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Effect of Chemical Treatment on Mechanical Properties of Hybrid Epoxy Composites Reinforced with Sisal and Bamboo Fibers

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The research utilized hybridized composites that were hand-laid with a combination of natural reinforcing materials, an epoxy polymer matrix, and fillers made of cellulose and graphite. The reinforcing materials utilized were bamboo and sisal. Investigations on mechanical properties, thermal stability, and reinforcing effects of hybrid composites were conducted by thermogravimetric and mechanical means. Mechanical testing showed that increasing the amount of bidirectionally woven bamboo fiber improved the hybrid composites' tensile and flexural strengths, whereas increasing the quantity of chopped sisal fiber reduced it. The findings of the Izod impact tests showed that chopped sisal fibers were more resistant to impact loads than braided bamboo mat fibers. Consequently, the hybrid composites' impact energy increased in direct proportion to the amount of chopped sisal fiber used. Researchers looked at the surface appearance of hybrid composites with scanning electron microscopy (SEM) and discovered multiple failure routes, such as fiber pullout and cracks.

Keywords: Bamboo; hybrid composites; graphite; mechanical properties; natural fiber; thermal stability; sisal

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The transportation and aerospace sectors are only two of several that have long made use of artificial fiber reinforced composites. Despite the attractiveness of synthetic fibers as a result of their biodegradability, recyclability, and eco-friendliness, increased environmental concerns have led to a boom in demand for composites reinforced with natural fibers [1]. Among their many useful qualities are the great strength, low weight, and durability of natural fiber polymer composites. Building construction, impact energy absorption, aircraft, and vibration isolation, are just a few of the many areas that utilize these composites [2]. The increased stiffness and strength imparted by the carbon bonds in a natural reinforcement's structure makes it preferable to synthetic reinforcements. It is possible that natural fiber-reinforced polymer composites will eventually replace conventional, non-biodegradable composites. Fiber, matrix, and filler material characteristics have been the focus of numerous evaluations of composite materials [3]. Researchers have examined a variety of natural fiber reinforcements, including wood, reed, grass, agave, sugarcane, leaf, seed (coir), core, bast, and waste.

The authors created composites with a matrix of epoxy polymer and reinforcements made of fibers. Composites strengthened with sisal, and bamboo fibers were tested and evaluated based on mechanical parameters like tensile, flexural, and impact behavior [4]. Fiber reinforced epoxy composite outperformed other natural composites like tamarind seed powder in terms of tensile strength and density. Although natural fibers have several advantages when used in composites, such as low density, biodegradability, and affordability, they also have certain disadvantages, such as poor matrix compatibility and comparatively maximum water absorption. To alter the surface properties of the fiber, chemical treatments are thus occasionally required [5]. The surface modification of the composites can improve their properties, according to previous studies. By treating the fiber with an alkaline solution and adding a compatibilizer, the wax component was removed, increasing the natural reinforcement's bonding potential with polymer matrices [6]. The amount of moisture in the finished product is another factor that influences the performance of natural reinforcing. As the moisture content in the natural reinforcement is evaporated at a high

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temperature during the fabrication process, it forms small bubbles [7]. These bubbles induce porosity in the composite, which in turn deteriorates its properties. Treatment of natural fibers improves their mechanical properties by 10 % to 15 % compared to untreated ones, according to the research. The impact, hardness, flexural, and tensile strengths of chemically treated hemp fiber laminates are higher than those of epoxy composites reinforced with untreated hemp fiber [8]. Mechanically and thermally, laminates composed of a polyester matrix reinforced with jute and bamboo fibers are superior than unreinforced composite. Our research suggests that, owing to their better thermal and mechanical properties, composites composed of bamboo fibers could supplant composites composed of manufactured glass fibers. The experimental investigation of the mechanical and thermal properties of alkali-treated sugarcane fiber and tamarind seed powder composite laminates was carried out [9]. The tensile strength of composites reinforced with treated fibers was higher than that of pure polymers. Mechanical characteristics of hand-layup epoxy matrices reinforced with olive and bamboo fibers have been the subject of multiple studies. The researchers found that the highest tensile strength was achieved with a greater weight-to-sisal fiber proportion [10]. In this study, hybridized epoxy-based composites strengthened with chopped sisal natural fibers and bidirectional woven mat bamboo were produced using a standard hand layup technique. Epoxy was filled with graphite and cellulose to increase the hybrid composite's performance at elevated temperatures. We evaluated the mechanical qualities and thermal stability of the hybrid composites in further detail and quantified the impacts of reinforcement using thermogravimetric and mechanical analyses.

EXPERIMENTAL METHODOLOGY

Materials

The materials used to create the composite laminates in this research were an epoxy matrix, filler, and two types of natural fibers sisal and bamboo. As its matrix, Huntsman's Araldite (LY 556) is made of a bisphenol-F epoxy polymer resin with the Aradur HY 951 hardener. Tables 1 and 2 detail the properties of epoxy and natural fibers respectively.

Preparation of Composites

The hybrid composite was created by employing the time-honored technique of hand layup. Some natural fibers undergo an alkaline treatment called mercerization before they are even processed. In a solution of sodium hydroxide (NaOH) and water, the natural fibers were let to soak for two hours at room temperature. Then, they were left to air dry. Natural fibers' surface quality was improved by the alkaline treatment, which removed surface impurities like lignin, wax, hemicellulose, and oil. A gentle stainless-steel mold has liquid wax applied to its walls to facilitate the substance's release. After 5 minutes of stirring with an electric stirrer, a mixture of 10 % hardener and 40 % epoxy resin was formed. The mechanical characteristics and thermal properties of the composites were enhanced by adding graphite to the mixture [11]. The hand layup procedure started after the matrix had been agitated for an additional five minutes with sawdust added. The mold was subjected to a 48-hour room temperature compression with a weight of 15 kg once the fabrication procedure was finished. Each of the five hybrid composite samples undergoes the same procedure. We tested five different mixes of bamboo woven cloth and chopped sisal fiber to see how the hybrid composite fared. Epoxy resin, graphite, bamboo, and sisal fiber are all listed in Table 3 along with their respective designations and compositions.

Table 1. Characteristics of the epoxy.

Properties	Range
Viscosity at 25ºC	10-12 cP
Glass Transition Temperature	140ºC
Density	1.2 g/cm^3
Temperature for Curing	80ºC
Texture	liquid

Table 2. Characteristics of the material used in this study

Properties	Bamboo Fiber	Sisal Fiber
Diameter of fiber (µm)	12	18
Density (g/cm^3)	1.45	1.4
Type	Mat	Chopped Fiber
GSM (µm)	135	205

Table 3. Composition of materials used in the hybrid composites.

Specimen Code	Epoxy (g)	Graphite (g)	Saw dust weight (g)	Bamboo (g)	Sisal (g)
S1	150	20	15	77.5	37.5
S2	150	20	15	67.5	47.5
S3	150	20	15	57.5	57.5
S4	150	20	15	47.5	67.5
S5	150	20	15	37.5	77.5

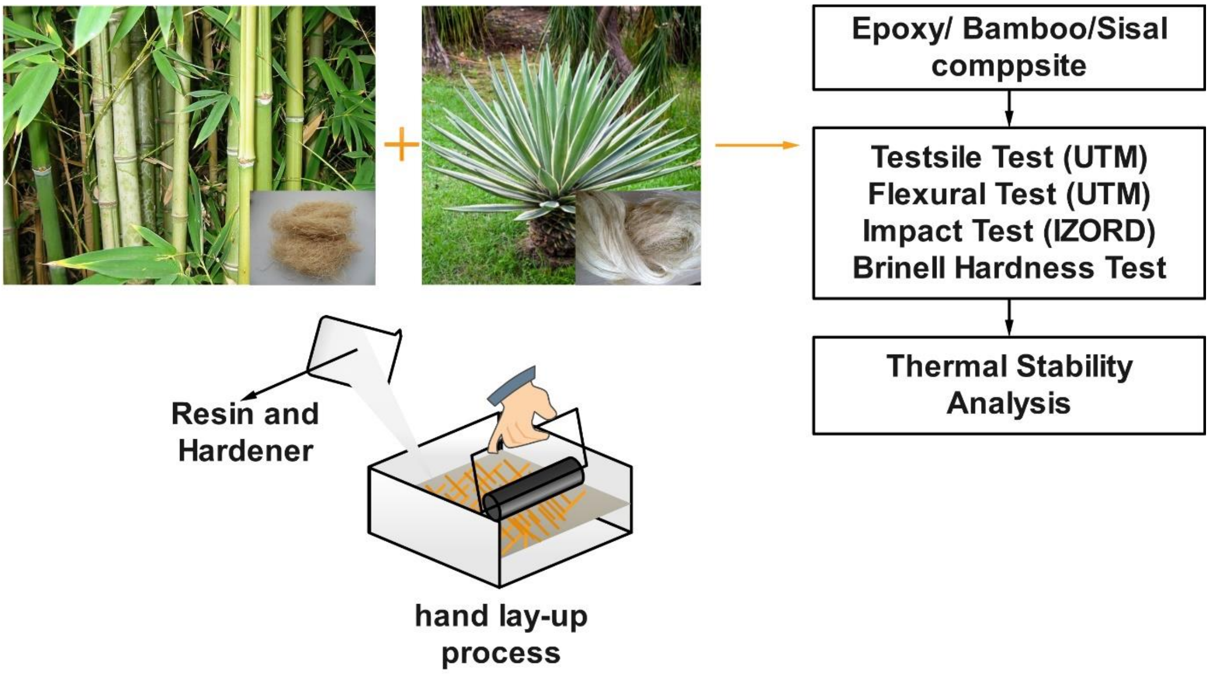

Figure 1. An illustration of experimental process of this study.

Properties of Fabricated Composites

In tests using hybrid composites, a number of mechanical properties were investigated. These included flexural strength (FS), impact strength (IS), thermal properties, and tensile test (TS). Figure 1 shows the details of the research approach. The tensile test was done using an Instron universal testing machine (UTM) in accord with the procedures specified by the ASTM D638 standard. The dimensions used for the tensile test samples' machining were 250×25×3 mm per standard. The FS on a sample measuring 130×12×3 mm was carried out in accordance with ASTM D790. In compliance with ASTM standard D256, the hybrid composite samples were machined to measurements of 35×12×3 mm and then put through an Izod impact test. A morphological investigation was conducted using a German scanning electron microscope (SEM) (ZESIS EVO 18). The thermogravimetric analysis test (ASTM E1131) is used to find out how stable a hybrid epoxy composite is when heated.

RESULTS AND DISCUSSIONS

Flexural Strength (FS)

In order to evaluate the FS of the hybrid epoxy composites, the 3-point flexural analysis was used. Presented in Fig. 2(a) are the findings from five different hybrid composite samples. A pattern comparable to tensile strength was observed. Sample S1 achieved the highest flexural strength of 55 MPa. In sample S4, the lowest flexural strength value was measured at 35.99 MPa. There was a 49 % decrease in flexural strength for sample S4 and a 41% decrease for sample S5, as compared to sample S1. Samples S4 and S5 may have had insufficient fiber and matrix impregnation, which could explain this. In comparison to the other four hybrid composite samples, Sample S1 has the ability to absorb a greater amount of flexural strength. This is because the bamboo and sisal fibers are very securely bound together by the polymer matrix [12].

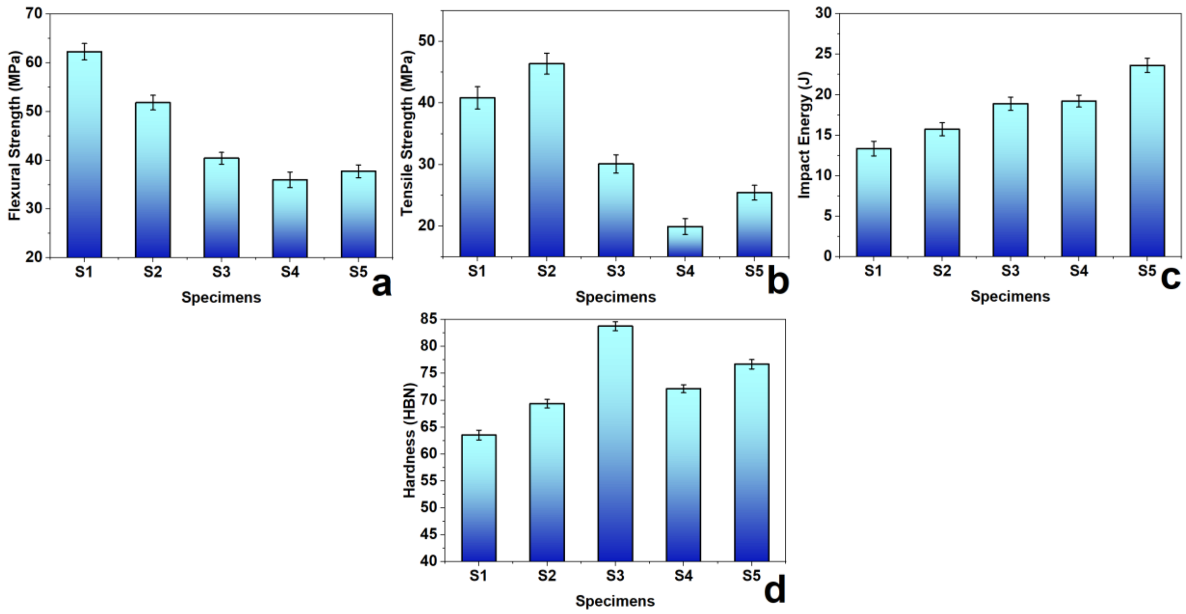

Figure 2. Evaluation of (a) Flexural strength (b) Tensile strength (c) Impact energy and (d) Hardness of the fabricated composites.

Tensile Properties

All of the hybrid composites that were made were tensile tested, and the findings are shown in Figure 2(b). Sample S1, a hybrid composite consisting of 77.5 g of bamboo and 37.5 g of sisal fiber, exhibited the highest tensile strength at 40.85 MPa among all the samples. The sample with the lowest recorded tensile strength was S4, which was composed of each 57.5 g of bamboo fiber and sisal fiber. The sample's strength was 19.93 MPa. Hybrid composites with an increased amount of chopped sisal fiber resulted in samples with lower TS; sample S5, with 25.44 MPa, was 48 % weaker than sample S1, which had the highest value. Researchers found that adding more bidirectional woven bamboo fiber to the hybrid composite increased its tensile strength, whereas adding more chopped sisal fiber diminished it [13]. The TS of a composite material composed of natural and synthetic fibers is most affected by the type of woven fabric [14].

Impact Energy

The hybrid composites developed for this study were evaluated for their energy assimilation capabilities using an Izod impact test, which measures the effect of fiber reinforcing on such laminates. Five hybrid composite samples were tested for their impact energy absorption capabilities, as shown in Figure 2(c). Out of all the hybrid composite samples tested, S5 exhibited the greatest impact energy at 23.62 J. Out of all the hybrid composite samples, sample S1 had the lowest impact energy at 13.36 J. Compared to sample S5, which had a value of 18.22 J and an equal amount of bamboo and sisal fiber, sample S3 had a value that was 33 % lower. Incorporating more chopped sisal fiber and bamboo woven fabric into the material resulted in a higher impact energy [15]. When comparing chopped fibers to woven mat fibers, it was found that the former could withstand more impact stress. The results are consistent with those of earlier studies [16, 17].

Hardness

The Brinell hardness test was employed to measure the hardness of the various composite. The findings may be seen in Figure 2(d).

The hybridized composites tested here ranged from very soft (S1) to very hard (S3), with S3 having the greatest hardness value (83.76 HV). Composites made of unidirectional mat fiber are harder than those made of chopped fiber. Therefore, the hardness values drastically continue to drop as the fiber loading increases [18]. The small empty space may have formed during composite production due to inadequate adhesion among the resin and fiber [19].

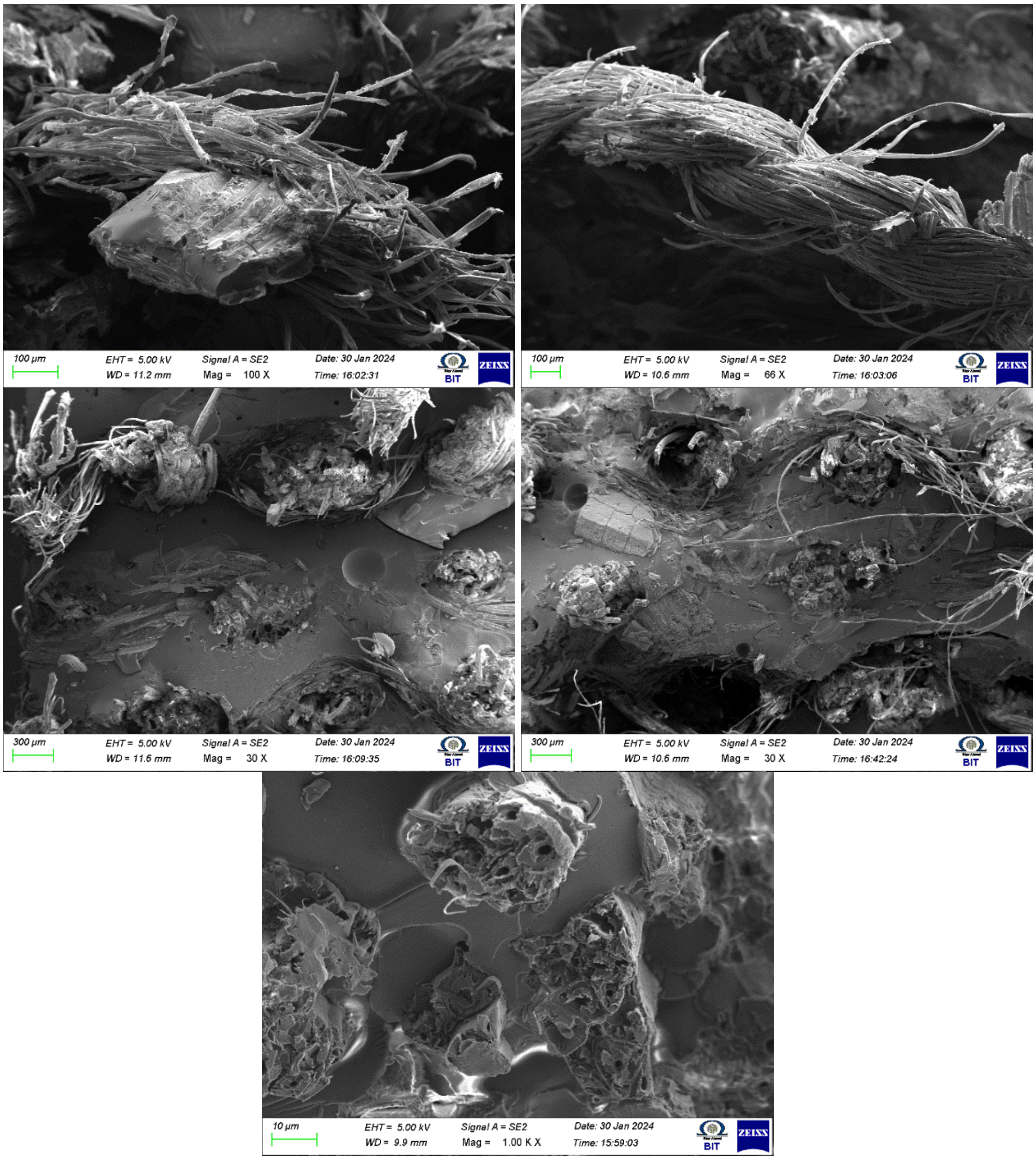

Figure 3. Scanning electron microscopic image of (a) sisal fiber (b) bamboo fiber, (c) S3, (d) S4 and (e) S5 of hybridized composites.

Morphological Study of Hybrid Composite

Using a SEM, we examined the surface morphologies of hybrid composites in flexural, tensile, and impact testings conducted under stress conditions of maximum value. A substantial decrease in the number of fiber pullouts was seen in the tensile failure mode as the weight percent of bamboo fibers in the hybrid composite rise [20, 21]. Additionally, the flexural and impact tests revealed a higher number of fiber breaks and pullouts. Therefore, the hybrid composite with a high bamboo fiber content was unaffected by the tensile load. The bamboo mat failed because the chopped sisal fibers did not adhere well to the bamboo mat strands [22, 23]. Fig. 3(a) to Fig. 3(e) shows that the failure of hybrid composites was caused by stress concentration, which was a result of insufficient adhesion and contact between the fibers [24].

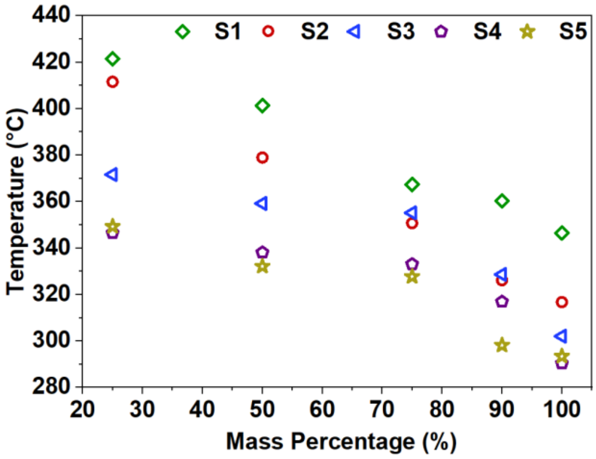

Figure 4. Evaluation of TGA of the hybridized composites.

Thermal Properties

The stability and degradation period of several hybrid composites were investigated in this work using thermogravimetric analysis are depicted in Fig. 4. Among the samples tested, Sample S1 exhibited the greatest degree of thermal stability. Meanwhile, S5 was the least thermally stable of the samples. Because lignin and hemicellulose degrade at roughly 300°C, thermal breakdown begins at that temperature. An investigation using thermogravimetric analysis showed that increasing the number of woven bamboo mat fibers in the hybrid composite resulted in a 25 % reduction in mass and an increase in heat resistance up to 421.49°C [25, 26]. Adding more bamboo fiber makes the material more thermally stable, which is useful for pyrolysis, which commonly produces carbonaceous matter and tar/char. One reason is that thermogravimetric testing of the composites results in reduced weight loss [27, 28].

CONCLUSIONS

Mechanical parameters including hardness, flexural strength, tensile strength, and impact energy of hybridized epoxy polymer composites strengthened with chopped sisal fibers and bidirectional bamboo weave are examined in this research. The testing shown that the S1 sample of the hybridized composites had the greatest TS. The TS of the hybridized composite was found to be positively correlated with bidirectionally woven bamboo fiber content and negatively correlated with chopped sisal fiber concentration. Composites reinforced with natural fibers had their tensile strengths affected most by the weave type, according to the results. Sample S1 had the greatest flexural strength, which was consistent with the increasing tensile strength of the hybridized epoxy composites. This was due to the fact that the polymer matrix was well-adhered to by the fiber properties of the bamboo and sisal. According to an outcome of the IS, sample S5 exhibited the maximum impact energy. Incorporating more chopped sisal fiber and bamboo woven fabric into the material resulted in a higher impact energy. When comparing chopped fibers to woven mat fibers, it was found that the former could withstand more impact stress. While sample S1 had the lowest hardness, sample S3 had the highest. The hardness values dropped dramatically as the fiber loading went up; this is because chopped fiber composites are much harder than unidirectional mat fiber composites. Surface morphological examination revealed minimal fiber pullouts during tensile failure mode when the weightage proportion of bamboo fibers in the hybrid composite was higher.

Additionally, the flexural and impact tests revealed a higher number of fiber breaks and pullouts. The bamboo mat failed because the chopped sisal fibers did not adhere well to the bamboo mat strands. Hybrid composites failed due to stress concentration brought on by insufficient adhesion and contact between fibers. Thermogravimetric analysis (TGA) revealed that carbonaceous matter and tar/char, mostly produced during bamboo fiber pyrolysis, were responsible for the improved thermal stability observed with increasing bamboo fiber content. The result is less mass loss when the composites are subjected to thermogravimetric testing. It is possible that this exploratory research will lead to the development of a novel hybrid composite with outstanding properties.

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