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Mechanical Characterization of Luffa-Bagasse Fiber Reinforced Polymer Based Hybrid Composite

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ABSTRACT
This research used agricultural wastes as reinforcements and epoxy polymer as a matrix to manufacture environmentally friendly composites. The fibre mat of the commonly cultivated crop Luffa aegyptica contains bundles of cellulosic fibrils with increased strength and initial modulus. The sugar industry employs sugarcane principally, but it also contains fibrous parts called bagasse that are considered agricultural waste after the juice from the cane is squeezed out. This sugarcane agricultural waste can be used for a wide range of sustainable purposes. In this research, hybrid composites reinforced with waste bagasse fibre and Luffa aegyptica fibre were created in various volume fractions (5%, 10%, 15%, 20%, and 25% weight percentages of the final composite) to assess their morphological and mechanical characteristics. Researchers have experimented with a luffa or bagasse fibre-based composites independently, but the hybrid composites used in this research (both luffa and bagasse fibre) are unique and have never been seen before. Tests using compression, tensile, flexural, and scanning electron microscopy provided varying results. The luffa-bagasse combination showed enhanced compression strength when results were compared to those from some related works (using various combinations of hybrid fibres).

KEYWORDS
agro waste, luffa, bagasse, environmentally friendly, hybrid composites, mechanical testing

INTRODUCTION

Scientists, engineers, and researchers are constantly looking for novel biodegradable materials and sustainable alternatives for use in the automotive, aerospace, and packaging industries because environmental sustainability is a major concern [1]. Synthetic fibres do not easily degrade in nature and are not favourable to the environment. The application of synthetic fibres in excess has led to grave catastrophes in recent years, and it is now a serious global concern for environmental sustainability. The only solution is to discover environmentally friendly substitutes; natural fibres are excellent sources of reinforcing elements and are used in place of synthetic fibres when creating composite products [2]. Due to their expansion across a wide range of applications, including the aerospace, automotive, marine, defence, and packaging industries, hybrid composites are in higher demand right now [3]. New hybrid composites have been developed as a result of the increasing demand for hybrid composites in these fields on the global market. When two or more types of filler or reinforcement materials are combined into a single matrix, the term "hybrid composites" is used [4]. Physical, mechanical, and chemical qualities can be used to judge whether fibre hybridization in composites has been successful. To create a hybrid material, a variety of methods can be used, including sandwiching the fibres, fusing two or more types of fibres, and using fabric as reinforcement [5]. Natural fibres are currently favoured more in the creation of composites due to their biodegradability, ease of supply, and environmental friendliness. Natural fibres can be employed as reinforcement in a variety of composite formations and help brittle materials retain their strength and ductility [6]. Bagasse fibres were used in the creation of epoxy-based hybrid composites because natural fibres like sisal, coir, jute, and others are safer possibilities for reinforcement [7]. Due to their eco-friendliness, non-abrasiveness, and affordability, bio-waste-based composites are becoming more and more popular. For the construction of an epoxy-based composite, corncobs from nearby agricultural areas were reinforced with boron nitride particles to assure efficient waste disposal and improve mechanical qualities [8]. Biocomposites are composites that are made of fibres from natural sources and then mixed with polymers that are derived from bio-based resources [9]. Some researchers have broadened this concept to include the integration of polymers derived from petroleum with natural fibres [10].

Some natural fibre-reinforced hybrid composites have been combined with a thermoplastic resin, such as polyester. One such hybrid composite has a polyester matrix and is reinforced with hemp and nettles [11]. Because hemp fibre has better mechanical qualities than other natural fibres, it exhibits outstanding physical and mechanical behaviour when reinforced with polyester resin. Another natural fibre blend that has been added to the polyester matrix as reinforcement is jute and coir. The investigation's findings showed that composite specimens are inherently more durable than pure coir specimens [12]. Additionally, in the hunt for new composite-based works, rambans (Agave) fibres have been discovered as a reinforcing material in polyester matrix. The maximal tensile strength and high impact strength of this composite were both present [13]. Epoxy, a thermoset resin, has many different scientific applications in the automotive, aerospace, and engineering fields, among others [14]. The fibre-matrix interface and the stress transfer function play a significant role in this type of research when determining the mechanical effectiveness of natural fibre-reinforced composites. Chemical fibre treatments remove contaminants that limit the attachment of the fibres to the matrix, whereas prolonged plasma treatments weaken the mechanical properties. Since sugarcane bagasse has a reasonable tensile strength and modulus, it is a popular fibrous material for creating natural fibre-reinforced polymer composites [15]. Over the years, a lot of research has been done on hybrid composites reinforced with bagasse fibre. To create unique hybrid composites employing an epoxy resin matrix, sugarcane bagasse fibres and palm sheath were hybridized [16]. In this experiment, tensile characteristics, flexural qualities, hardness, and impact properties were assessed under two settings: NaOH-treated and untreated conditions. The investigation's findings showed that the best composite had improved tensile strength, Young's modulus, impact strength, hardness value, and flexural strength and may be used in car dashboards.

Sugarcane bagasse consists of cellulose, hemicellulose, lignin, ash and many extractives having a length of approximately 1.7 (0.8-2.8) mm and a width of around 0.034 mm [17]. The chemical compositions of bagasse fibre are given in Table 1. Fillers/fibres from natural resources have high specific properties, low density and low cost with few limitations like poor moisture resistance [18]. Sugarcane bagasse offers many potential applications for the production of value-added products and economic utilization of agro-industrial residues [19]. The development of a composite material made out of bagasse fibre has also been found suitable for materials that are used in the interiors of automobiles [20]. Bagasse-reinforced epoxy composites have been initially found in use as substitutes for wooden agglomerates [21]. This earlier work regarding bagasse-based epoxy composites took place having the potential to reduce native forest destruction as well as considering the low cost for fabrication of the composites using polymeric resins and sugarcane bagasse waste. Additionally, chemically-treated sugarcane bagasse fibre-reinforced epoxy composite was studied for the morphological examination as well as for the investigation of physical and mechanical behaviour [22]. An enhanced maximum tensile strength with maximum elongation was found in the result. Epoxy resin has also been used as a matrix in composite fabrication with reinforcement materials such as waste tires. One such research is waste scrap tires reinforced epoxy composites where epoxy resin samples exhibited excellent results in toughening the polymer network [23]. The resultant composite showed low density and high tensile strength which makes it a potential candidate for fabricating lightweight structures.

Although bagasse fibre has been widely found in the development of composite material, fibre from Luffa aegyptiaca has been found in a limited number of works. From the previous works, it has been observed the genus Luffa has 5 to 7 numbers of species [24]. In most luffa fibre-related research works, Luffa cylindrical fibre is mostly chosen species for luffa apart from other species thus Luffa aegyptiaca needs further research.

The novelty of this research is the selection of reinforcement which is unique in terms of hybridization. Researchers have worked with Luffa or bagasse fibers-based composites separately but they were not hybridized together in single composite fabrication. This present investigation has this unique combination in reinforcement and from this, the mechanical properties such as compression, tensile, and flexural along with scanning electron microscopy results were evacuated.

Table 1 contains the chemical and mechanical composition of luffa and bagasse fibre. Luffa aegyptiaca-based composites have previously been found in 5%, 10%, 15%, 20% and 25% weight ratios of fibre reinforcement but without any hybridization (in both treated and untreated form) using epoxy resin

[25,26,27]. So this investigation aims to find out some new findings and for this mechanical and micro-structural effects were studied. The test result revealed more compact structures when those were compared to some relevant work of composites.

Table 1. General chemical compositions and mechanical properties of luffa and bagasse fibres

Compositions and properties		Luffa fibre	Bagasse fibre	References
Chemical composition	Cellulose (%)	63.0	36.0	[28,29]
	Hemicellulose (%)	14.4	24.5	
	Lignin (%)	1.6	21.9	
	Others (%)	21	17.7	
Mechanical properties	Tensile strength (MPa)	3	180-290	[30,31]
	Tensile modulus (GPa)	0.004	15-19	
	Elongation at break (%)	7	1-5	
Density (g/cm^3)		2.2	0.72-0.88	[30,31]

EXPERIMENTAL

Materials and Methods

Preparation of Fibers

Luffa fibre was purchased from a local market (Dhaka, Bangladesh) in dried sponge foam (which is commonly sold as a cleaning scrubber). To extract the fibres of luffa, the sponges were soaked in water until they softened. Then, the soaked-softened fibres were cut to open the fibre mat. Then the fibre mats went to dry at room temperature, followed by chopping into small pieces about 0.5-1 cm long, without any further treatment.

Bagasse fibres, usually obtained as a residue of sugarcane after extracting the juice, are often dumped simply as waste by local vendors; hence, the fibres collected free from the local market (Dhaka, Bangladesh). Then, to ensure full drying, the fibres were washed and air-dried, followed by drying for a day and finally chopped into 1 cm long small pieces. Figure 1 represents both luffa and bagasse fibre before and after preparation.

a) b) c) d)

Figure 1. Reinforcement material a) luffa; b) cut luffa fiber; c) raw bagasse fibers; d) cut bagasse fiber

In fibre preparation, dried bagasse fibres are cut into small cubic pieces of 1 cm to go into a composite. The dried luffa fibre is also evenly chopped into small 1 cm cubic pieces and then ready to go for mixing with bagasse fibres. To make a hybrid composite, the amount of bagasse and luffa fibre used in samples 1-5 have been given in Table 2. Here the different weight percentage of both fibres is measured in grams and incorporated as a matrix material for the formation of composites.

Preparation of Resin

For binding the fibres, epoxy resin from the family of epoxide, (4, 4')- Isopropylidenediphenol also commercially known as Lapox B-11 (Epoxy Resin) (Atul LAPOX brand, Mumbai, India) was used. Also, a hardener, Lapox K 6, purchased from Atul LAPOX brand (Mumbai, and India) was used with epoxy resin at 1:9 ratios.

Table 2. Mixing ratio of different components

Composites	Luffa	Bagasse	Resin	Hardener	Sample image
Composite 1 (C1)	1	4	85.5	9.5	
Composite 2 (C2)	2	8	81	9	
Composite 3 (C3)	3	12	76.5	8.5	
Composite 4 (C4)	4	16	72	8	
Composite 5 (C5)	5	20	67.5	7.5	

Fabrication of Composites

Square composite bars of 30 cm x 30 cm with 1 cm thickness were prepared at different mixing ratios as mentioned in Table 2. First, all materials such as fibres, epoxy resin and hardeners were mixed manually with the help of the spatula. To obtain a square composite bar, a steel mould is used covered with polyethylene, and the mixture was poured and compressed with a 10 kg dead weight for 48 hours. Then, the weights were unloaded to de-mould the composites and at last, the composites were dried at room temperature for four days. As the full process was done by following the hand lay-up [33] method, no specific curing temperature was set for the fabrication of composites. Thickness was controlled with the help of steel mould that was filled with the materials with accuracy.

Characterization

ASTM D 3039 [1 inch wide and 10 inches long], ASTM D 695–15 [12.7 x 12.7 x 25.4 mm] and ASTM D790-10 [3.2 mm x 12.7 mm] standards were followed to investigate the mechanical properties such as tensile, compression and flexural, respectively of the developed hybrid composites using Universal Testing instrument (Autograph AG-X Plus, Shimadzu, Japan) [30-32]. For the hardness test, the specimens were made following ASTM D 785 requirements for composites, and they were tested for Rockwell-B hardness with a 20 mm length and a 25 mm diameter [34]. The test specimens were prepared by cutting with a steel saw. The specimens were mounted to the tester using a grip pressure of 2000 PSI. The strain rate for all the tests was 3 mm/min, and all the tests have repeated three times. The values during the test were recorded until the fracture occurred in the sample. The surface micrographic characterization was conducted using Scanning Electron Microscopy (SEM) (SU 3800, Hitachi, Japan) and the samples are cut using a normal cutter for the size of 1 cm x 1 cm.

RESULTS AND DISCUSSION

Tensile Properties of the Developed Composites

The evaluation of tensile loads of the developed hybrid composites has shown in Figure 2, which represents the strength variations of different specimens with different fibre-resin ratios. Figure 2, indicates a gradual increase in tensile load from 10% fiber content (C2) to 20% fiber content (C4). Figure 3 represents the ultimate tensile strength values of developed hybrid composites. It can be noticed that there is a gradual decrease in ultimate tensile strength from 15% fibre content (C3) to 25% fibre content (C5). The increase of the fibre content, binding with the epoxy and presence of voids in the composites (C3-C5) are the causes of the decrease in the ultimate tensile strength. Table 3 contains tensile properties in terms of ultimate tensile stress and elongation values. The results revealed that among all the samples in the 25% fibre loading sample (S5), there was a decrease in strength due to weak interfacial bonding. These result trends are (nearly) as similar as Ichetaonye et. al. However, when the newly developed hybrid composites were compared with plain epoxy composite and 10% bagasse composite, results revealed that developed composites have a very less amount of ultimate stress compared to plain epoxy composite and 10% bagasse composite.

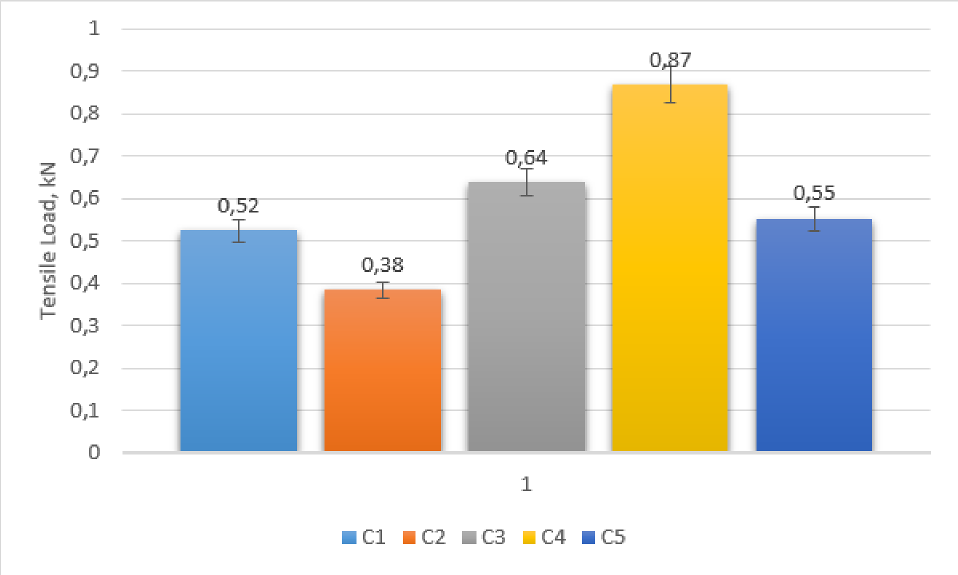


Figure 2. Breaking tensile loads on hybrid composite

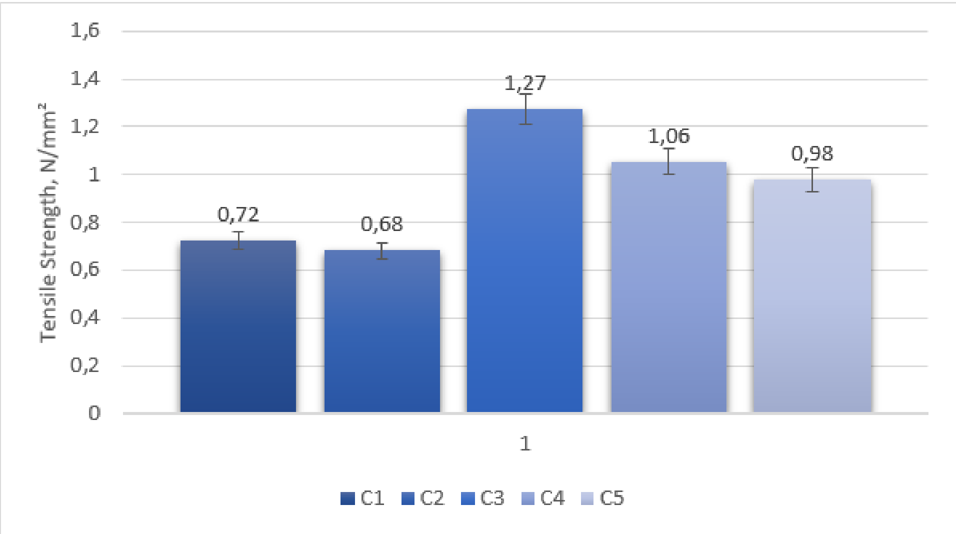


Figure 3. Tensile strength of hybrid composites

Table 3. Tensile properties of the developed hybrid composite materials

Properties	C1	C 2	C 3	C 4	C 5	Plain epoxy composite [37]	10% bagasse-epoxy composite [37]
Ultimate stress, (N/mm²)	2.34	2.19	2.36	1.85	1.80	35.79	22.26
Elongation (%)	1.97	4.72	2.52	1.65	2.46	1.40	1.64

Compression Properties of the Developed Composites

Figure 4 shows the compressive load of developed composites. The variation of compressive strength differs with the fibre contents. The compression strength results of the developed hybrid composites are presented in Table 4 along with their stress-elongation values. Comparing all the developed luffa-bagasse composites, C4 has the highest number of ultimate superior compressive strengths in terms of remaining hybrid composite samples. This improved ultimate compressive strength results in C4, achieved due to proper adhesion in the fibre and matrix (more fibre presence, makes it more compact with the use of the right amount of resin mixture). However, compression test results of developed luffa-bagasse hybrid composites when compared with bagasse-glass hybrid composites, C5 of luffa-bagasse hybrid composite showed higher compression test results. An overall addition of luffa in bagasse fibre substantially increases the capacity of the developed material to resist more load. Table 5 attached below includes the stress-strain diagram during the tensile test.

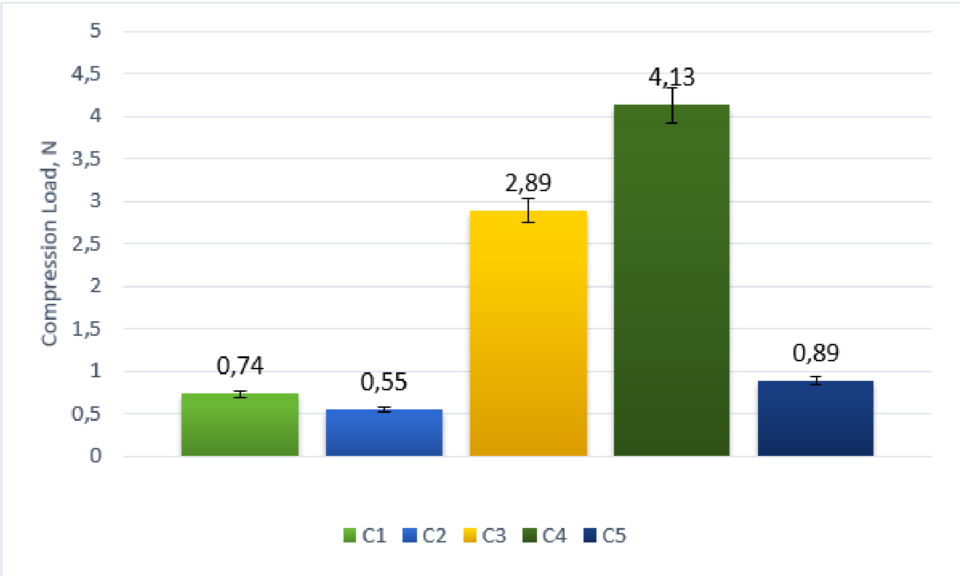
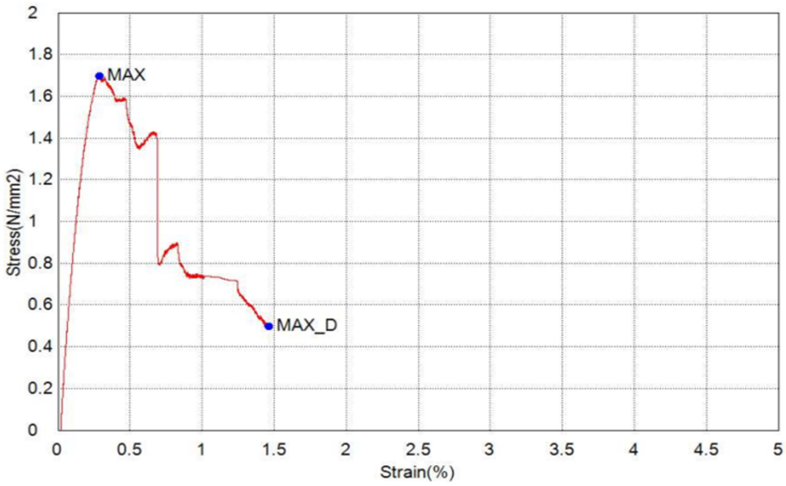
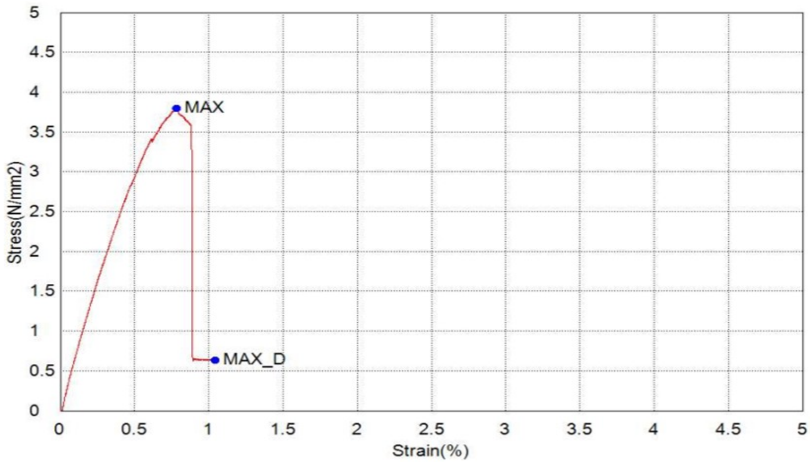
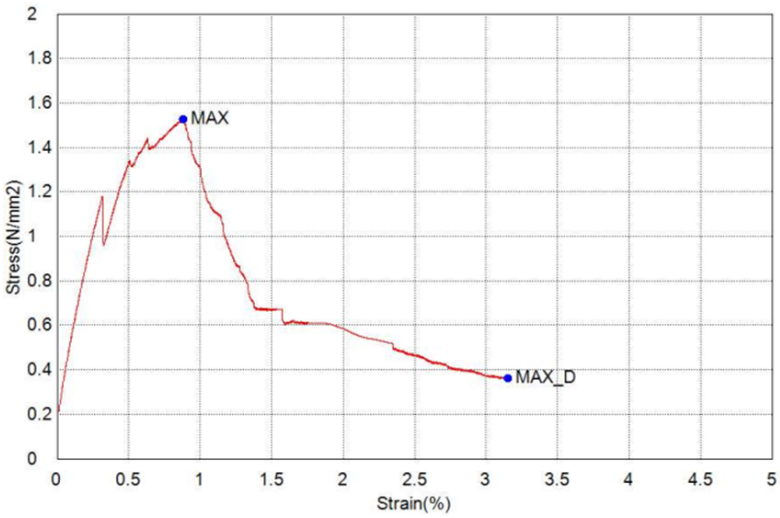


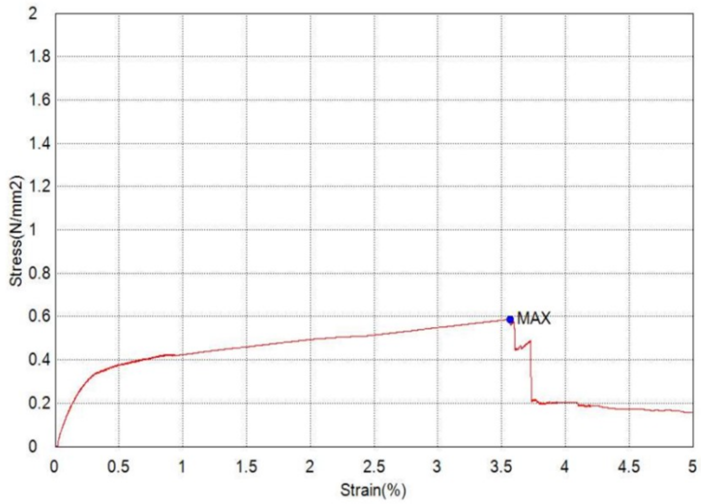
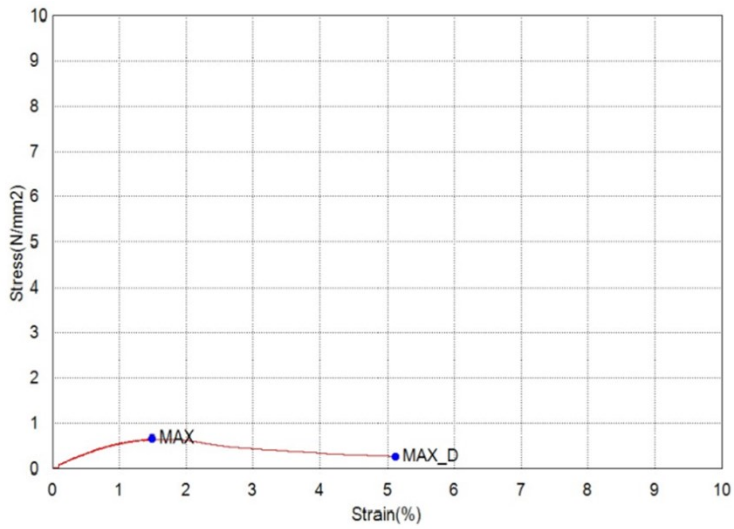
Figure 4. Compression loads on hybrid composite

Table 4. Compression properties of the developed hybrid composite materials

Properties	C1	C 2	C 3	C 4	C 5	Plain epoxy composite [37]	10% bagasse-epoxy composite [37]
Ultimate stress, (N/mm²)	10.71	10.27	11.82	22.22	10.13	65.28	49.85
Elongation (%)	1.46	2.12	2.17	3.13	1.78	0.74	0.51

Table 5. Tensile stress-strain diagram of hybrid composite materials

Sample	Stress-strain curve
C1	
C2	
C3	

Sample	Stress-strain curve
C4	
C5	

Flexural Properties of the Developed Composites

The evaluation of flexural loads of the developed hybrid composites has shown in Figure 5. The figure indicates a gradual decrease in flexural load in composites from 15% to 25% fibre per cent (C3-C5). The decrease in 25% fibre loading occurred due to the further addition of fibre content that weakened the fibre and polymer matrix bond. Moreover, table 5 contains the flexural strength test results of developed luffa-bagasse hybrid composites along with their stress-elongation values. The presence of proper bagasse and luffa fibre proportions with the resin matrix enhances the load-bearing capacity of the composite.

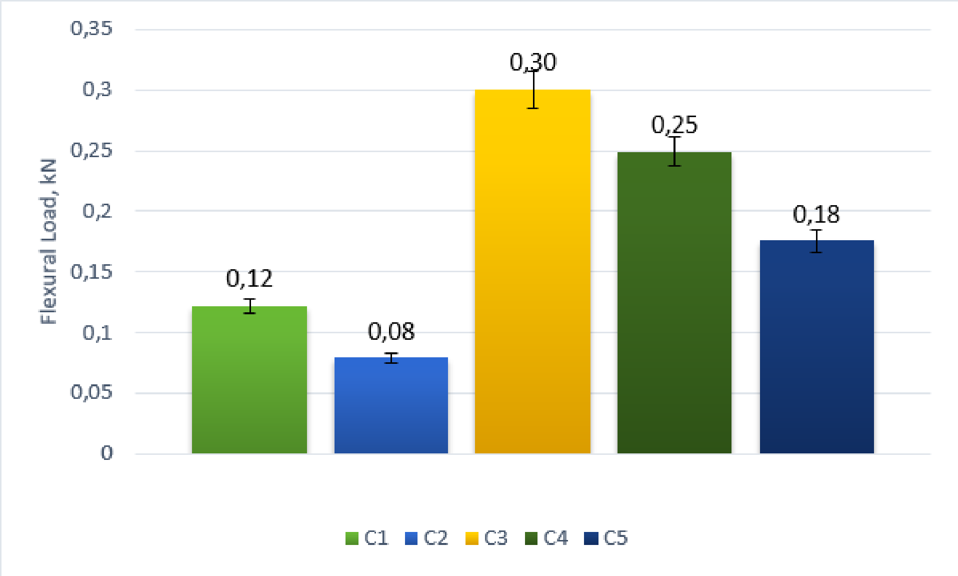


Figure 5. Flexural loads on hybrid composite

Table 6. Flexural properties of the developed hybrid composite materials

Properties	C 1	C 2	C 3	C 4	C 5
Ultimate stress (N/mm²)	9.93	3.86	8.22	6.78	6.91
Elongation (%)	6.26	17.97	12.40	4.63	12.50

The hardness of developed composites

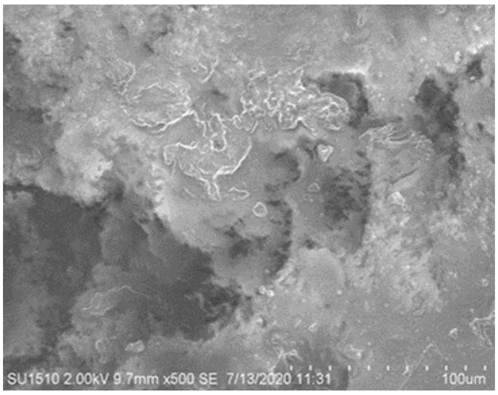
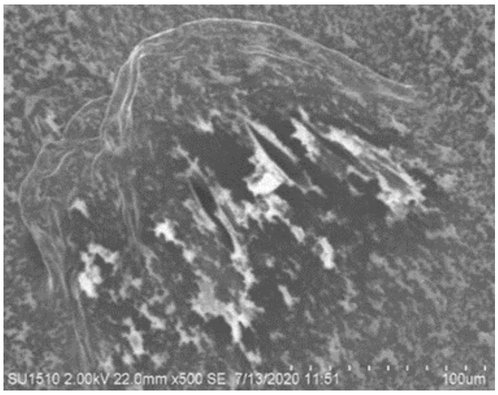
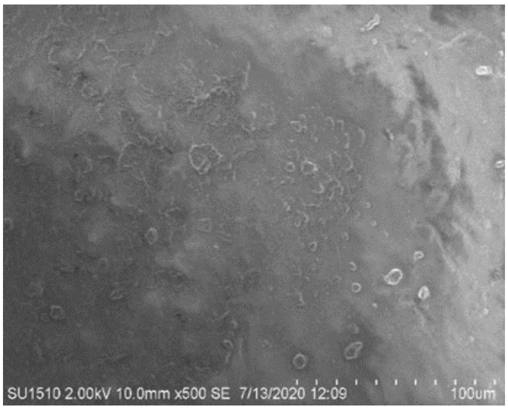
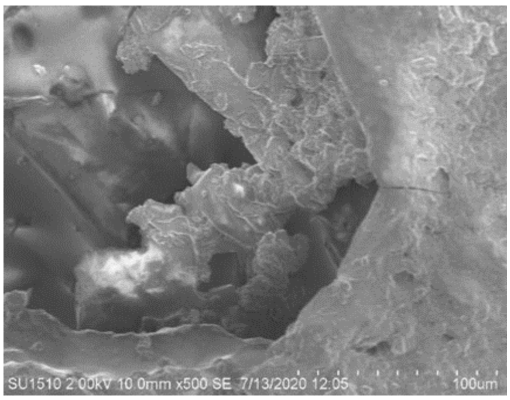
Two significant elements that influence the qualities of the composite are fibre configuration and volume fraction. For this test, only continuous, unidirectional fibres that are the same length as the specimen may be used. By applying an indentation load normal to the fibres' diameter and length, the composites' hardness characteristics are examined. The Rockwell hardness number found for samples C1, C2, C3, C4 and C5 were 20, 23, 28, 30 and 24 respectively. The hardness of a composite is increased by adding fibres to it that have higher moduli. This is because hardness depends on the relative fibre volume and modulus.

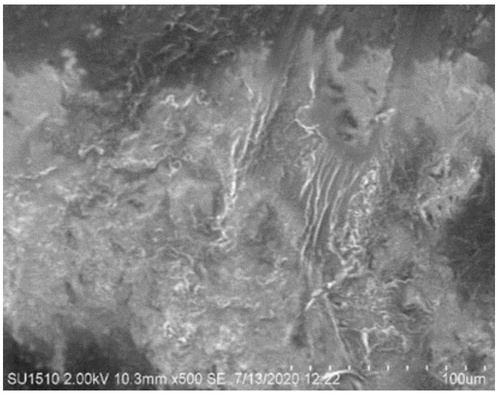
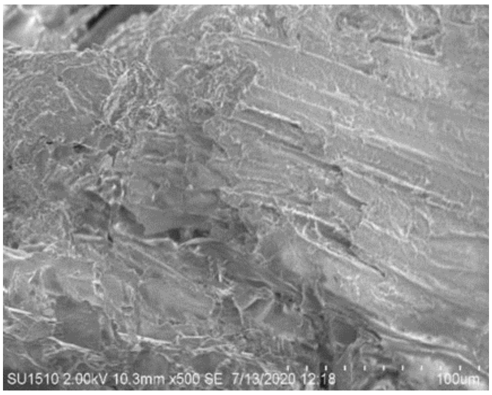
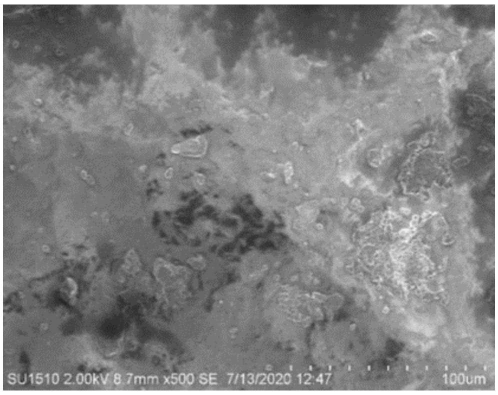
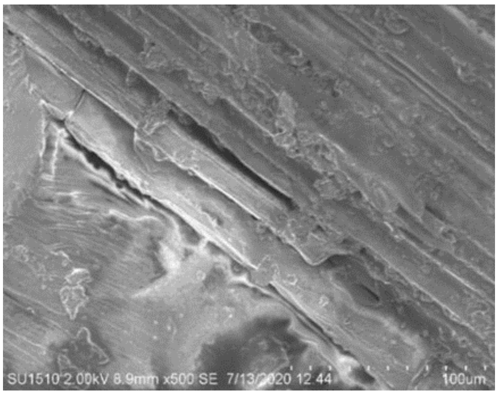
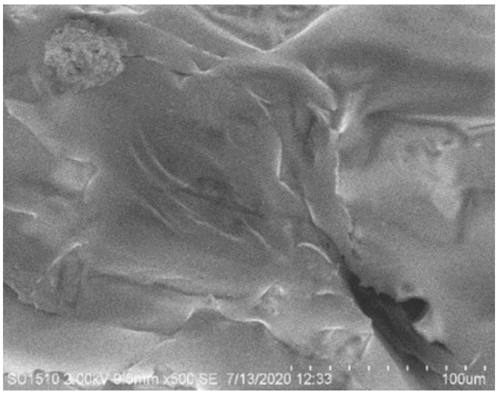
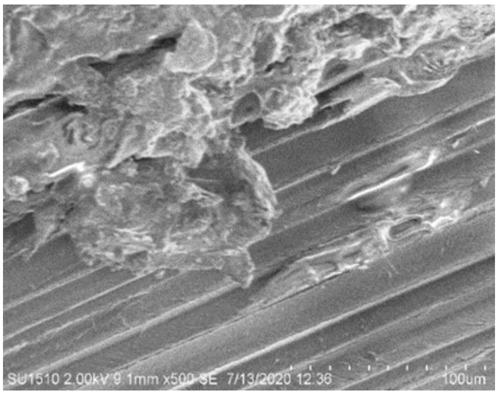
Microscopic Test for Morphological Studies

For microscopic analysis to study the morphological structures (particularly the surface characteristics) of the luffa-bagasse hybrid composites, a Scanning Electron Microscopy (SEM) test was undertaken. Scanning Electron Microscopy (SEM) test result plays an important role in the mechanical properties of the composite showing the state of dispersion of fibres into the resin matrix. After the SEM test, the fibre dispersion in developed luffa-bagasse composites has been evaluated. The test result revealed the dispersion of fibres for different weight percentages of composites in the epoxy resin matrix.

Table 7 contains SEM micrographs (from both surface and side view) of different hybrid composite samples at 100-µm magnification. From Scanning Electron Microscopy (SEM) test results, the SEM micrograph of C1 shows good dispersion of chopped bagasse-luffa fibres in the epoxy resin matrix. This type of result has occurred due to using the highest amount of epoxy matrix portion compared to the remaining samples. Hence, from the SEM micrograph of C1 it can be said that despite some uneven surface area overall good dispersion of chopped luffa and bagasse fibre is seen and as a result, a remarkable effect on the mechanical properties is obtained. SEM micrograph of C2 shows some fibre tears and pulls out this is due to an increased number of fibre proportions. The presence of blowholes and chopped fibres surface can be visibly observed. SEM micrograph of C3 shows porous holes. Overall, good adhesion has been seen in C3 when compared with the remaining micrographs. SEM micrograph of C4 depicts overall good adhesion between the epoxy matrix, luffa and bagasse fibres and the presence of more fibres. SEM micrograph of C5 shows even more fibres presence and a rough porous surface. As a result, the stress transfer is also less and a decrease in strength characteristics has been observed.

Table 7. Scanning electron microscopic view of composites

Composite No.	Front View	Side View
C1		
C2		

Composite No.	Front View	Side View
C3		
C4		
C5		

CONCLUSION

This research concentrated on using agricultural waste to produce innovative hybrid composites made of natural fibres. In this recently created Luffa aegyptiaca and sugarcane bagasse fibre-based epoxy hybrid composite, some mechanical properties and morphological qualities (through SEM test) were assessed in the presence of various fibre-matrix ratios. Following are the summarized results after the evaluation:

- Luffa fibres added to bagasse in the epoxy matrix increase compression strength. The highest compression strength was demonstrated by a composite (C4) with a 20% fibre content.
- Combining bagasse fibre with luffa fibre enhances the composite's flexural qualities. The composite with a 15% fibre content (C3) displayed the highest flexural strength out of all those developed.
- However, luffa fibre addition was unable to outperform ordinary bagasse-based composites currently on the market in terms of increasing ultimate tensile strength.
- Despite some fibre pull-outs and small porous surface patches, overall good fibre dispersion has been seen in SEM images of luffa-bagasse hybrid composite samples.

This natural fibre-reinforced hybrid composite is being developed, and it has the potential to be employed in a variety of industries, including packaging, particleboards, and plywood. However, additional research is needed to evaluate the shortcomings and make improvements to the features for future applications that will be practical.

Author Contributions

Conceptualization – Haque S and Siddique AB; methodology –Haque S; formal analysis –Haque S and Karim FE; investigation –Haque S; resources –Haque S and Karim FE; writing-original draft preparation – Haque S; writing-review and editing –Islam MR; visualization –Islam MR; supervision –Siddique AB. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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