strength and sample C has the highest value. There was an increase in the flexural strength with an increase in BF content from 5 to 15%. The ES content influenced the flexural strength of the composite. As the ES decreases with a simultaneous increase in the BF, the flexural strength increases until 10% ES and 15% BF when the maximum tensile strength was obtained for the produced samples. A decrease in the flexural strength was observed when the BF content increased by more than 15% in the composition. The maximum flexural strength of the reinforced composite is 64.7% better than the Control (pure polymer matrix composite). Reinforcing the epoxy polymer matrix with BF, RH, and ES significantly improves the flexural strength which conforms to the findings reported by [40].

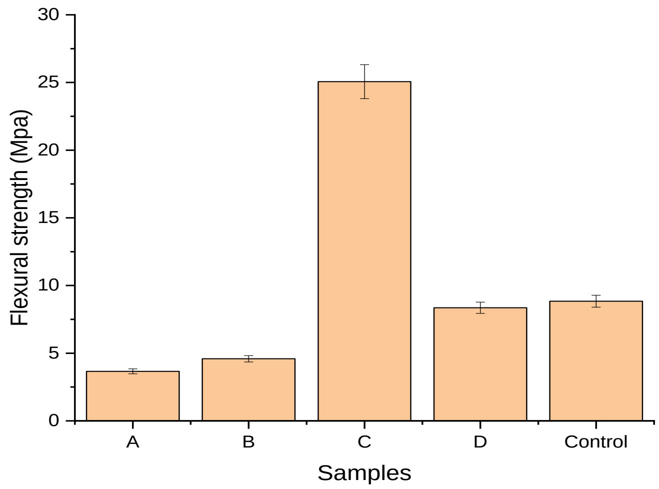


Fig. 10. Flexural strength of BF/RH/ES reinforced polymer matrix composite

3.2.3 Flexural Modulus of Produced Samples

Figure 11 shows the flexural modulus of different composite samples; A, B, C, D, and Control. The flexural modulus describes the ability of materials to resist deformation under load when subjected to bending. This property helps to understand structural applications of materials where flexure and bending are of concern e.g. panels and different structural components.

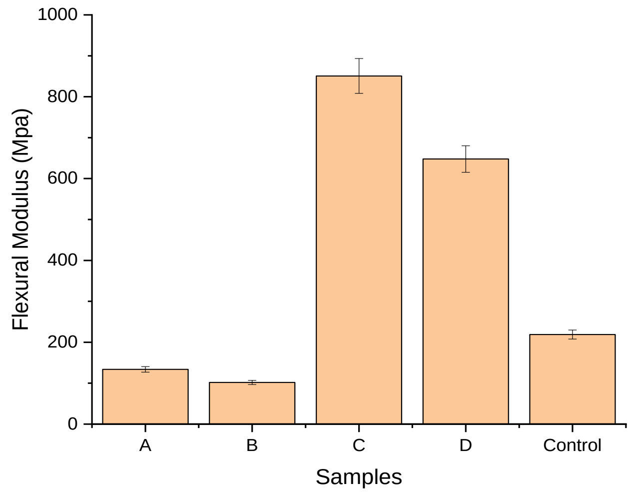


Fig. 11. Flexural modulus of BF/RH/ES reinforced polymer matrix composite

Sample C has the highest flexural modulus compared to other samples with the lowest error bar which indicates reliability and consistency of the result. The high flexural strength value of Sample C indicates high resistance to bending forces, thus, making it excellent for applications that require significant stiffness and rigidity. The high flexural modulus of Sample C was attributed to the presence of BF/RH/ES used as reinforcement that enhances the composite stiffness. The lower flexural modulus in Sample A and B is due to material composition difference, and degree of cross-linking in the polymer matrix [41].

3.3 Impact Strength of the Produced Samples

Impact testing investigates the resilience of the material and its capacity to absorb during a high-velocity impact. The outcome from this evaluation indicates the impact strength of the epoxy matrix composite samples. Figure 12 shows different samples of the composite made from different combinations. It was observed that the impact value increases with the % w.t of the reinforcement addition. Sample C has the best impact value compared to the control due to the increase in the %

wt. of the reinforcement. Progressively from 5% BF, the impact strength increases to 15% BF and begins to decline after the 15% BF, the study agrees with Amir *et al*. [40].

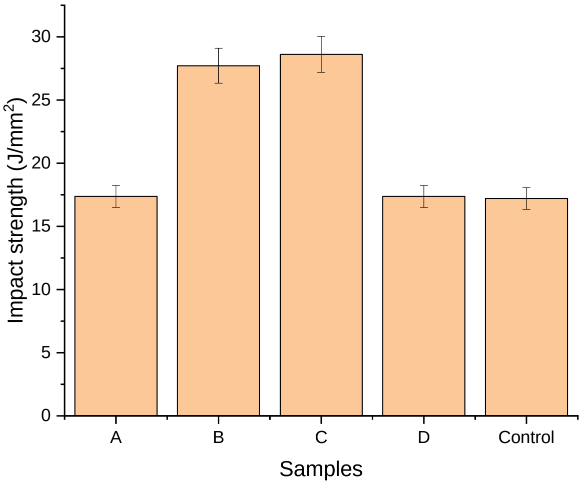
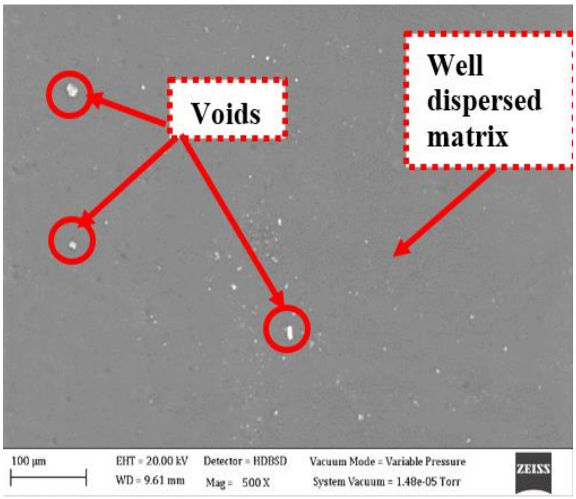


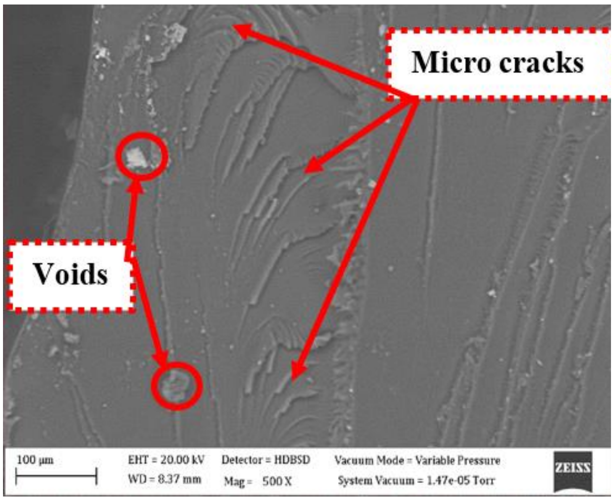
Fig.12: Impact strength of BF/RH/ES reinforced polymer matrix composite

3.4. Morphological Examination of Unfractured and Fractured Samples

Figure 13 shows the Scanning Electron Morphology (SEM) for the control and the best sample of the produced composite. Figure 13 (a) and (b) show a uniformly dispersed epoxy matrix and fractured surface of the control sample. The voids promote the micro cracking as shown in Fig. 13 (b). Figure 13 (c) shows that the rice husk and the banana fibre were evenly dispersed. There is no agglomeration of the fibre that reduces its mechanical strength which is why it was the best composite sample produced. Figure 13 (d) shows the fractured sample in which the eggshell, rice husk, and banana fibre were evenly distributed. The treatment of the fibre causes surface roughness of the fibre to promote strong interfacial bonding. A better distribution of fibres or filler in the matrix aids interfacial bonding that causes an increase in the mechanical properties of the composite Oladele *et al*. [37].



(a)



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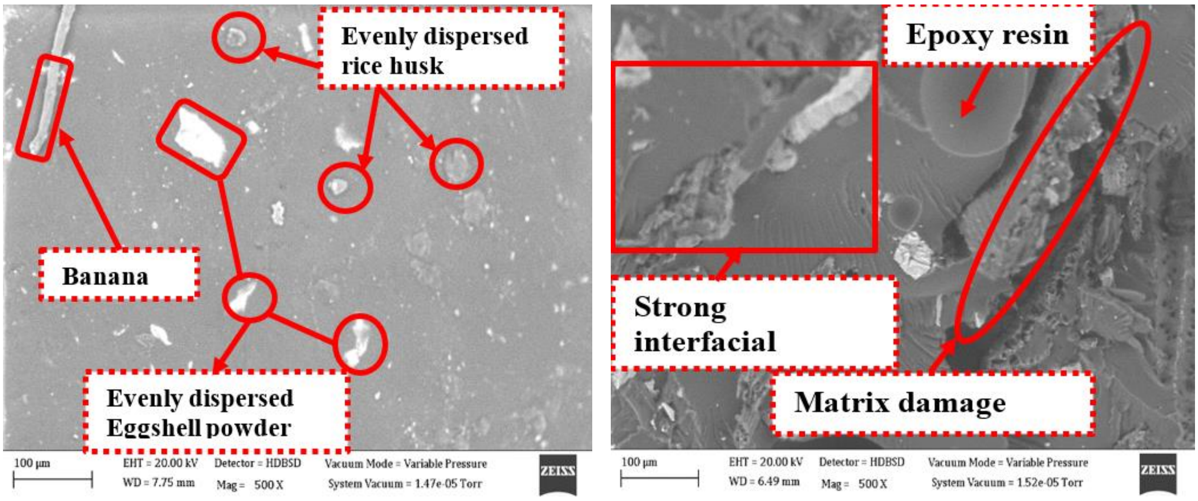

(c) (d)

Fig.13. (a) SEM image of the Control sample before fracture, (b) fractured surface of the Control sample, (c) Sem image of Sample C before fracture, and (d) Sample C fractured surface

4. Comparison of Previous Studies with the Current Studies

Table 5. Mechanical properties comparative table of previous studies and the current studies on the utilization of Rice husk, Eggshell, and Banana fibre as reinforcement for composite development

Ref.	Natural fibre types	Fibre/ filler ratio	Proportion of best sample	Matrix type	Method of production	Tensile strength (MPa)	Flexural Strength (MPa)	Impact strength (J/mm^2)
[46]	BF	10, 20, 30, 40, 50	30	Epoxy	Hand lay-up	65.6	38.1	2.8
[47]	BF	0, 5, 10, 15, 20	20	Polyester	Vacuum moulding	15.40	31.67	6.87
[48]	BF	5, 10, 15, 20	15	Polyester	Hand lay-up	19.9	66.8	6.08
[49]	ES	20, 40, 50, 70, 80	20	Polyester	Hand lay-up	22.20	52.97	0.4152
[50]	ES	0.5, 5, 10	10	Epoxy		22.80	-	-
[51]	RH	2.5, 5, 7.5, 10, 12.5 & 15	5	Epoxy	Hand lay up	16.67	28.21	4.91
[52]	RH	10, 15, 20	10	Epoxy	Solution casting	66.5	-	-
[53]	BF & ES	20:2.5, 25:2.5, 30:2.5	25:2.5	Epoxy	Compression moulding	31.21	33.69	2.84
Current Studies	BF, ES, & RH	45	15:10:20	Epoxy	Hand lay-up	17.42	25.06	28.61

It is evident from Table 5, that single reinforcement of fibres does not possess the required mechanical properties needed for automobile applications such as the door panel, bumper, or dashboard where materials that absorb more energy before failure are needed. Developing composite material with higher impact strength without compromising the flexural and tensile properties is very key in automobile applications. Although the tensile and flexural strength of the previous studies with the use of RH, ES, and BF as reinforcement is greater than the current studies, their impact strength is very low. The tensile and flexural strength of the current study is within the acceptable standards for automobile applications. Therefore, more study is needed for the formation of composite with higher impact, flexural, and tensile strength in the automobile industry to reduce the rate of automobile parts destruction during a collision.

5. Conclusion

The mechanical properties of a hybridized BF, RH, and ES as reinforcement in an epoxy polymer matrix were studied. The cured samples were subjected to mechanical tests and the findings promote the composite usage for automotive and construction applications. The outcome of the results for the study are as follows:

- The hybridization of the BF, ES, and RH affects the flexural strength of the composite. There was an increase in flexural strength as the banana fibre increased until it reached 15% and decreased after 15% BF. The maximum flexural strength for the sample was 25.06 MPa which is 64.7% better than the pure matrix. The flexural strength of the reinforced samples increased due to the increase in BF in the composite.
- The tensile strength of the pure epoxy matrix was enhanced by 9.3%. The highest tensile strength among all the samples was Sample C which indicates the best composite that is resistance to the tensile forces. This suggests that the material composition 15:10:20 of BF, ES, and RH respectively is the most suitable composite for applications of high tensile strength. An increase in the BF was proportional to the tensile strength increase. The increase in fibre content in the matrix results in agglomeration which leads to the propagation of cracks in the composite and in-turns causes matrix damage. The strong interfacial bonding causes an increase in the tensile strength. The maximum tensile strength for the composite samples was 17.42 MPa which is better than the pure epoxy polymer matrix.
- The impact properties of the composite samples increased with an increase in BF. It ranged from 14.98 to 28.61 J/mm^2. Sample C showed a very impressive impact response which was 39.84% better than the pure epoxy matrix. This means the composite has the best impact value compared to the control and can be used where resistance to fracture and high energy absorption is essential. In comparison with the previous studies, as illustrated in Table 5, the present study has a better impact strength which is a significant property for an automobile application (door panel, dashboard, and bumper). It helps to minimize losses, especially during collisions or accidents.
- The produced samples can be grouped according to the area of application using the mechanical test results. Sample A & B will be good at making boat parts, Sample C will have good applications in automobile and construction industries such as door panel lining, bumper, and so on due to its high impact strength and Sample D will be good at making the helmet dues to high impact response and flexural strength.

6. Recommendations

Elaborate studies are needed to be carried out on BF/RH/ES hybrid composite and different properties to be investigated such as tribological, flame-retardant, durability tests, etc as the properties would be relevant for automotive and construction applications. Different methods of production of polymer composite such as injection moulding, etc. should also be encouraged. In addition, different agricultural wastes should be hybridized to obtain better mechanical material properties to reduce environmental pollution. Also, an analytical study for fibre contribution with an analytical model to quantify the effect of each fibre on the composite is recommended for further studies.

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References

[1] Raju GU, Kumarappa S, Gaitonde VN. Mechanical and physical characterization of agricultural waste reinforced polymer composites. J Mater Environ Sci. 2012;3(5):907-16.
[2] Jain N, Somvanshi KS, Gope PC, Singh VK. Mechanical characterization and machining performance evaluation of rice husk/epoxy: an agricultural waste-based composite material. J Mech Behav Mater. 2019;28(1):29-38. https://doi.org/10.1515/jmbm-2019-0005
[3] Mahir FI, Keya KN, Sarker B, Nahiun KM, Khan RA. A brief review on the natural fibre used as a replacement of synthetic fibre in polymer composites. Mater Eng Res. 2019;1(2):88-99. https://doi.org/10.25082/MER.2019.02.007
[4] Arjmandi R, Hassan A, Majeed K, Zakaria Z. Rice husk filled polymer composites. Int J Polym Sci. 2015;2015:1-10. https://doi.org/10.1155/2015/501471
[5] Bisht N, Gope C. Mechanical properties of rice husk flour reinforced epoxy bio-composite. J Eng Res Appl. 2015;5(5):66-71.
[6] Adediran AA, Akinwande AA, Balogun OA, Olasoju OS, Adesina OS. Experimental evaluation of bamboo fibre/particulate coconut shell hybrid PVC composite. Sci Rep. 2021;11(1):5465. https://doi.org/10.1038/s41598-021-85038-3
[7] Alkaron WA, Hamad SF, Sabri MM. Studying the fabrication and characterization of polymer composites reinforced with waste eggshell powder. Adv Polym Technol. 2023;2023:1-11. https://doi.org/10.1155/2023/7640478
[8] Bisht N, Gope PC. Effect of alkali treatment on mechanical properties of rice husk flour reinforced epoxy bio-composite. Mater Today Proc. 2018;5(1):14089-96. https://doi.org/10.1016/j.matpr.2018.10.228
[9] Ogundipe O, Adetunla A, Igbinosa O, Ikumapayi O. A cost-effective ceramic filter for water purification in developing nations. In: 2023 International Conference on Science, Engineering and Business for Sustainable Development Goals (SEB-SDG); 2023 Apr 1-5; IEEE. p. 1-5. https://doi.org/10.1109/SEB-SDG57117.2023.10124576
[10] Bisht N, Gope PC. Effect of rice husk (treated/untreated) and rice husk ash on fracture toughness of epoxy bio-composite. J Mech Behav Mater. 2020;29(1):177-85. https://doi.org/10.1515/jmbm-2020-0018
[11] Premnath AA, Nivedhitha R. Effect of rice husk filler on hardness and impact strength of basalt fibre epoxy polymer composite. Mater Its Charact. 2022;1(2):90-5. https://doi.org/10.46632/mc/1/2/4
[12] Shah AH, Zhang Y, Xu X, Dayo AQ, Li X, Wang S, et al. Reinforcement of stearic acid treated eggshell particles in epoxy thermosets: structural, thermal, and mechanical characterization. Materials. 2018;11(10):1-15. https://doi.org/10.3390/ma11101872
[13] Mohan TP, Kanny K. Thermal, mechanical, and physical properties of nano eggshell particle-filled epoxy nanocomposites. J Compos Mater. 2018;52(29):3989-4000. https://doi.org/10.1177/0021998318773445
[14] Ogundipe OL, Adediran AA, Ikubanni PP, Adekanye TA, Ajisegiri ES, Ikumapayi OM, et al. Influence of eggshell addition on the properties of natural fibre-reinforced epoxy composite-a mini-review. In: 2024 International Conference on Science, Engineering and Business for Driving Sustainable Development Goals (SEB4SDG); 2024 Apr 1-7; IEEE. p. 1-7. https://doi.org/10.1109/SEB4SDG60871.2024.10629942
[15] Petrasek S, Muller M. Polymeric particle composites based on filler from hen eggshells. Eng Rural Dev. 2017;16:175-80. https://doi.org/10.22616/ERDev2017.16.N034
[16] Sapuan SM, Leenie A, Harimi M, Beng YK. Mechanical properties of woven banana fibre reinforced epoxy composites. Mater Des. 2006;27(8):689-93. https://doi.org/10.1016/j.matdes.2004.12.016
[17] Srinivasan T, Suresh G, Santhoshpriya K, Chidambaram CT, Vijayakumar KR, Munaf AA. Experimental analysis on mechanical properties of banana fibre/epoxy (particulate) reinforced composite. Mater Today Proc. 2021;45:1285-9. https://doi.org/10.1016/j.matpr.2020.05.103
[18] Ramesh M, Sri Ananda Atreya T, Aswin US, Eashwar H, Deepa C. Processing and mechanical property evaluation of banana fibre reinforced polymer composites. Procedia Eng. 2014;97:563-72. https://doi.org/10.1016/j.proeng.2014.12.284
[19] Sahoo M, Gopinathan R, Kumar KP, Rani JJA, Pradhan R, Parida L. Study on the influence of stacking pattern on mechanical behaviour of banana/snake grass fibres hybrid epoxy composite. Mater Today Proc. 2022;2022:1-8. https://doi.org/10.1016/j.matpr.2022.08.185

[20] Ho MP, Wang H, Lee JH, Ho CK, Lau KT, Leng J, et al. Critical factors on manufacturing processes of natural fibre composites. Compos B Eng. 2012;43(8):3549-62. https://doi.org/10.1016/j.compositesb.2011.10.001

[21] Ravi M, Dubey RR, Shome A, Guha S, Anil Kumar C. Effect of surface treatment on natural fibres composite. IOP Conf Ser Mater Sci Eng. 2018;376(1):1-8. https://doi.org/10.1088/1757-899X/376/1/012053

[22] Birniwa AH, Abdullahi SS, Ali M, Mohammad REA, Jagaba AH, Amran M, et al. Recent trends in treatment and fabrication of plant-based fibre-reinforced epoxy composite: a review. J Compos Sci. 2023;7(3):1-20. https://doi.org/10.3390/jcs7030120

[23] Samanth M, Subrahmanya Bhat K. Conventional and unconventional chemical treatment methods of natural fibres for sustainable biocomposites. In Sustainable Chemistry for Climate Action. 2023; 3. https://doi.org/10.1016/j.scca.2023.100034

[24] Mohammed L, Ansari MNM, Pua G, Jawaid M, Islam MS. A review on natural fibre reinforced polymer composite and its applications. Int J Polym Sci. 2015;2015:1-15. https://doi.org/10.1155/2015/243947

[25] Deepan S, Jeyakumar R, Mohankumar V, Manojkumar A. Influence of rice husk fillers on mechanical properties of banana/epoxy natural fibre hybrid composites. Mater Today Proc. 2023;74:575-80. https://doi.org/10.1016/j.matpr.2022.09.459

[26] Ganesan V, Chohan JS, Subburaj GS, Panneerselvam H, Nagabhushanam KY, Venkatesan MK, et al. Experimental analysis of mechanical properties of banana fibre/eggshell powder-reinforced hybrid epoxy composite. Eng Proc. 2024;61(1):18. https://doi.org/10.3390/engproc2024061018

[27] Lokesh KS, Kumar KS, Keerthan N, Revanth R, Sandeep S, Lakkundi SB, et al. Experimental analysis of the rice husk and eggshell powder-based natural fibre composite. J Inst Eng India Ser D. 2023;1-8. https://doi.org/10.1007/s40033-023-00557-9

[28] Dashtizadeh Z, Abdan K, Jawaid M, Khan MA, Behmanesh M, Dashtizadeh M, et al. Mechanical and thermal properties of natural fibre based hybrid composites: a review. Pertanika J Sci Technol. 2017;25(4):1-10.

[29] Ahmed A, Hameed AM, Abdullaha SA. Improve mechanical properties of epoxy composite material by enhancing it with natural fibres hybridization. AIP Conf Proc. 2024;3002(1):1-8. https://doi.org/10.1063/5.0208085

[30] Akubueze EU, Nwaeche FC, Muniru OS, Ezeanyanaso CS, Nwaze IO, Nwauzor GO, et al. Hybrid thermosetting composite of kenaf/banana fibres for utilisation in a passenger car bumper. J Mater Sci Res Rev. 2019;2(4):474-9.

[31] Kengkhetkit N, Wongpreedee T. Physical and mechanical properties of natural rubber composites filled with rice husk and rice straw. Creat Sci. 2021;13(3):86-95.

[32] Nandiyanto ABD, Fatimah S, Ragadhita R, Husaeni DN. Particle size and pore size of rice husk ash on the resin-based brake pads performance: experiments and bibliometric literature review. J Eng Sci Technol. 2022;17(6):4065-81.

[33] Prakash KB, Fageehi YA, Saminathan R, Manoj Kumar P, Saravanakumar S, Subbiah R, et al. Influence of fibre volume and fibre length on thermal and flexural properties of a hybrid natural polymer composite prepared with banana stem, pineapple leaf, and S-glass. Adv Mater Sci Eng. 2021;2021:6329400. https://doi.org/10.1155/2021/6329400

[34] Ernest EM, Peter AC. Application of selected chemical modification agents on banana fibre for enhanced composite production. Cleaner Mater. 2022;5:100131. https://doi.org/10.1016/j.clema.2022.100131

[35] Alam SS, Munshi MR, Shufian A, Haque MM, Haque MR, Hasan M, et al. Influence of alkalisation and eggshell particles on mechanical, thermal, and physical properties of rattan-bamboo fibre reinforced hybrid polyester laminated composite. Adv Mater Process Technol. 2024;10(2):329-48. https://doi.org/10.1080/2374068X.2022.2157079

[36] Skórczewska K, Lewandowski K, Szewczykowski P, Wilczewski S, Szulc J, Stopa P, et al. Waste eggshells as a natural filler for the poly(vinyl chloride) composites. Polymers. 2022;14(20):1-20. https://doi.org/10.3390/polym14204372

[37] Oladele IO, Makinde-Isola BA, Adediran AA, Oladejo MO, Owa AF, Olayanju TMA. Mechanical and wear behaviour of pulverised poultry eggshell/sisal fibre hybrid reinforced epoxy composites. Mater Res Express. 2020;7(4):1-10. https://doi.org/10.1088/2053-1591/ab8585

[38] Daramola OO, Akinwande AA, Adediran AA, Balogun OA, Olajide JL, Adedoyin KJ, et al. Optimization of the mechanical properties of polyester/coconut shell ash (CSA) composite for lightweight engineering applications. Sci Rep. 2023;13(1):1066. https://doi.org/10.1038/s41598-022-26632-x

[39] Adediran AA, Akinwande AA, Balogun OA, Bello OS, Akinbowale MK, Adesina OS, et al. Mechanical and optimization studies of polypropylene hybrid biocomposites. Sci Rep. 2022;12(1):2468. https://doi.org/10.1038/s41598-022-06304-6

[40] Amir N, Abidin KAZ, Shiri FBM. Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite. Procedia Eng. 2017;184:573-80. https://doi.org/10.1016/j.proeng.2017.04.140
[41] Panchal M, Raghavendra G, Reddy AR, Omprakash M, Ojha S. Experimental investigation of mechanical and erosion behavior of eggshell nanoparticulate epoxy biocomposite. Polym Polym Compos. 2021;29(7):897-908. https://doi.org/10.1177/0967391120943454
[42] Fan Y. Study on preparation and application of banana fibre-based composites. J Phys Conf Ser. 2023;2539(1):1-10. https://doi.org/10.1088/1742-6596/2539/1/012093
[43] Patel BY, Patel HK. Retting of banana pseudostem fibre using Bacillus strains to get excellent mechanical properties as biomaterial in textile & fibre industry. Heliyon. 2022;8(9):e09902. https://doi.org/10.1016/j.heliyon.2022.e10652
[44] Olaitan AJ, Terhemen A, King G, Oluwatoyin O. Comparative assessment of mechanical properties of groundnut shell and rice husk reinforced epoxy composites. Am J Mech Eng. 2017;5(3):76-86.
[45] Thiagamani SMK, Pulikkalparambil H, Siengchin S, Ilyas RA, Krishnasamy S, Muthukumar C, et al. Mechanical, absorption, and swelling properties of jute/kenaf/banana reinforced epoxy hybrid composites: influence of various stacking sequences. Polym Compos. 2022;43(11):8297-307. https://doi.org/10.1002/pc.26999
[46] Gairola SP, Tyagi YK, Gangil B, Sharma A. Fabrication and mechanical property evaluation of non-woven banana fibre epoxy-based polymer composite. Mater Today Proc. 2021;44:3990-6. https://doi.org/10.1016/j.matpr.2020.10.103
[47] Ernest EM, Peter AC. Application of selected chemical modification agents on banana fibre for enhanced composite production. Cleaner Mater. 2022;5:100131. https://doi.org/10.1016/j.clema.2022.100131
[48] Ezeh EM, Onukwuli OD. Physicochemical characterization of cow horn ash and its effect as filler material on the mechanical property of polyester-banana fibre composite. World J Eng. 2020;17(6):823-9. https://doi.org/10.1108/WJE-08-2020-0351
[49] Khashi'Ie NS, Hamzah K. Mechanical properties of jute fiber polyester hybrid composite filled with eggshell. Semarak Eng J. 2024;6(1):20-8.
[50] Souza JWL, Jaques NG, Popp M, Kolbe J, Fook MVL, Wellen RMR. Optimization of epoxy resin: an investigation of eggshell as a synergic filler. Materials. 2019;12(9):1489. https://doi.org/10.3390/ma12091489
[51] Olaitan, A. J., Terhemen, A., King, G., & Oluwatoyin, O. Comparative assessment of mechanical properties of groundnut shell and rice husk reinforced epoxy composites. Am. J. Mech. Eng. 2017 5(3), 76-86.
[52] Jain N, Somvanshi KS, Gope PC, Singh VK. Mechanical characterization and machining performance evaluation of rice husk/epoxy: an agricultural waste-based composite material. J Mech Behav Mater. 2019;28(1):29-38. https://doi.org/10.1515/jmbm-2019-0005
[53] Ganesan V, Chohan JS, Subburaj GS, Panneerselvam H, Nagabhushanam KY, Venkatesan MK, et al. Experimental analysis of mechanical properties of banana fibre/eggshell powder-reinforced hybrid epoxy composite. Eng Proc. 2024;61(1):18. https://doi.org/10.3390/engproc2024061018