



Development of banana fabric incorporated polymer composites for printed circuit board application

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Abstract

Printed circuit board application shows how banana fiber-reinforced polymer composites can be used to make printed circuit boards (PCBs). The study looks into how well banana fiber works as a reinforcement material for polymer composites and how it could be used to make PCBs. The banana fabric is treated with alkali to improve its mechanical properties. It is then mixed with epoxy resin to make a composite material. The composite's mechanical, thermal, and electrical properties were characterized. The results showed that the banana fiber-reinforced composites exhibited comparable mechanical properties and thermal stability to the conventional substrates. The dielectric constant and loss tangent of the composite were also within the acceptable range for PCB applications. The paper concludes that banana fabric-incorporated polymer composites have great potential for PCB fabrication, especially in applications where environmental sustainability is a priority. The use of natural fibers like banana can reduce the environmental impact of PCB fabrication while also providing good mechanical and electrical properties. This study opens up new opportunities for the use of natural fiber-reinforced composites in the electronics industry.

Keywords Composites · Epoxy · Flammability · Mechanical · Electrical

1 Introduction

Sales of printed circuit boards (PCBs) hit a record \$54.30 billion in 2020, thanks in large part to the increasing demand for electronic goods around the world. This resulted in an estimated 60 million square meters of laminate usage and 300 million square meters of prepreg usage. Concerns have been expressed concerning the environmental fate of PCBs because of the increased resources and energy needed for their production, the toxicity of these compounds, and the absence of feasible disposal options. However, it appears that there are currently no other options that can meet the same criteria. The standard approach to environmental design for electronics has been to recycle or reuse components whenever possible; this works well for simple components like housings but not for complicated hardware like printed circuit boards. Therefore, a new strategy is desperately needed to lessen the environmental risks of PCBs, and it must place a greater emphasis on the selection and design of materials. In this way, scientists all over the world have been looking into ways to add biodegradable natural fibers to the polymer matrix. Researchers are becoming increasingly interested in this area because natural fiber-based composites have superior mechanical, thermal stability, electrical, optical, and wear resistance

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qualities compared to a wide range of pure polymers. Typical uses for PMCs can be found in aerospace, automotive, and electronic devices. PCBs are typically made using paper, glass fiber mat, nonwoven glass fibers, nonwoven aramid fibers, and other fibers as reinforcements in addition to woven glass fiber cloths. PCB base materials can be found in a wide range of forms and dimensions. Resin systems, reinforcements, and conductors can be found in all of them. Many different types of resins are employed, including but not limited to epoxy, cyanate ester, polyimide, polyester, and polytetrafluoroethylene. Fiber-reinforced thermoplastic composites have shown their superior qualities in a wide range of technical applications. Natural fibers are becoming increasingly popular as a thermoplastic reinforcing material due to their low density, superior thermal insulation, mechanical qualities, reduced tool wear, endless availability, low cost, and easy disposal [1–6]. These bio-based composite materials can be worked with in many ways, like milling, drilling, slotting, and finishing the surface. All of these can improve the mechanical properties of the material. It would be ideal to use these biofibers in PCBs, as doing so would make the PCBs more environmentally friendly and less expensive. To the best of the authors' knowledge, there has been very little study conducted on bio-based PCBs and published on them. Bharath et al. developed bio-based PCBs. The bio-based composite made from rice husk-epoxy resin could replace traditional PCB composites. Tensile, bending, dielectric, thermal, moisture absorption, microdrilling, biodegradability, and flammability were evaluated. These biocomposites showed promise for PCB use. Guna et al. created biodegradable PCBs. Biocomposites are manufactured from agricultural wastes like banana stems and wheat gluten. PCBs using electronic-friendly composites were made [7]. Lincoln et al. developed a PCB utilizing a thermoset matrix of deoxidized linseed oil, melamine polyphosphate, and woven flax fiber. The laminates prepared passed thermal, mechanical, and electrical tests utilizing IPC 4101A/24 for thick PCB laminates, except for wet conditioning. Sodium hydroxide and octa-decyl-trichloro silane improved flax fibers moisture resistance. The upgraded bio epoxy-flax PCB design is a viable alternative to current PCBs with lesser environmental implications [8]. Genc et al. made Luffa fiber-reinforced/epoxy PCB (Luffa-PCB) laminates. The frequency dependence of dielectric permittivity, capacitance, ac conductivity, impedance, and electric modulus of Luffa-PCB laminates for prospective PCB applications was examined using impedance spectroscopy from 10 Hz to 10 MHz. An electrometer/high resistance meter and resistivity test fixture were used to test the electrical resistivity of Luffa-PCB laminates. All results were compared to FR2 and FR4 PCB laminates. According to the results, Luffa-PCB laminates can replace standard laminates [9]. Zawawi et al. used oil palm empty fruit bunch to make PCBs. As filler, polypropylene (PP) was put to oil palm empty fruit bunch. Five natural fiber loadings reinforced with varied percentages of PP were modeled for the prototype [10]. Sun et al. examined using recycled glass fibers

from waste printed circuit boards (WPCB) as sound absorption and thermal insulation. Fluidized-bed recycling produced glass fibers. RGF acoustic qualities were compared to expanded perlite (EP), expanded vermiculite (EV), and commercial glass fiber. Zhan and Wool developed greener PCBs for their study [11]. Soybean oil resins, chicken feathers, and E-glass were used to make bio-composites. Halogen-free melamine polyphosphate and diethylphosphinic salt flame-retard PCBs. Mechanical, electrical, thermal, flammability, and peel strength of bio-composites/bio-PCBs were tested. PCB-friendly features were observed [12]. Hidehito et al. did a microdrilling on PCBs to find out if there was a link between the quality of the hole and the radial run-out of the drills. During the whole drilling process, a drill with a diameter of 0.1 mm was used, and the speed of rotation was kept at $3 \times 10^5 \text{ min}^{-1}$ [13]. Bharath et al. suggested *Moringa oleifera* fruit fibers as a possible green fiber for natural fiber-based polymer composites. XRD, thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and SEM analyses, as well as anatomy, density, and tensile tests, were done. The results show that these fibers could be used in commercial engineering goods [14]. Chaturvedi et al. discussed on the popularity of environmentally friendly bionanocomposites reinforced with cellulose fibers. The authors explored the mechanical and thermal properties, fabrication processes, and physical properties and tribology of bionanocomposites reinforced with agro-industrial wastes. The chapter also covered the use of cellulose nanofibers in various polymers such as natural rubber, xylan, polyvinyl alcohol, and others [15]. Arpitha et al. look into how corncob waste and boron nitride particles can be used as reinforcement materials in making epoxy-based composites that are good for the environment and do not cost too much. The composites are characterized through various tests, and the results show that the 3.5/3.5 boron nitride and corncob ratio composite possesses the best flexural strength and exhibits 2–3 times improvement in tensile strength compared to neat epoxy resin. The authors suggest that natural fibers may play an important role in developing biodegradable composites to address ecological and environmental problems [16]. Arpitha et al. used sugarcane bagasse and alumina micro-fillers to reinforce epoxy polymer composites, with optimal contents of 3.5 wt.%. The fillers improved the physical, thermal, and mechanical properties of the epoxy resin, as confirmed by SEM examination

Table 1 Physical characteristics of Banana fiber

Characteristics	Range
Tensile strength (Mpa)	650–780
Tensile modulus (Mpa)	29,000–32,000
Elongation of Break (%)	2–4
Cellulose Content (%)	64–65
Lignin Content (%)	21%
Diameter (mm)	1 to 3
Density (g/cm^3)	1.3

Table 2 Physical characteristics of Epoxy Lapox L12

Characteristics	Range
Density (kg/m ³)	1100–1400
Tensile modulus (GPa)	2–6
Elongation (%)	1–8.5

[17]. Vinod et al. looked at the effect of surface modification on agro-waste soy stem fibers and their composites to see if they could be used as a sustainable and renewable resource in polymer matrices. Chemical treatments increased cellulose content and improved thermal stability and mechanical performance. Silane treatment showed the best results, followed by oxalic acid and alkali treatments. The study shows that agro-waste soy fiber can be used for lightweight structural applications [18]. Binoj et al. looked into how discarded fruit waste could be used to reinforce polymer composites. They looked at the properties of the areca and tamarind fibers that were made from the waste of the fruit. The study showed that these fibers could be used as a reliable reinforcement in polymer composites for lightweight and home applications. The use of these natural fibers can help reduce deforestation and promote effective waste management, making it a sustainable option for the composites industry [19].

In this work, a bio-based composite made of chemically treated banana fabric and an epoxy L-12 matrix was made to see if it could be used as a PCB material. To ensure the rationale of using the produced composites as PCB materials, tests for critical qualities such as mechanical properties, dielectric properties, thermal properties, moisture absorption, micro-drilling, biodegradability, and flammability were carried out.

2 Experimental

2.1 Materials

In this experiment, the composite laminate was made by putting together different materials. Banana fibers, an epoxy Lapox L12 matrix, a K-6 hardener, and sodium hydroxide

(NaOH) were used to treat the fabric chemically. The banana fibers that were used in the experiment came from Go Green Products, which is in the Indian state of Tamil Nadu. The company provided woven plain fabrics made from the collected banana fibers. The physical characteristics of the banana fibers are detailed in Table 1. To complete the fabrication process, the epoxy Lapox L12 matrix, K-6 hardener, and sodium hydroxide (NaOH) were procured from Yuje Enterprises, located in Bengaluru, India. The physical characteristics of the epoxy Lapox L12 matrix are detailed in Table 2. Overall, the combination of these materials and their respective characteristics played a crucial role in the success of the fabrication process.

NaOH treatment is a standard approach to improving natural fabrics' polymer matrix compatibility. A simple and inexpensive NaOH solution removes contaminants, hemicellulose, and lignin and increases the fibers' cellulose content, surface area, and crystallinity. This improves the mechanical, thermal, and chemical properties of the composite. According to various studies, NaOH treatment affects the properties of hybrid composites. Refaii et al. tested untreated and NaOH-treated ramie-hemp composites for mechanical properties. A 6% diluted NaOH solution was used to hand-lay up woven ramie and hemp fibers in different stacking sequences. Hemp-based hybrid composites were stronger than four-layer composites. NaOH-treated hybrid composites are stronger. Impact sample H/R/H/R was the best. Their work is part of a hybrid composite high-velocity impact application [20]. Ramesh et al. examined the wear testing of *Calotropis gigantea* fiber-reinforced epoxy composites treated with NaOH. Compression molding was used to make composites from NaOH and KMnO₄-modified fibers. Varying wear time affects tribological properties. NaOH-treated CGF composites had better tribological behavior than untreated and KMnO₄-treated composites, losing between 0.0013 and 0.0018 g [21]. Siakeng et al. looked at PLA hybrid composites with different amounts of coir fibers that had been treated with alkali and pineapple leaf fibers (PALF). The strongest C3P7 hybrid composites were

Fig. 1 **a** Mixing of NaOH solution with water; **b** NaOH treated banana fiber mat

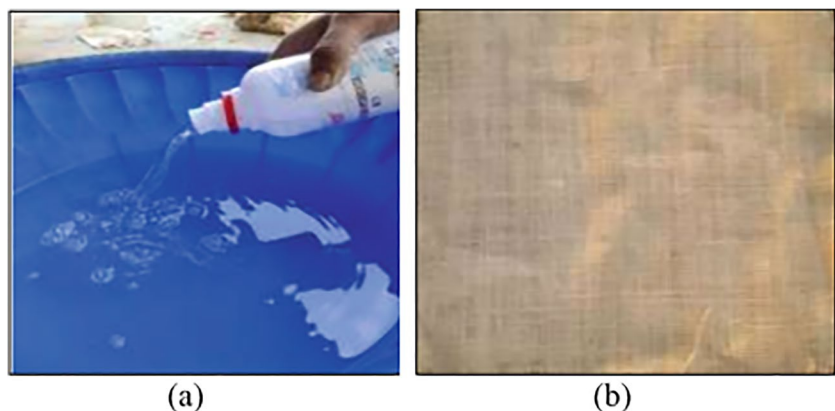


Table 3 Volume fraction calculation

For 10 mm thickness of cross section 200 mm × 200 mm

	Formulae	Result
Area of cross section	–	200 mm × 200 mm
Volume of composite	Area of cross section × Thickness	= 200 mm × 200 mm × 10 mm = 400,000 mm ³
Weight of one layer	–	12.6 g
Thickness of banana fiber mat	–	0.4 mm
Volume of one layer	Area of cross section × Thickness of banana fiber mat	= 200 mm × 200 mm × 0.4 mm = 16,000 mm ³
Density of material	Weight of one layer/Volume of one layer	= 12.6 g/16,000 mm ³ = 0.000787 g/mm ³
Volume of one layer of fabric	Weight of one layer/density of material	= 12.6 g/0.000787 = 16,010.16 mm ³
Amount of fabric in composite	Volume of composite × % of fiber [50% fiber]	= 400,000 × (50/100) = 200,000 mm ³
Number of layer	Amt. of fabric in composite/ Volume of 1 layer	= 200,000/16,010.16 = 12.49 ≈ 13 layers
Volume of resin	Volume of composite × 0.5	= 400,000 × 0.5 = 200,000 mm ³ = 200 mL

alkali-treated. SEM showed alkali-induced fiber-matrix adhesion. CF's higher lignin concentration boosted C1P1 and C7P3's thermal stability and char content. Due to

their improved mechanical, thermal, physical, and CTE properties, treated hybrid composites were suitable for outdoor and food packaging applications [22].

Fig. 2 Composite laminate preparation in the present study. **a** Composite laminate preparation using hand lay-up technique. **b** Prepared banana fiber mat composite laminate



(a) Composite laminate preparation using hand lay-up technique



(b) Prepared banana fiber mat composite laminate

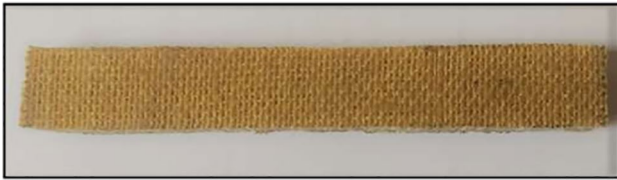


Fig. 3 Tensile specimen before fracture

In the study, a NaOH solution was used to improve the mechanical properties of the banana fibers. A normal NaOH solution of 5% was prepared by mixing it with water, and the banana fiber mat was submerged in the solution for a full day. This treatment was done to obtain the desired characteristics of the fibers. After this, the fibers were sun-dried completely. Figure 1a and b illustrates the process of mixing the NaOH solution with water and the banana fiber mat after it was treated with NaOH [23]. This treatment process played a crucial role in modifying the fibers and making them suitable for the fabrication process. By utilizing this technique, the mechanical properties of the fibers were significantly improved. The resulting fibers were more robust and durable, which made them ideal for use in the fabrication process. The use of NaOH solution treatment was a key factor in achieving the desired properties of the fibers and creating a successful final product.

2.2 Volume fraction calculation

To determine the volume fraction of a composite material, we need to add the volumes of both the reinforcement and matrix together. This will give us the total volume of the composite. Before starting the fabrication process, it is crucial to decide the percentage of matrix and reinforcement that will be utilized. Once the volume or mass of composite material required for the given mold dimensions has been established, it can be added to the mix. Table 3 indicates the volume fraction calculation performed in this study.

2.3 Preparation of composites

The fabrication method used here is hand lay-up followed by pressure application using a hydraulic press. After

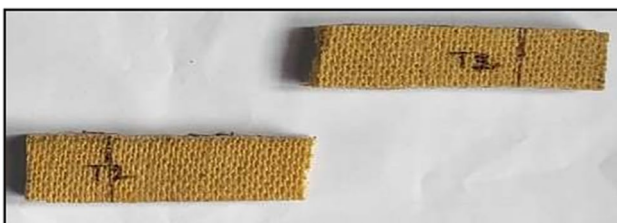


Fig. 4 Tensile specimen after fracture

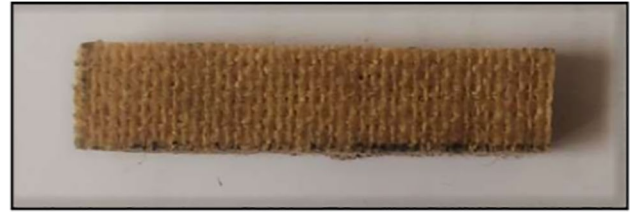


Fig. 5 Bending specimen before fracture

laying down a banana fiber mat over a polished mold (flat granite slab of $200 \times 200 \text{ mm}^3$) that has been treated with a releasing agent, the next step in the manufacturing process involves working a liquid thermosetting resin, i.e., epoxy Lapox L12 into the reinforcement by hand using a brush. Pre-mixed resin and hardener are typically designed to cross-link and harden when the temperature is at or near room temperature. This manufacturing process has a significant amount of flexibility, which allows it to accommodate a wide variety of mold sizes and complex shapes. This is the primary benefit of using this method. After placing one layer of banana fiber mat on the mold, the calculated quantity of resin and hardener in the ratio of 10:1 was then taken for the 13 layers of banana fiber mat with a consistent cross-section. After that, the resin is applied one layer at a time until the composite is finished being assembled. After the hand-layup method has been completed in its entirety, the composite material is placed into a hydraulic press for 24 h. The layers of the composite are entirely bound together as a result of the weights being maintained on the composite. Finally, after the composite has been thoroughly dried, it is cut to the desired size as per standard ASTM methods so that it can be used for further study. The composite preparation employed in the present study is illustrated in Fig. 2.

3 Mechanical testing

3.1 Tensile test

In the current research investigation, the tensile test was carried out using the standard ASTM D638 method. The experiment



Fig. 6 Bending specimen after fracture



Fig. 7 Vertical flammability test specimen

was carried out with the assistance of a universal testing machine (KIC-2-1000-C) that had a capacity of 100 kN and a loading rate capacity of 2.5 mm/min. During the experiment, the top and bottom jaws were used to grip the specimens, and the jaws were gradually opened further and further apart at a consistent rate in order to stretch out the specimens. The tensile specimens both before and after they were tested are depicted in Figs. 3 and 4 respectively.

3.2 Bending test

In general, bending tests are carried out on brittle materials such as ceramics, plastics, glasses, woods, and stones. This is because these materials tend to break in a straight line when they break. The UTM that was used for the tensile test was also used for the bending test. The bending test was performed using a bending test fixture that had a load cell of 10 kN. The current investigation made use of the standard dimensions specified in ASTM D790-07, and Figs. 5 and 6 display flexural specimens both before and after being put through testing.

3.3 Flammability test

An examination of the flammability of the finished composites was carried out using a standard UL-94 method. As can be seen in Figs. 7 and 8, the dimensions of the specimen were $125 \times 13 \times 1.5$ mm. The apparatus that was utilized was a laboratory burner with a tube length of 100 ± 10 mm and an interior diameter of 9.5 ± 0.3 mm along with a burner mounting fixture, ring stands, timing devices, wire gauze, a supply of methane gas, and a measurement scale. The burner was adjusted so that it produced a blue flame that was 20 ± 1 mm in height. In the course of the test, both horizontal (UL94HB) and vertical (UL94V) burning circumstances were replicated. In this work, the procedure for carrying out the flammability test was as follows: (a) applying the flame 10 mm below the bottom end of the specimen and maintaining it



Fig. 8 Horizontal flammability test specimen



Fig. 9 TGA test sample

for 10 s; (b) following that, withdrawing the burner away from the specimen and noting down the after flame time, t_1 ; (c) finally, when the after flaming of the specimen was stopped, the burner shall be again placed below the specimen for a time of 10 s and removed to note down the after flame time.

3.4 Thermogravimetric analysis

Thermogravimetric analysis (TGA) measures weight loss while heating a substance to assess its thermal stability and volatile fraction. It measures mass when the sample temperature changes. Many other measurements can be generated from mass, temperature, and time in TGA. TGA of the composites that were synthesized in the study in powder form was performed on a PerkinElmer thermogravimetric analyzer in a nitrogen atmosphere. TGA provides an accurate representation of the thermal stability and decomposition behavior of the materials that are the subject of the investigation by expressing the results in terms of the percentage weight loss as a function of temperature. Throughout the entirety of the investigation, the heating rate was kept at 10 °C/min, and the temperature remained between 0 and 1000 °C.



Fig. 10 DSC test sample

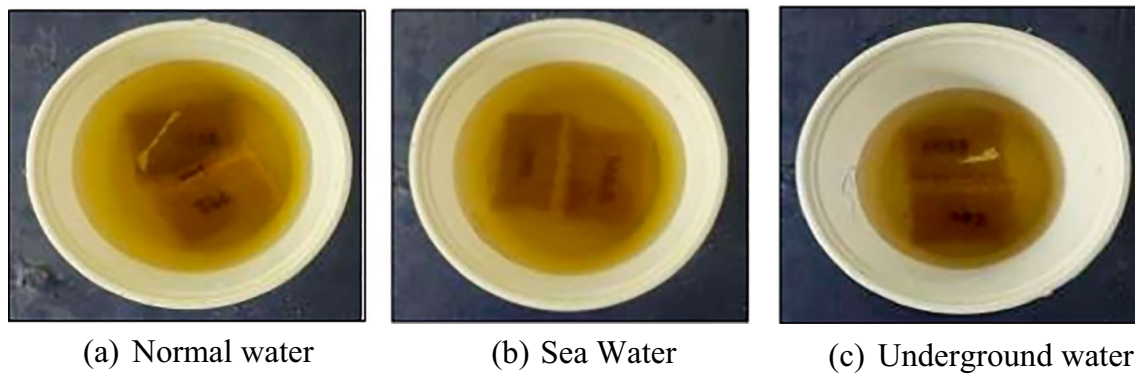


Fig. 11 Moisture absorption specimens. **a** Normal water. **b** Sea water. **c** Underground water

3.5 Differential scanning calorimetry analysis

Differential scanning calorimetry (DSC) quantifies the amount of temperature and heat flow associated with material thermal transitions. It involves the investigation, selection, comparison, and assessment of the end-use performance of materials in research, quality control, and manufacturing applications. For this experiment, a Mettler DSC 822 was utilized for the purpose of determining the temperature transitions of the composites. A heat scan was performed on 10 mg of samples that were kept in a Tzero hermetic alumina pan and subjected to temperatures ranging from 0 to 450 °C. During the course of the analysis, a nitrogen atmosphere with a pressure of 20 psi was maintained, and the sample purge flow rate was kept within a range of 50 mL min⁻¹. Additionally, the heat rate was kept at approximately 10 °C/min. Figures 9 and 10 show TGA and DSC test samples respectively.

3.6 Moisture absorption test

This method uses the change in mass of an exposed sample over time to calculate and track changes in the amount of water in the sample. This technique of testing allows us to quantify the amount of water taken in after being exposed to it in a free-water environment. ASTM D5229 standard is used for the preparation of moisture absorption specimen.

The specimens are immersed in three types of water conditions for moisture absorption analysis, i.e., normal water, sea water, and underground water. Each day, the weight and thickness of the specimen is measured and recorded. It is recorded for around 11 days until it reaches saturation. The experiment was conducted at an ambient temperature range of 24 °C. Figure 11 shows water absorption specimens under three different immersed water conditions.

3.7 Biodegradability test

The biodegradability test is a complicated biochemical reaction process that takes place when specific types of microbes devour a certain kind of material. This method of testing assesses the degree of aerobic biodegradation of composite materials as well as the rate at which it occurs when the materials are exposed to an environment of controlled composting in a laboratory setting. The ASTM D6400 standard is followed when checking the biodegradability of a polymer based composites in an aerobic environment. In a closed respirometer, the amount of oxygen needed was measured to find out how well organic compounds in cow dung break down in an aerobic environment. Figure 12a and b depicts the biodegradability test specimen and set-up used in this study.

Fig. 12 Biodegradability test specimen. **a** Test specimen. **b** Set-up

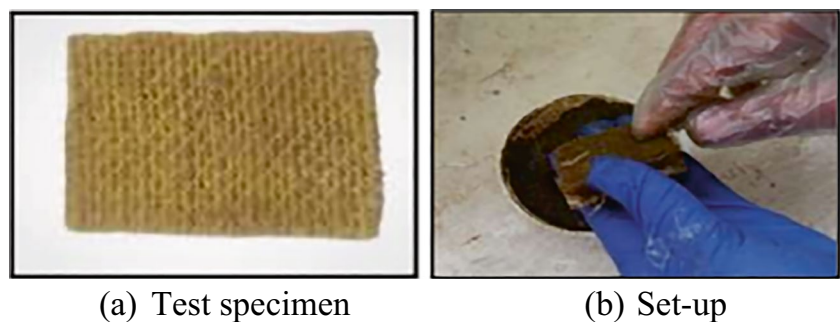


Table 4 Dielectric test specimen details

Mold type	Thickness (mm)	Diameter (mm)	Area (mm ²)
Round	2.24	13	1.326×10^{-4}

3.8 Dielectric test

The dielectric test, which is also called the “high potential” test, is done to make sure that a part's insulation works well. In this study, flat samples made for this purpose are being put through a short-term test. During testing, simple test electrodes are used to apply a uniform voltage with a frequency of 60 Hz to the opposite sides of the samples. The rate of 500 v/s is used in the study, and the average breakdown time is chosen to be between 10 and 20 s. Table 4 indicates the dielectric test specimen details.

3.9 Tan delta loss/dissipation factor test

Tan Delta, which can also be referred to as the dissipation factor or the Loss Angle, is a diagnostic procedure that is used to evaluate electrical equipment in order to measure the quality of the insulation. In the present study, banana fiber in powder form was evaluated for performing the tan delta loss analysis. The insulation is evaluated with a very low-frequency test voltage. If the tan delta is good, the equipment's voltage is raised 1.5 to 2 times. The tan delta controller measures values. A

Table 5 Tensile test results

Sl. No.	Load (kN)	Deformation (mm)
1	0.2	0.1
2	0.4	0.25
3	0.6	0.46
4	0.8	0.63
5	1	0.95
6	1.2	1.2
7	1.4	1.35
8	1.6	1.6
9	1.8	1.85
10	2	2.1
11	2.2	2.35
12	2.4	2.62
13	2.6	2.85
14	2.8	3.05
15	3	3.42
16	3.2	3.62
17	3.5	4.02
18	4	4.42
19	4.5	5.09

Table 6 Bending test results

Sl. No.	Load (kN)	Deformation (mm)
1	0.00077	0.02
2	0.05571	0.92
3	0.16712	1.63
4	0.26020	2.53
5	0.36968	3.47
6	0.49426	4.43
7	0.6226	5.4
8	0.75036	6.33
9	0.87658	7.25
10	1.03	8.17
11	1.0723	8.73

loss angle analyzer is attached to a tan delta measuring unit to compare and analyze tan delta values at normal voltage and higher voltages.

3.10 Microdrilling test

In this study, microdrilling was done using a process called microelectrical discharge machining (MEDM), which is a variation on EDM. For testing, a board made of banana fabric-reinforced polymer matrix material was used. The bottom of the composite board was held up by a wooden board, and the two were clamped together. For this test, three drilling trails were done. The microdrilling was done when the temperature in the room was 24 °C.

4 Results and discussions

4.1 Tensile and bending test

In accordance with the findings of the tensile and bending tests, the load and deformation values are given in Tables 5 and 6 respectively. After taking measurements, it was determined that the specimen had a maximum withstanding tensile and bending load capacity of 4.5 kN and 1.0723 kN respectively. Both tests that were performed on the material demonstrated that the composite material, consisting of banana fabric and epoxy matrix, had a beneficial influence on the material's mechanical strength, and as a result, it strengthened the bonding between the fabric and matrix. This is most likely owing to the banana fabric being properly impregnated with the epoxy matrix during fabrication, resulting in strong interfacial adhesion between the two materials. These discoveries have important implications for the manufacture of a PCBs using this composite material. The material's excellent tensile and bending load capacities make it a viable candidate for use in electronic devices requiring great mechanical stability and longevity [24].

Table 7 Result of flammability test

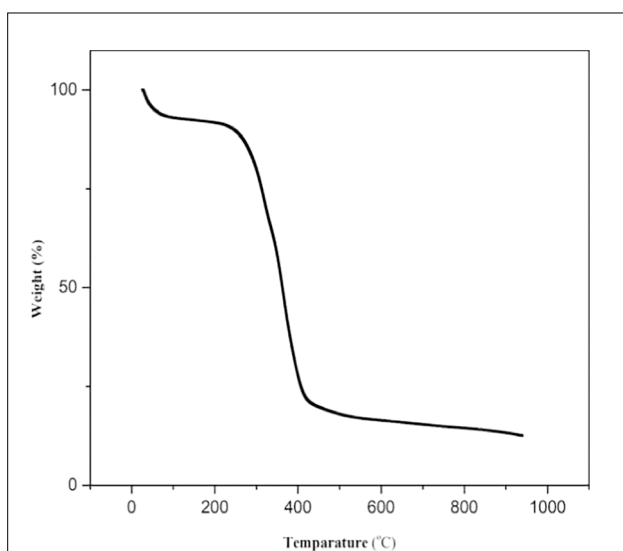
Type of test		Initial weight (g)	Final weight (g)	Time “t” (s)	Flame travel (mm)	Weight loss (gm)
Vertical	F1	12.99	12.76	10	65	0.23
	F2	14.43	14.17	10	67	0.26
Horizontal	F3	12.53	12.22	30	15	0.31
	F4	18.05	17.71	30	16	0.34

4.2 Flammability test

This test was made so that pyrolysis and flame spread could be judged more accurately. Table 7 shows how fire resistance affects the composite that has been made. The findings of the flammability test indicate that the utilization of the epoxy resin does, in fact, increase the flammability properties of the composite sample consisting of banana fibers. Epoxy was added to the material, which resulted in a decrease in the material’s flammability and an increase in its loss on ignition (LOI). This finding is supported by the fact that epoxy resin has high thermal stability, resulting in a higher LOI of the composite material. Furthermore, the chemical connection between the banana fibers and the epoxy resin increases the material’s structural integrity and lessens its inclination to catch fire. These findings imply that the composite material consisting of banana fibers and epoxy resin has a significant potential for usage in fire-resistant applications such as PCBs [25].

4.3 TGA analysis

The graph of TGA can be seen in Fig. 13 below. The temperature range for TGA is 0 to 1000 °C at a rate of

**Fig. 13** TGA graph

10 °C/min. The initial temperature stability was significantly better than average. The fact that the weight of a substance (in this case, banana fiber) does not change up to a temperature of 400 °C is evidence that banana fiber is thermally stable up to this temperature. After 400 °C, the temperature of a substance begins to fall, indicating that the breakdown process has begun. The weight loss was consistent up to a temperature of 1000 °C. After reaching this temperature, the material sample will continue to maintain the same weight. Therefore, these results suggest that banana fiber can maintain its stability and weight up to a specific temperature, making it suitable for various high-temperature applications like PCBs [26].

4.4 DSC analysis

The DSC test graph, which can be shown in Fig. 14, showed that the test started at 25.08 °C. The temperature that is thought to represent the peak’s crystallization temperature is the one that can be found at the peak’s highest point. The temperature at which crystallization occurs is often referred

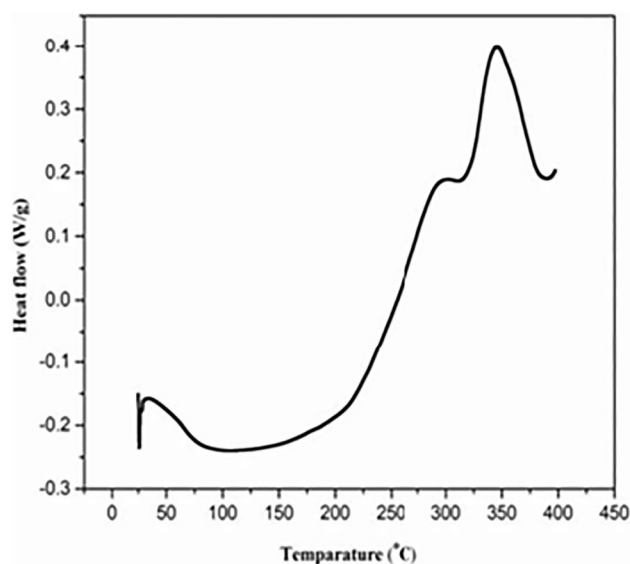
**Fig. 14** DSC graph

Table 8 Result of moisture absorption test

DAYS	Normal water Unit in g, mm		Sea water Unit in g, mm		Underground water Unit in g, mm	
	g	mm	g	mm	g	mm
Day 1	12.78	10.1	13.36	10.1	14.37	10.1
Day 2	22.27	11.1	22.0	11.2	24.15	11.1
Day 3	24.45	12.5	23.74	12.3	25.05	12.3
Day 4	25.12	12.9	24.62	12.9	26.36	12.8
Day 5	26.29	13.1	25.21	13.2	27.08	12.9
Day 6	26.43	13.5	25.55	13.6	28.24	13.6
Day 7	26.5	13.7	25.77	13.7	28.5	13.7
Day 8	26.82	13.8	26.21	13.85	29.1	13.8
Day 9	27.15	13.9	26.5	13.9	29.5	13.9
Day 10	27.16	14	26.52	14	29.52	14
Day 11	27.17	14	26.54	14	29.54	14

to as the exothermic transition. In this figure, the exothermic transition occurs at a temperature of about 350 °C. The sharp decline in the DSC curve reveals the glass transition temperature to be between 75 and 225 °C. At 397.13 °C, the DSC test was terminated. These findings suggest that the composite material made of banana fibers and epoxy resin has an acceptable glass transition and crystallization temperature for use in PCBs [27].

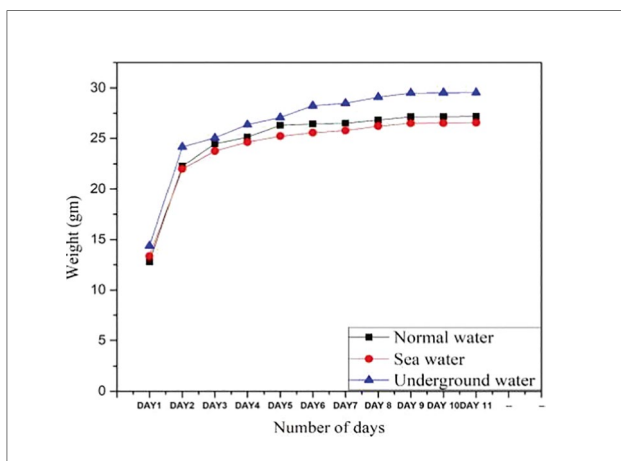
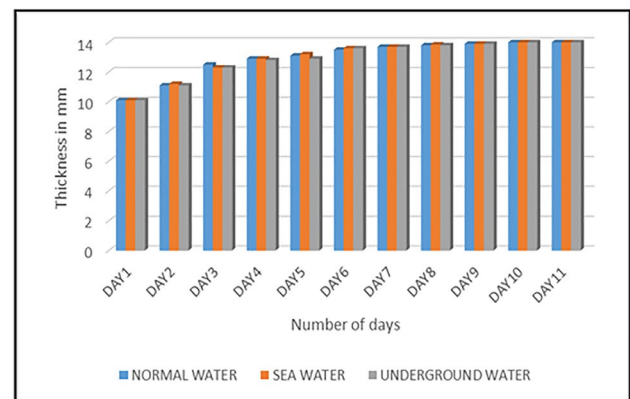
4.5 Moisture absorption test

According to ASTM D5229 standards, the specimen was cut to a size of 75 × 50 × 10 mm for the moisture absorption test, and the test was then carried out. In the moisture absorption test, the specimen is submerged in three different types of water: freshwater, seawater, and groundwater. Daily measurements are made of the specimen's weight and thickness, as shown in Table 8 and Figs. 15 and 16. Until saturation is reached, the readings are recorded. The moisture

absorption test is critical for PCBs because they are frequently exposed to different environmental conditions, and moisture absorption might alter their effectiveness. According to the results of the test, all of the samples treated with normal water, sea water, and distilled water gained weight over time until they reached saturation. Similarly, the sample's thickness rose over time and became saturated. These findings suggest that the banana-epoxy composite material used in the PCB has some moisture absorption, which could compromise the PCB's performance in humid situations. As a result, necessary steps, such as employing a protective coating or encapsulating the PCB, must be taken to avoid or decrease moisture absorption [28].

4.6 Biodegradability test

The weight variation test is a simple and common way to find out if natural fibers can break down in nature. Figures 17 and 18 illustrate the result of the biodegradability test w.r.t. weight variation and thickness variation,

**Fig. 15** Result of moisture absorption test (weight variation)**Fig. 16** Result of moisture absorption test (thickness swelling)

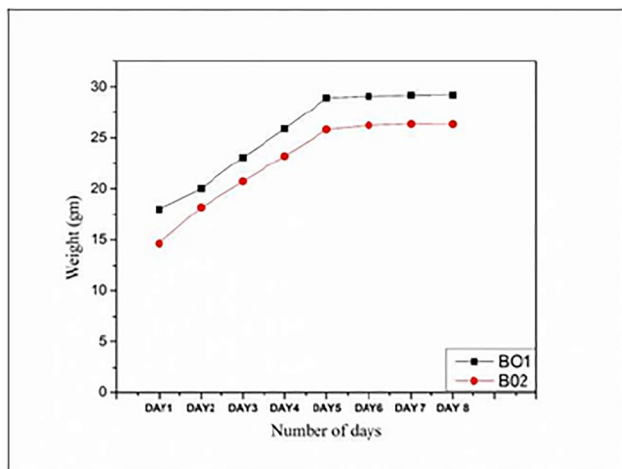


Fig. 17 Result of biodegradability test (weight variation)

respectively. The test was carried out for a period of time during which the weight and thickness of the samples were increased. A higher weight loss percentage indicates that the fiber has undergone significant biodegradation and is more environmentally friendly. However, it is important to note that other factors, such as the type of soil or compost and the conditions in which the sample is buried, can also affect the biodegradation rate [29]. Overall, the biodegradability test results are encouraging and suggest that the composite material has potential for use in PCBs. Table 9 indicates the results of the biodegradability tests carried out in the present investigation.

4.7 Dielectric test

The dielectric constant was measured for the PCB samples at room temperature and at a frequency ranging from 10 kHz to 1 MHz. The results are shown in Fig. 19, where the logarithmic frequency is plotted on the x-axis and the dielectric constant (real) is plotted on the y-axis. It was

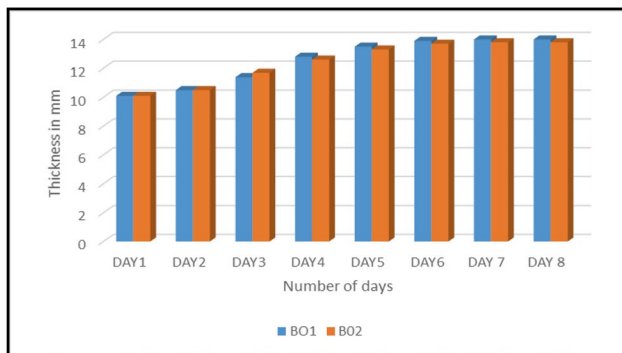


Fig. 18 Result of biodegradability test (thickness variation)

Table 9 Result of biodegradability test

Days	Biodegradability (Unit in g, mm)			
	BO1	B02	B01	B02
Day 1				
Day 2	18	14.61	10.1	10.1
Day 3	20	18.2	10.5	10.5
Day 4	23.1	20.7	11.4	11.7
Day 5	25.86	23.22	12.8	12.6
Day 6	28.93	25.8	13.5	13.3
Day 7	29.1	26.2	13.9	13.7
Day 8	29.2	26.30	14	13.8

observed that the dielectric constant decreased with an increase in frequency but increased with an increase in temperature. The dispersion in the dielectric constant was rapid at lower frequencies, while it was slow at higher frequencies. The maximum dielectric dispersion was observed at frequencies between 20 and 40 kHz. The dielectric constant of any material is generally due to dipolar, electronic, ionic, and interfacial polarizations. In the case of PCBs, dipolar and interfacial polarizations were found to play a dominant role at lower frequencies. Lower dielectric values are desirable in integrated circuits since a decrease in the dielectric constant increases the operating speeds, particularly at higher temperatures [30, 31]. The results of the dielectric constant tests carried out in the present investigation are presented in Table 10.

4.8 Tan delta loss/dissipation factor test

In Fig. 20, the logarithmic frequency is used as the x-axis and Tan as the y-axis to show the results of the Tan test. The results of the tan delta test carried out in the present investigation are presented in Table 11. It is discovered that the dielectric loss tangent decreases with frequency. The variance of dielectric losses is significantly influenced by a material’s density. Low dielectric losses are the result of high porosity and low density. If the insulation is flawless in tan, the loss factor will be almost the same across the whole range of test frequencies. Yet, it is evident from the graph that a material’s loss factor progressively increases with higher frequencies, indicating that the material’s insulation is adequate. The dielectric loss tangent’s frequency response exhibits strange behavior, with smaller-than-expected peaks (relaxation processes) at higher frequencies. In a condensed material, distinct ions are typically surrounded by different environments, which are commonly linked to the dispersion of relaxation times [32, 33].

4.9 Microdrilling

In this investigation, banana fiber composite board was evaluated using the micro-drilling technique. The lower component of

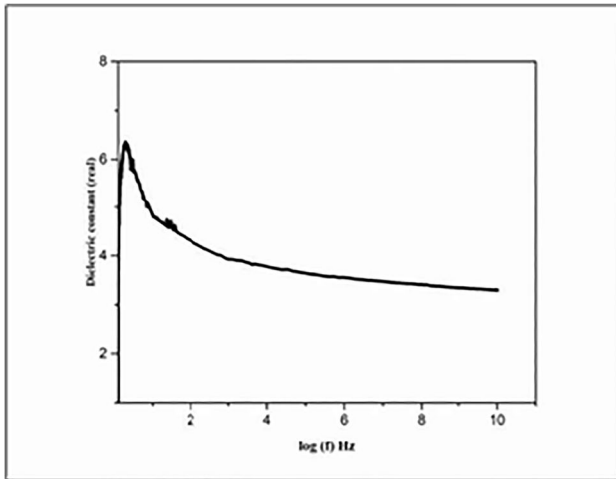


Fig. 19 Result of dielectric constant test

the composite board was bolted to a wooden backing board that was used to provide stability. Three drilling experiments were conducted at room temperature (25 °C) during the experiment.

Table 10 Result of dielectric constant test

Frequency (kHz)	Dielectric constant (real)
10	– 4.69275
10.47	3.7134
15.16	5.4207
19.56	5.8553
25.23	6.2354
40.008	6.0866
50.52	5.7412
74.88	5.2029
101.16	4.7922
153.44	4.5228
202.55	4.2989
255.29	4.0853
300.18	3.9282
352.97	3.8548
405.55	3.7692
455.29	3.7161
511.16	3.6273
560.72	3.5724
601.10	3.5528
659.29	3.4994
706.72	3.4685
757.53	3.4359
811.98	3.4041
850.47	3.3781
911.59	3.3457
954.77	3.3197
1000.0	3.2987

The drill diameter was altered while the spindle speed and input rate remained constant. The primary purpose of the drilling experiment was to establish the cutting speed for various parameter combinations. Drilling circuit boards requires careful consideration of the hole's quality and the extent of the burr. Burr formation results from material deformation, which can cause damage to the circuit board and impair its functionality. Therefore, the burr form was evaluated to determine the cavity quality and burr size. The results of the micro-drilling test can assist in determining the optimal drilling parameters for the composite board made from banana fiber. This information is essential for the production of circuit boards of superior quality [34–37]. Table 12 presents the details of cutting speed for different drill diameters.

5 Conclusion

In the end, this study looked at how natural cellulose fiber could be used as an environmentally friendly alternative to make biodegradable printed circuit boards (PCBs). The biocomposites made of banana fibers showed promising results in terms of their mechanical, thermal, and electrical properties. Tensile and bending tests showed that the composites had about the right amount of strength and flexibility for most uses. The TGA and DSC analyses indicated that the composites were thermally stable up to 200 °C and had good thermal degradation properties. The Tan/Delta test showed that the composites had a low dielectric loss, which is desirable for electronic applications. Furthermore, the biodegradability test confirmed that the composites had undergone significant biodegradation and were environmentally friendly. The dielectric test demonstrated that the dielectric constant decreased with an increase in frequency, and lower

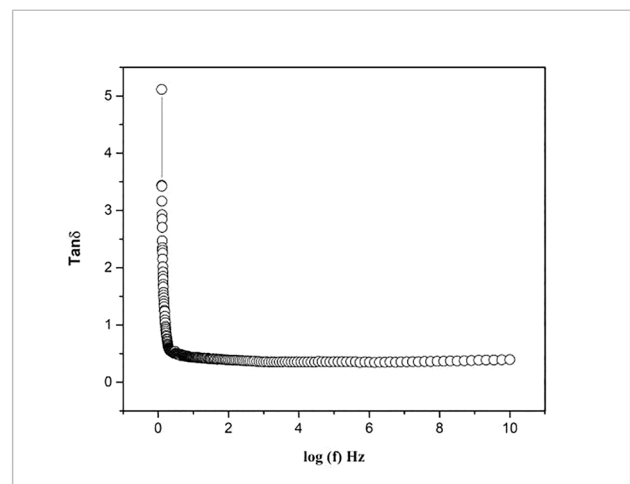


Fig. 20 Result of Tan delta test

Table 11 Result of Tan delta test

Frequency (kHz)	Tan delta (tan δ)
10	5.11
10.47	3.42
15.16	1.568
19.56	1.152
25.23	0.748
40.008	0.525
50.52	0.503
74.88	0.464
101.16	0.433
153.44	0.407
202.55	0.388
255.29	0.373
300.18	0.3547
352.97	0.3543
405.55	0.3559
455.29	0.3598
511.16	0.3571
560.72	0.3587
601.10	0.3469
659.29	0.3541
706.72	0.3549
757.53	0.3601
811.98	0.3659
850.47	0.3719
911.59	0.3829
954.77	0.3881
1000.0	0.3952

dielectric values were desirable for faster operating speeds in integrated circuits. The biodegradability test showed that these composites can undergo significant biodegradation and are environmentally friendly, although the biodegradation rate can be affected by factors such as the type of soil or compost and burial conditions. Additionally, the micro-drilling test demonstrated that the composites prepared in this investigation can be drilled with sufficient quality and burr size for most applications. In summary, the use of natural cellulose fiber in the development of biodegradable PCBs is a promising and sustainable solution for reducing electronic

Table 12 Cutting speed for varying diameter

Drill diameter (mm)	Spindle speed (min^{-1})	In feed (mm/s)	Cutting speed (mm/min)
0.7	15,000	30	0.105
0.75	15,000	30	0.1125
0.8	15,000	30	0.12

waste and promoting environmental stewardship. The composites made of banana and coir fibers have the potential to replace conventional PCBs in most electronic applications while minimizing their environmental impact.

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Data availability Not applicable.

Declarations

Ethics approval The authors hereby state that the present work is in compliance with the ethical standards.

Consent to participate Not applicable.

Competing interests The authors declare no competing interests.

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