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Original Article

Investigation of Mechanical and Wear Properties of Novel Hybrid Composite based on BANANA, COIR, and EPOXY for Tribological Applications

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Abstract *- Natural fibers are multifunctional elements that can replace glass fiber-based composite materials. Natural fiber-based hybrid composites result from reinforcing natural fibers into a matrix due to its many benefits, including low cost, lightweight, high strength, and low wear rate. Biocomposites are environmentally friendly, and they also have good mechanical properties, such as being non-abrasive and bio-degradable. As a result, the current study investigates the feasibility of using a hybrid banana-coir-epoxy composite for tribological applications. The present work has synthesized a banana-coir-based hybrid composite by mixing the biofibers into the epoxy resin by hand layup technique. Regarding binding efficacy, epoxy resin has been used, while solidum hydroxide (NaOH) alkali treatment is used for better adhesion. Banana coir epoxy-based hybrid composites are characterized for determining tensile strength properties by universal testing machine and specific wear rate by using pin on disc apparatus. ASTM standard has been followed while performing the test procedure and essential calibration. In the current research, banan-coir epoxy composite based on five different sets of banana and coir fibers has been synthesized by volume fraction. This study helps to determine the most suitable banana-coir epoxy hybrid composite for tribological applications. The results demonstrate that BBCC (20% coir, 20% banana, and 60% epoxy) provides the lowest specific wear rate, while BBBB (0% coir, 40% banana, and 60% epoxy) delivers the highest mechanical strength.*

Keywords *- Banana-coir-epoxy, Biodegradable, Thermosetting, Natural fiber, Synthesis, and Characterization.*

1. Introduction

Many multicomponent materials can be used as composites. Composites are intriguing because they combine material properties in surprising ways. Two or more constituents combine to form composite materials. In many cases, the matrix or continuous phase is formed by a stiff and robust or structural component embedded in softer and more compliant constituents. A polymer composite is a material with at least one polymer component. biofibers or natural fibers consist of sugar, starch, lignin, moisture, oils, proteins, cellulose, hemicellulose, carbohydrates, etc. Environmental and economic benefits are driving the trend toward bio-based polymers and materials. Seed, bast, fruit, stalk, and leaf are plant-based fibers. Oil, banana (also known as musa), wheat, jute, kenaf, wood, flax, and other bio fibers are all available for reinforcement to make the composite. Plant-based composites are more ecologically friendly, lightweight, corrosion-resistant, cheap in cost, low population density, adequate high modulus, and biodegradable. Biofiber reinforced composites could be a nontraditional, high-value material. Natural fibers are very strong and stiff, but their fibrous nature makes them challenging to utilize in load-bearing applications. Fiber acts as reinforcement in fiber-reinforced composites by giving structural stability and rigidity. Simultaneously, epoxy functions as an anchor to hold the fiber in place while creating adequate structural components.

The design application of mechanical components needs to consider the wear and tear of the functional components. While executing their functions, the functional components have been in relative motion, which causes wear and tear. These factors can be minimized but cannot be excluded [1,2]. Parikh and go [3] reviewed the tribological behavior of reinforced polymer composites. They found that Friction and wear are two factors that add to dissipate energy and minimize the material performance. They also observe that reinforced polymer composite materials can be substituted for neat polymer, showing enhanced tribological behavior. Aldousiri et al. [4] researched fiber reinforced polymer composites. They assert that the composite may be used as a substitute for traditional metals and alloys in various structural and tribological applications. Zsidai et al. [5] have executed an investigation on fiber-reinforced composite. They discovered that fiber length, volume percentage, and internal adhesion between the matrix material and fibers affected the composites.

Additionally, they report that desirable composite strength, stiffness, and tribological characteristics may be reached by including extra fibers in the matrix materials. Numerous experiments have been carried out to correlate mechanical properties to the fiber's length of reinforced composite polymers[2,6–9]. They discovered that the length of the fiber has a substantial effect on mechanical qualities such as stiffness, strength, and impact properties. There is a significant opportunity to study composite materials' wear and frictional behavior in collaboration [10–13]. Tiwari et al. [14] have investigated bearing wear, earth moving equipment wear, and mining. They discovered that the most severe wear in the applications is abrasive wear. Friedrich et al. [15] have created fiber-reinforced polymers. They determined that the interfacial bonding between matrix and reinforcement is critical in defining composite properties.

Furthermore, they found that continuous fiber reinforcement is more effective than discontinuous fiber reinforcement in reducing abrasive wear in composites when damage to longer fibers is concentrated as wear with abrasive particles. The remaining fibers contribute to the composites' wear resistance. Bahadur and polineni [16] experimented on glass-reinforced composite for varying fiber lengths. They reported that fiber length erosion is not influenced at high impact angles. They also notice that the composite has high mechanical strength, a lower frictional coefficient, and a significant wear rate than steel surfaces. Pihtili [17] experimented with evaluating the mechanical properties of natural fibers-based composite as a replacement for glass fiber due to its demeriting environmental issues. They observe that natural fibers as reinforcement have high specific mechanical properties and are biodegradable. Kishore et al. [18] experimented on a glass–epoxy composite system. They highlight that natural fiber-based composites have limited structural applications due to their inferior strength and stiffness compared to synthetic fiber-based composites. Until recently, there has been a minimal investigation into the tribological application of natural fiber-based compounds as a replacement for glass fiber reinforced composites. Many analyses have shown that biocomposites have poor stiffness and mechanical performance, which may be enhanced with proper structural engineering and better natural fiber configurations [10,19–22].

Natural fibers are low-cost and lightweight than synthetic polymers, but their minimal mechanical properties have become a concern for many researchers. Hybridization of natural fibers or nanofillers in natural fiber can be used to solve the problem [23–25]. Das and Biswas[26] conducted an experimental investigation on coir epoxy composite. They discovered that natural fiber-based hybrid composites had structural characteristics. They also note that composite density increases with fiber content while decreasing with fiber length. Also, hardness and tensile strength increase with fiber length and composition. Boopalan et al.[27] synthesized jute banana epoxy-based composites. They observed that adding banana fiber up to 50% by weight improves jute/epoxy's mechanical and thermal characteristics of jute/epoxy. And also the hybrid composite wear is also affected by the order in which layers are stacked. Gates [28] concluded that wear could also be known by abrasion, and in any abrasion wear, 3-body abrasion, 2-body abrasion can appear. Banana is very abundant in India, and it is extracted from banana tree bark, whereas coir is obtained from the coconut tree. The fiber density and mechanical properties of bananas are influenced by many parameters[29–33]. Srinivasan et al. [34] experimented on banana-flax-based natural fiber composite. They found that banana is a lingo-cellulosic fiber with superior mechanical properties. They also claim high strength, comparable to conventional materials such as glass fiber. Perov and Khoroshilova [35] reviewed polymer hybrid composite materials. They notice that environmentally friendly items with mechanical characteristics combine to form a hybrid composite material with the most conceivable uses. Muralikrishna et al. [36] evaluated the mechanical properties of banana fiber composite. They found that fiber loading improves the mechanical characteristics of the composite, but they also claim that glass may be substituted with banana fiber. Ku et al. [37] have tested the mechanical characteristics of kenaf, sisal, coir, and jute reinforced composites. They concluded that Increases in fiber volume fraction had improved the tensile properties of the coir-based composite. Boopalan et al. [27] also the hybrid composites made from treated banana fibers have higher ultimate tensile values than the jute fiber hybrid composite. Banana [38,39], Sisal [40], Coir [41–44], jute [45] and bamboo[46] have all been studied as natural fibre composites. Yogish et al. [33] investigated the effect of coir fiber and rice husk to improve the polymer composite's mechanical property with epoxy resin as the base material. Coir is the fibrous substance consisting of the coconut fruit's (Cocos Nucifera) dense middle layer (mesocarp). The husk contains approximately 25% fine material and 75% fibers. Sivaranjana and Arumugaprabu [47] reviewed banana fiber-based composite. They found many factors influencing hardness and other mechanical properties. They found that the addition of polyester gives good harness properties. Vardhinhi et al. [48] evaluated the effect of alkali treatment on banana fiber-based composite. They found that it has more substantial mechanical properties and absorbs less water. Chavhan and Wankhade [49] have reviewed banana and coir fibers' physical characteristics and stated many practical engineering applications. Table 2. Consists list of various engineering applications based on composites.

Table 1. An important application of hybrid composites[32]

Area	Applications
Electrical and electronic appliances	Packaging, switches, Casting, pipes, etc.
Aerospace industries	Propellers and helicopter fan blades, Wings, Tails, etc.
Civil industry	wall, roof tiles, floor, partition boards, panels, window and door frames, false ceilings, etc.
Transportation	Gears, railway coach interior, Automobile, etc.
Daily used substances	helmets, suitcases, baseball bats, ice skating boards, bicycle frames, lampshades, etc.
Furniture	Table, bath units, Chair, hanger, shower, handle, door panel, etc.
Storage tank	Grain storage silos, biogas containers, dryers, Post-boxes, etc.
Marine and military application	Various applications.

Shanmugam and Thiruchitrambalam [50] evaluated the effect of hydrophilic content of natural fibers on composite. They found that it is the essential element of natural fibers that causes poor adherence between fibers and matrix, reducing the engineering characteristics of the composite. Chemical treatments of fibers, such as thermal, alkali, potassium permanganate, etc., can mitigate these limitations. Prasad et al. [44] checked the effect of NaOH treatment on varying lengths of banana fiber. They found improved mechanical properties and less water absorption capability in the composite. Kumar et al. [51] experimented with evaluating the effect of layering patterns and chemical treatment on banana coir-based composite. They found a positive effect on better energy absorption capability, i.e., damping indication, and it also improves mechanical performance. Adhikari and Gowda [52] conducted a test to identify the effect of volume fraction of fiber on banana jute-based hybrid composite. They observe that flexural, tensile, and impact strength increase continuously with increasing fiber volume fraction for banana jute hybrid polyester composite.

The previous studies on banana-coir epoxy hybrid composite materials report that the synthesis and characterization of banana-coir epoxy composite have been performed for general applications. However, literature on the synthesis and characterization of banana-coir epoxy composite for frictional materials application is less available. Therefore, the present work attempts to investigate the best-suited Banan-coir epoxy hybrid composite, synthesized to use as frictional materials. Hence, the investigation has been carried out using a banana-coir-epoxy-based hybrid composite for tribological applications. The current research focuses on the varying composition of banana coir epoxy fibers to determine the lower specific wear rate, acceptable Somerfield number, and desired mechanical strength acoustically stable material.

2. Materials and Methods

This section has thoroughly discussed the materials and methods used in this experimental investigation.

2.1. Materials

A local retailer provided the epoxy resin kit and alkali (NaOH). Manually extracted banana fiber is from banana tree bark and coir purchased from local retailers. Hardener and epoxy were mixed in a 1:1 weight ratio.

2.2. Chemical Treatment of Banana and Coir

Fibers were chemically treated with NaOH solution before fabrication of composite samples to improve fiber adhesion. The coir and banana fibers were soaked for 8 hours in a 0.05N NaOH solution before being thoroughly dried in the sun to remove moisture. Chemical treatment was used to increase the fiber's roughness in fabrics. Fibers' alkaline treatment removes wax and oily material from the fiber surface, causing the surface to become even tougher.

Table 2. Chemical properties of banana and coir

Fibers	Moisture (wt %)	Cellulose (wt. %)	Hemi-cellulose (wt. %)	Lignin (wt. %)
Banana	10-12	63-65	19	5
Coir	8-10	33-36	13	45

2.3. Mold preparation

The mold box is made up of mild steel with dimensions of 200mm×200mm×50mm. The composite samples were made using The Hand Layup Process. The molding box serves as a cover for the fibers, compressing them and preventing leakage during compression. ASTM standards were followed while preparing the molding box.

2.4. Fabrication of composites

Initially, epoxy was taken as the base material, mixed with banana fiber and coir fiber. Both the fibers have a length of 10 mm. The molding box was cleaned using normal water; immediately after cleaning, the box dried for 30 minutes of dwell time in sunlight. The wax was single coated throughout the molding box for easy removal of samples. Hand layup techniques have been used to fill the prepared mold box with the required mixture of banana, coir fiber, and epoxy. The molding box was subjected to continuous 200 Newton loads until achieved the required composite layer thickness, and then the hardener was poured. The details of the fabrication of composite samples are provided in Figure 1.

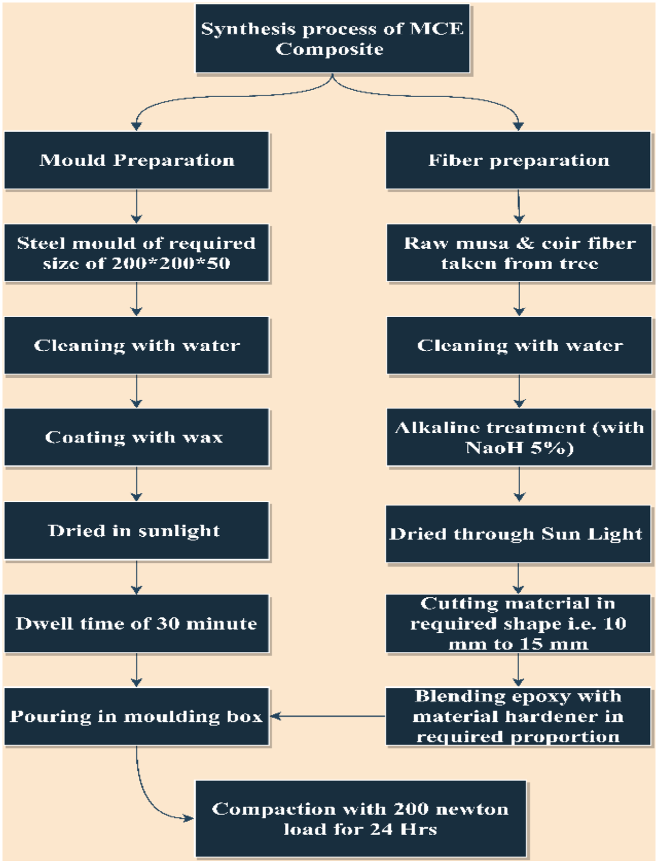
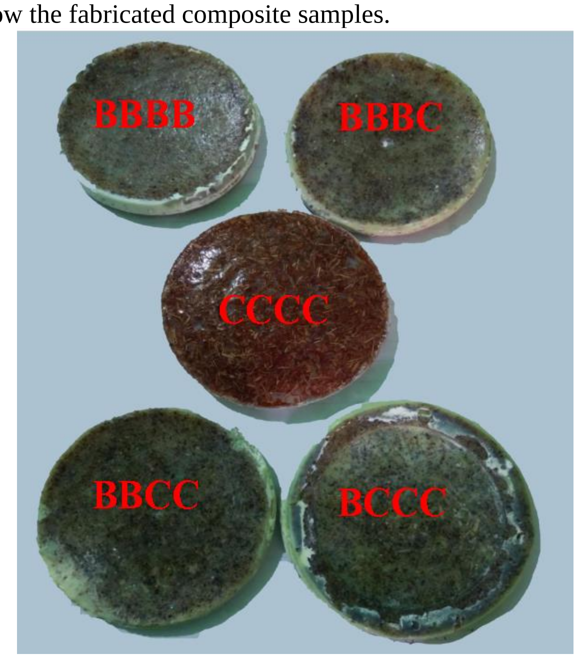
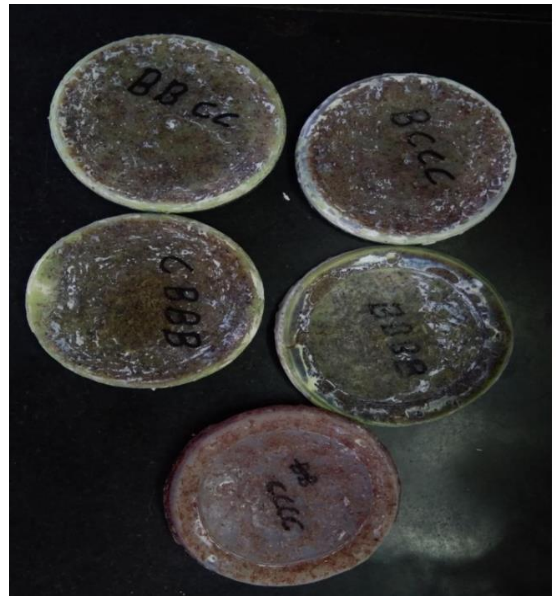


Fig. 1 Fabrication process of Banana-Coir based composite

Composite samples were taken from the mould after curing and sliced to shape by ASTM standards to analyze mechanical behavior. Compositions of composite samples by volume % are shown in Table 4, and Figures 2(a) & 2(b) show the fabricated composite samples.



(a)



(b)

(c)

Fig. 2 Fabricated composite samples. (a) and (b) front and top view of Sample for Wear Test, (c) Sample for Tensile test

Table 3. Composition of specimens

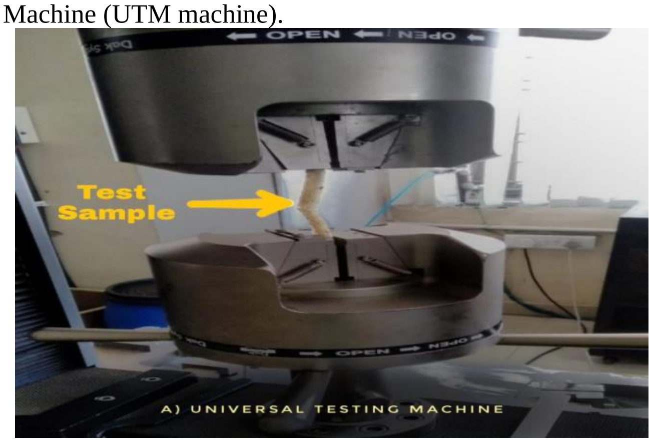
Sr. No	Designation	Composition (% volume)
1	CCCC	Coir (40%) +Banana fiber (0%) + epoxy (60%)
2	CCCB	Coir (30%) + Banana fiber (10%) +epoxy (60%)
3	CCBB	Coir (20%) + Banana fiber (20%) +epoxy (60%)
4	CBBB	Coir (10%) + Banana fiber (30%) +epoxy (60%)
5	BBBB	Coir (0%) + Banana fiber (40%) +epoxy (60%)

2.5. Wear Test

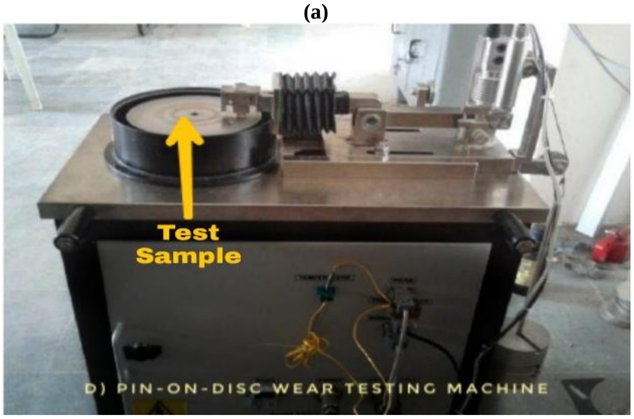
A pin-on-disc wear machine was used in the research. The testing is carried out using Pin on Disk equipment following ASTM D3702, as shown in Figure 3. (b). A unique attachment is designed to enable the machine to carry the sample in the holder. Before and after the wear test, weigh the samples. The parameters are load, speed, and sliding distance [38]. It is believed that the sliding rate is 200 rotations per minute. The loads were 10, 15, 20, and 25 Newton. The distance between the two points is kept at 1000 meters. All other factors are similar to testing requirements.

2.6. Tensile Test

The most basic mechanical test that can be done on any material is a tensile test, often known as a tension test. Tensile tests are simple, affordable, and completely standardized. ASTM D638 standards made the composite samples. The specimens of composites measured 12.7 mm in width, 5 mm in thickness, and 127 mm in length. Figure 3 (a) shows that the tensile test was done in a Universal Testing Machine (UTM machine).



(a)



(b)

Fig. 3 (a) UTM machine, (b) Pin-On-Disc wear testing machine[37]

3. Results and Discussion

3.1. Tribological Characteristics

The test included two fixed parameters and one variable. The fixed parameters were a 200rpm sliding rate and 1000m as center distance. In contrast, the effect of increment in loads from 10, 20, 30, and 40 Newton has been tested to determine the specific wear rate (mm3/Nm) of Banana-coir composite samples. Figure 4 illustrates that when load rises, so does the specific wear rate for all samples since heat development on the mating surfaces and frictional forces are also variables. For all samples, the specific wear rate of composites rises as the load exerted increases. Because the applied load on the asperities is the same everywhere over the irregularity, each one enters deeper into the surface as the applied load rises. Deep penetrations result in a greater wear rate. Plastic deformation at the body allows the worn surfaces to heat up, allowing the matrix and fiber interface to debond.

Consequently, a significant portion of the material from the wear surface is lost when a higher load is applied, as shown in Figure 4. Because the reinforcement of natural fibers, the volume fraction of natural fibers in the composites, and the chemical treatment of the composites all affect their tribological properties. The NaOH alkali treatment assists in debonding between fibers into the matrix, enhancing the composite to carry higher loads. The use of thermoset epoxy resins leads to a further reduction in the specific wear rate of the banana-coir epoxy composites. The path was followed by reinforcing fibers into filler epoxy resins to reduce specific wear rates under adhesive wear loading such as mechanical and tribological.

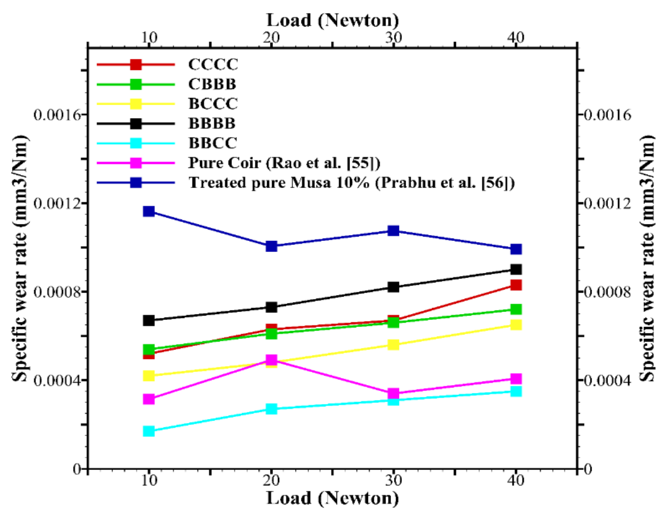


Fig. 4 Specific wear rate for banana-coir epoxy samples under different loads (N)

3.2. Tensile test

Figure 5 illustrates the composite specimens and their tensile test results. Fiber characteristics affect the mechanical properties of banana coir-based epoxy composites. The figure shows that as the volumetric percentage of banana fiber loading increases, the tensile strength of hybrid composites also increases. The highest tensile strength can be seen for the BBBB sample and the lowest tensile strength for CCCC. As the banana fiber content increases in banana-coir-epoxy-based hybrid composite, it adds structural stability compared to coir.

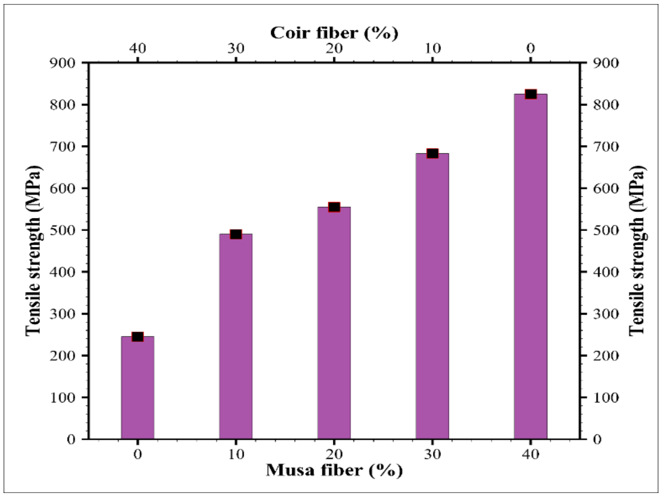


Fig. 5 Variation in tensile strength due to changes in banana and coir fiber loading on banana-coir epoxy hybrid composites and previous work

4. Conclusion

This experimental investigation of banana-coir-epoxy-based novel hybrid composite's mechanical and wear behavior leads to various very significant and novel conclusions.

- The wear characteristic of composites improves by hybridizing banana and coir fiber.
- The tensile strength of composites increases as the percentage of banana fiber loading increases.
- All specimens exhibit a higher wear rate as load values increase.
- This study also shows that minimum wear strength is obtained by mixing banana and coir fiber in equal amounts.
- The results demonstrate that BBCC (20% coir, 20% banana, and 60% epoxy) provides the lowest specific wear rate, while BBBB (0% coir, 40% banana, and 60% epoxy) delivers the highest mechanical strength.

Since mechanical elements should have a low specific wear rate while also providing strength to withstand loads, BBCC (20% coir, 20% banana, and 60% epoxy), which shows the same properties, can be recommended for tribological applications.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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