

Research Article

Characterization of Thermal Properties of Highland Bamboo Fibers

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Characterization of thermal properties of different ages highland bamboo fiber attributes extracted chemically and mechanically is the focus of this study. Samples of length 25–30 cm were harvested at various ages from the middle of the stem, which was then soaked in different NaOH weight-by-volume concentrations and soaked in water for different days. Using a rolling machine that has three rollers, the fiber is mechanically extracted. The sample was subjected to different analyses for each corresponding age (1, 2, and 3 years) and NaOH concentration (untreated, 1%, 2%, and 3%) levels using thermogravimetric analysis, differential scanning calorimetry, derivative thermogravimetric analysis, and differential thermal analysis for thermal property characterization. Scanning electron microscopy (SEM) was used for morphological studies, whereas Fourier transform infrared spectroscopy (FTIR) was used for the identification of functional groups of the fibers. The surface appearance of the cell wall and microfibril aggregates were changed by alkali treatment. From the SEM results, 3% NaOH-treated fiber resulted in more wrinkles on the surface of bamboo fibers when compared with the 1% and 2% NaOH bamboo fibers. Using thermal analysis measurements, this study investigated that weight loss increased as alkali concentration increased, but the scenario functioned for proper concentration. The first degradation stage is responsible for the biggest weight loss since it includes the disintegration of all of the fiber's primary components (cellulose, hemicellulose, and lignin).

1. Introduction

Many scientists and engineers are focusing on using natural fiber as an alternative to synthetic fiber in polymer matrixes. Focus is being placed on natural fiber-reinforced polymer matrix since it is more affordable, has less impact on the environment, and exhibits better mechanical qualities than polymer resins. When superior corrosion resistance is required, natural fiber-reinforced composites are preferable to metals. For particular applications, thermal properties are also necessary in addition to mechanical properties [1].

Bamboo plant is a plentiful resource that plays an important role in socio-economic development [2, 3]. It has a very robust, flexible, and light wood frame [4].

From an environmental standpoint, bamboo forests are an important source of carbon mitigation, with carbon sequestration capacity comparable to or exceeding that of timber forests in biomass. The culm has become tapered, hollow, and segmented through time. The nodes and internodes of the culm structure can be separated. The internodes are hollow plates with axially directed cells [5]. As indicated in Figure 1, a diaphragm is developed inside the node, and the culm-sheath and branches emerge from the outside [6]. Lignin, cellulose, hemicelluloses, ash, moisture, and extractive make up 41.8%, 59.8%, 29.3%, 1.5%, 6.1, and 3.3% of the chemical composition of bamboo, which is identical to that of wood [7].

Bamboo fiber is a thin, discrete reinforcement material made from a variety of materials, such as steel, plastic, glass,

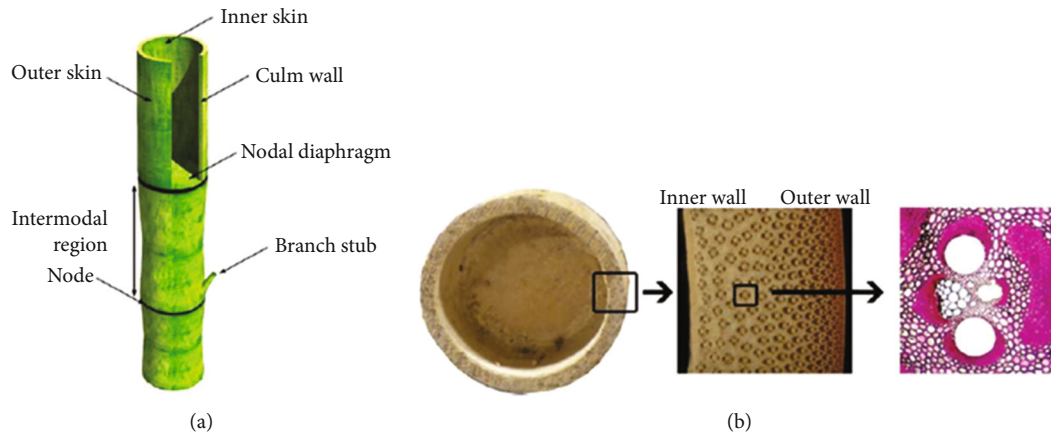


FIGURE 1: (a) Schematic of a culm segment and (b) section of culm wall showing grading of vascular bundles [8].

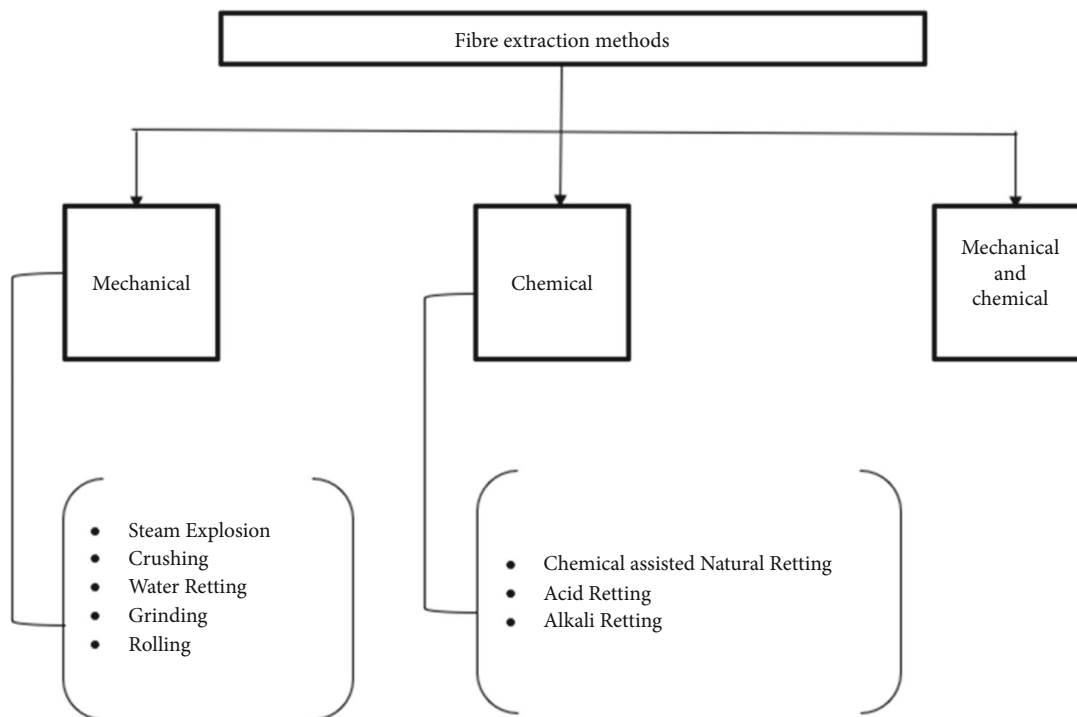


FIGURE 2: Different fiber extraction methods [12].

carbon, and natural materials in a variety of shapes and sizes [9]. Bamboo fibers have always had a wide range of applications since their introduction to the market. The following desirable material features contribute to its durability: a green raw material with an almost infinite supply and excellent mechanical qualities, particularly tensile strength. Bamboo fiber is a poor heat conductor in terms of weight, but it has excellent heat, acoustic, and electrical insulation characteristics. Bamboo fiber has a lower abrasive nature than glass fiber, which provides advantages in technology, material recycling, and composite material manufacture in general. Bamboo fiber has strong insulating characteristics, is environmentally benign, and is biodegradable. Natural fibers will biodegrade under certain conditions as a result of their ability to absorb water and reactivity: the hydroxyl groups pres-

ent in the contents of the cell wall not only supply water absorption sites but also are eligible for chemical alteration [10]. Bamboo fibers are used in the production of paper, textiles, energy structural parts, and boards [11].

The diaphragm and node of bamboo plants were extracted first to harvest fibers from bamboo culm in more scientific investigations, and then, the hollow sections were used for processing. Then, several procedures for removing bamboo fibers were adopted, depending on their intended use. As shown in Figure 2, chemical, mechanical, and mechanical and chemical combinations are the different types of processes [12].

Over the actions and applications of fiber, such methods of manufacture have their benefits and drawbacks. The fibers removed by steam explosion, for example, are hard and

TABLE 1: Thermal measurement techniques for each property.

Abbreviation	Measurement technique	Property	Unit
DSC	Differential scanning calorimetry	Enthalpy	$W = J/\text{seconds}$
DTA	Differential thermal analysis	Different temperature	$^{\circ}\text{C}$ or μV
TGA	Thermogravimetric analysis	Mass	g
DTG	Derivative thermogravimetric	Weight	dm/dt



FIGURE 3: Highland bamboo plants in Ethiopia.

black, and single fibers are not efficiently separated from fiber bundles. Because the bamboo fiber cell walls have been split and the bamboo fiber has become brittle, the crushed cell walls impacted on the bamboo fiber surfaces have a low shear resistance. It was mostly used to make pulp. Crushing procedures capture tiny fibers, which get powdered as a result of mechanical over-processing [12].

Natural fibers are complicated in shape and typically lignocellulose made of helically bonded cellulose microfibrils in an amorphous matrix of lignin and hemicelluloses. Chemical approaches for improving fiber–matrix interfacial adhesion are available. Chemical-assisted natural retting procedures, while removing more lignin than alkali and acid retardation, are not suitable in my situation due to the high moisture content of the extracted fiber [13].

According to the examination of different literature for the study, alkali and acid retting procedures are relevant due to the properties of acquiring long fiber and enhancing the interfacial adhesion between the fibers and the matrix.

Thermal analysis of bamboo fiber using thermal measurement techniques, as shown in Table 1, is a useful tool for determining the properties of bamboo polymeric materials. A thorough understanding of the thermal stability of bamboo fiber is required for creating new goods. The top limit of temperature in fabrication is determined by the breakdown threshold temperature. With a better understanding of the matrix, you can optimize the processing temperature and time [14]. The heat stability or decomposition behavior of bamboo fiber was investigated using thermogravimetric analysis (TGA, SKZ Industrial co. Limited, location China) and derivative thermogravimetric (DTG, SKZ Industrial co. Limited, location China). Three thermal decomposition stages characterized the

complete degradation profile of bamboo fiber: moisture evaporation, cellulose and hemicellulose decomposition, and lignin decomposition [15]. The exothermic and endothermic events can be measured from differential thermal analysis (DTA, SKZ Industrial co. Limited, location China) using simultaneous TGA and DTA measurements [16]. Hemicellulose begins to deteriorate earlier and decomposes between 220 and 350 $^{\circ}\text{C}$. Hemicellulose low thermal stability is thought to be related to a lower degree of polymerization than cellulose and lignin [17, 18]. By measuring the heat flow rate associated with a thermal event as a function of time and temperature, differential scanning calorimetry (DSC) assists us in obtaining quantitative information on melting and phase transitions. DSC's primary applications include determining melting, glass transition, crystallization, chemical reactions, thermal history, and specific heat capacity [14].

Ethiopia has more than 1.3 million hectares of bamboo, accounting for 67% of Africa's bamboo-producing area and 7% of the world's bamboo area. Two common bamboo species found in Ethiopia are *Yushania alpina* (highland bamboo) and *Oxytenanthera abyssinica* (lowland bamboo) [19]. Highland bamboo inhabits an estimated 300,000 ha in Ethiopia's southern, southwestern, central, and northwestern highlands [20]. However, the thermal characteristics of single highland bamboo fibers have not yet been investigated. This is a major stumbling block to their application. This study intends to bridge information gaps in order to prepare for Ethiopian bamboo's intensive scientific use in textile, energy, and structural applications [21].

2. Methodology

2.1. Materials

2.1.1. Bamboo Sample. Figure 3 shows the bamboo plant utilized in the experiments: highland bamboo. Bamboo stem samples were collected from 1- to 3-year-old plantations in Enjibara, Awi area, West Gojam, Amhara region, and Ethiopia (latitude: 10,057'N, longitude: 36,056'E, elevation: 2560 m above sea level).

2.1.2. Chemicals. NaOH at a different weight-by-volume concentration of 1%, 2%, and 3%, respectively, was included in this study.

2.2. Methods

2.2.1. Raw Material Preparation. When the bamboo plants were collected, they were a wet mess of various fragments. They were chopped with a slicer at the center stem to remove the residual pieces, which were around 25–30 cm long and 2.0–2.5 mm thick, as shown in Figure 4.



FIGURE 4: Highland bamboo plants were chopped with a slicer.



FIGURE 5: Untreated and treated highland bamboo fiber extraction process.

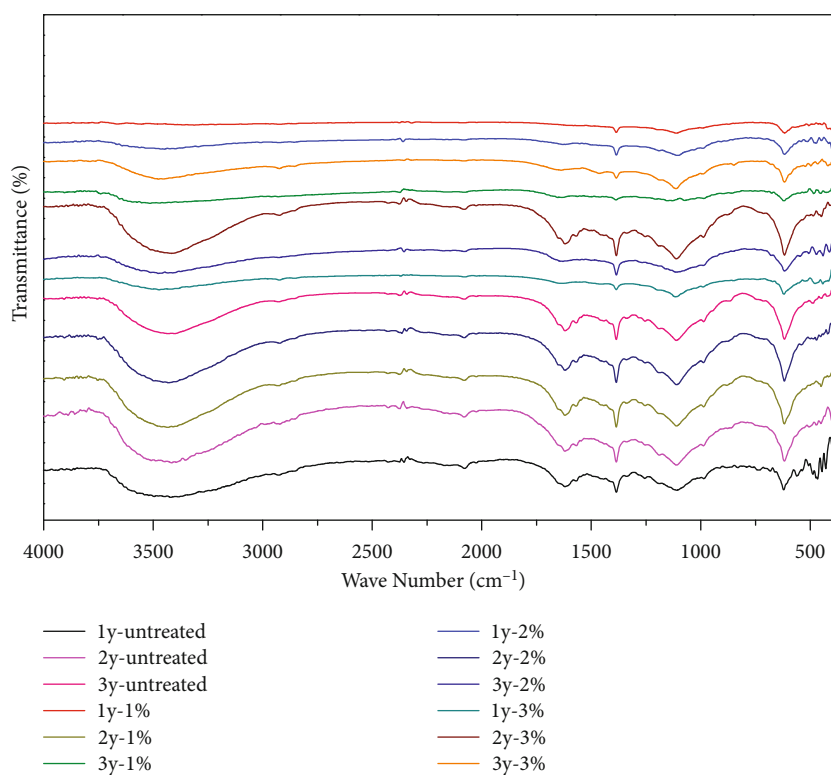


FIGURE 6: FTIR analysis of treated and untreated highland bamboo fiber at different concentrations.

2.2.2. *Extraction.* Retting for 3 days with water and NaOH concentrations (1–3 wt%/vol), plant age (1–3 years), and rinsing the fibers with tap water until the solution was neutralized

after extraction were the variables used. The extracted fibers were then dried to a constant mass at 105°C in an air-forced drier. A roller crusher machine (Phoenix Products, Belgaum,

TABLE 2: Characteristic bands for a functional group of untreated and alkali-treated highland bamboo fiber at various concentrations [25–30].

Wavenumber (cm^{-1})	Functional group	Compounds
3400–3425	–OH	Alcohol (cellulose, hemi-cellulose, and lignin), phenol (bond H), and carboxylic acid
22,075–2083	C–H	Alkanes
1617–1620	C=O	Hemicelluloses and lignin
1380–1382	C–H	C–H deformation in cellulose and hemicellulose
1106–1109	C–O	Alcohol (cellulose, hemicellulose, and lignin), ether, carboxylic acid, and ester
613–619	O–H	Out of plane bending

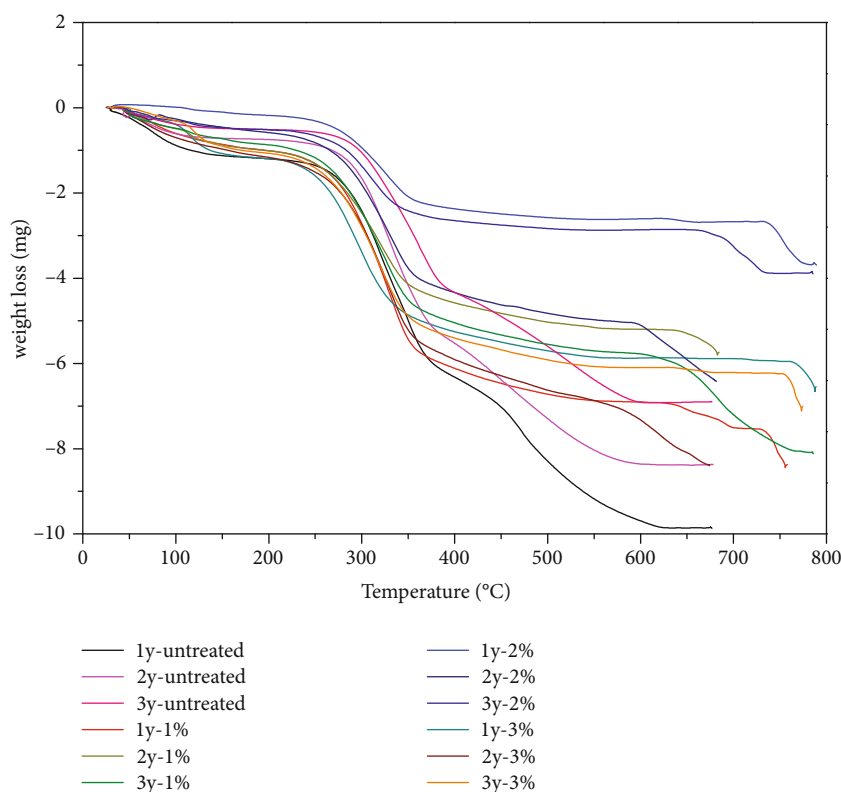


FIGURE 7: TGA analysis of untreated and alkali-treated highland bamboo fiber.

Karnataka, India) was utilized to extract fibers from the untreated and alkali-treated chunks, as shown in Figure 5.

2.2.3. Characterization. Untreated and alkali-treated highland bamboo fibers were subjected to Fourier transform infrared spectroscopy (FTIR; Jasco, Easton, MD21601 United States, Model 6600) analysis in the wave range of $4000\text{--}400\text{ cm}^{-1}$ to identify the functional groups and other pollutants. The morphological changes generated by alkali treatment of fibers with a random orientation at various concentrations, magnifications, and an acceleration voltage of 10 kV were visualized using an SEM (JEOL Ltd. (JP), location India) (Model: JCM 6000Plus).

Thermal stability was investigated using TGA (Model: SKZ1053), DTG (Model: SKZ1053), and DTA (Model: SKZ1053) at temperatures ranging from 20 to 700°C at a rate of $20^\circ\text{C}/\text{minute}$ in an air atmosphere. In addition, the ther-

mal stability was explored using DSC (Model: PerkinElmer DSC 4000, Waltham, MA, USA) in a range of $30\text{--}400^\circ\text{C}$ at $15^\circ\text{C}/\text{minute}$ under a nitrogen environment in addition to these thermal property characterization devices. The samples (about 10 mg) were placed in lidded aluminum pans. After the first scan, the samples were quickly cooled at the same rate, and the second scan was always recorded at the same heating rate.

3. Results and Discussion

3.1. FTIR Analysis. The chemical structures of 1- to 3-year-old highland untreated and treated with 1–3% NaOH bamboo fibers were studied using FTIR. Figure 6 shows how the FTIR spectra were vertically shifted for clarity using the Software Origin. Typical cellulose yielded by all the samples was spectra, which was in line with earlier research [22–24]. The

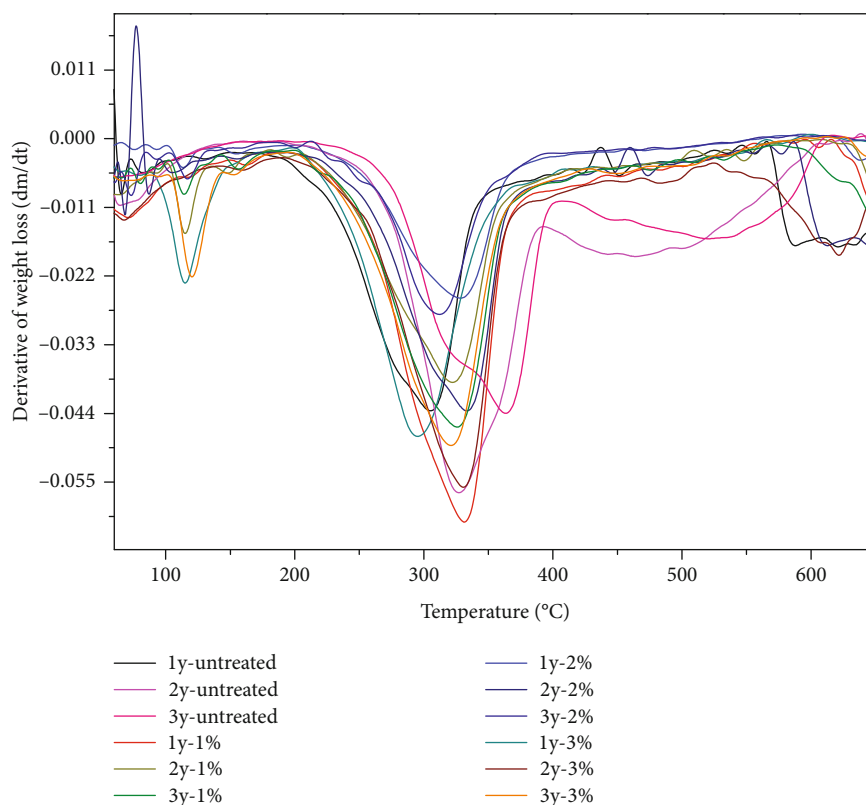


FIGURE 8: DTG analysis of untreated and alkali-treated highland bamboo fiber.

TABLE 3: TGA data thermal stability of untreated highland bamboo fiber at different ages.

Stages	Untreated (water retting)								
	1 year			2 years			3 years		
	T_o °C	Weight loss mg	Weight loss %	T_o °C	Weight loss mg	Weight loss %	T_o °C	Weight loss mg	Weight loss %
Dehydration	≤ 207.9	1.21	12.1	≤ 193.2	0.74	7.4	≤ 139.6	0.48	4.8
First degradation	207–372	4.69	46.9	193.2–373	4.33	43.3	139.6–387.6	3.685	36.85
Second degradation	372–501.8	2.43	24.3	373–547	2.953	29.53	387.6–586.6	2.67	26.7
Third degradation	501.8–675.5	1.51	15.1	547–677	0.37	3.7	586.6–675.6	0.06	0.6

TABLE 4: TGA data thermal stability of 1% alkali-treated highland bamboo fiber at different ages.

Stages	1% alkali-treated								
	1 year			2 years			3 years		
	T_o °C	Weight loss mg	Weight loss %	T_o °C	Weight loss mg	Weight loss %	T_o °C	Weight loss mg	Weight loss %
Dehydration	≤ 194.7	1.0	10	≤ 192	0.99	9.9	≤ 195.7	0.86	8.6
First degradation	194.7–356.2	4.62	46.2	192–348	3.12	31.2	195.7–354.9	3.75	37.5
Second degradation	356.2–555.7	1.26	12.6	348–561	1.07	10.7	354.9–566	1.12	11.2
Third degradation	555.7–756	1.52	15.2	561–683	0.57	5.7	566–785	2.28	22.8

FTIR spectra of all the samples were nearly identical, indicating that no new functional groups in the cellulose molecules had been added. As the alkali concentration rises, the O–H stretching and H-bonded broad absorption band in the region decreases. The addition of an extra peak in the free

hydroxyl bond structure is caused by a decrease in the functional group of phenolic or aliphatic hydroxyl in the fiber as a result of the reaction with sodium hydroxide, which promotes free hydroxyl, resulting in the addition of an extra peak in the free hydroxyl bond structure, with the absorption band

TABLE 5: TGA data thermal stability 2% alkali-treated highland bamboo fiber at different ages.

Stages	2% alkali-treated								
	T_o °C	1 year		2 years			3 years		
		Weight loss mg	%	T_o °C	Weight loss mg	%	T_o °C	Weight loss mg	%
Dehydration	≤203	0.185	18.5	≤193.9	0.57	5.7	≤194.4	0.51	5.1
First degradation	203–367	2.065	20.65	193.9–356.45	3.35	33.5	194.4–339	1.81	18.1
Second degradation	367–530	0.36	3.6	356.45–562.3	1.08	10.8	339–642	0.54	5.4
Third degradation	530–787	1.05	10.5	562.3–682.7	1.21	12.1	642–785	1.02	10.2

TABLE 6: TGA data thermal stability of 3% alkali-treated highland bamboo fiber at different ages.

Stages	3% alkali-treated								
	T_o °C	1 year		2 years			3 years		
		Weight loss mg	%	T_o °C	Weight loss mg	%	T_o °C	Weight loss mg	%
Dehydration	≤184.8	1.17	11.7	≤181.2	1.164	11.64	≤180.6	1.03	10.3
First degradation	184.8–351	3.7	37	181.2–335.4	3.5	35	180.6–358.3	4	40
Second degradation	351–641.8	1.0	10	335.4–547.1	1.22	12.2	358.3–565.4	1.07	10.7
Third degradation	641.8–787.85	0.73	7.3	547.1–787.6	0.76	7.6	565.4–773	1.0	10

TABLE 7: TGA data maximum temperature and weight losses of highland bamboo fiber at different alkali concentrations and ages.

		1 year	2 years	3 years
Untreated (water retting)	Temperature (°C)	373	373	387.6
	Weight loss (%)	46.9	43.3	36.86
1%	Temperature (°C)	356.2	348	354.9
	Weight loss (%)	46.2	31.2	37.5
2%	Temperature (°C)	367	356.45	339
	Weight loss (%)	20.65	33.5	18.1
3%	Temperature (°C)	351	335.4	358.3
	Weight loss (%)	37	35	40

of untreated fiber being the most pronounced [25]. The removal of hemicellulose and lignin from alkali-treated fibers could explain the decrease in certain vibrational bands of the infrared spectra [15]. Table 2 depicts the characteristics of untreated and alkali-treated highland bamboo fibers at various NaOH concentrations, as indicated in Figure 6.

3.2. Thermal Stability Analysis. The thermal characteristics of untreated (water retting) and alkali-treated highland bamboo fiber were investigated using TGA, DTG analysis, DSC, and DTA for different ages and concentrations of NaOH. The sample mass was approximately 10 mg, and it was heated in an air environment at temperatures ranging from 20 to 800°C at a rate of 10°C/minute for TGA examination. Figures 7 and 8 show the DTG and TGA curves of untreated (water retting) and alkali-treated highland bamboo fiber. These curves have revealed that hemicellulose, cellulose, and lignin degrade at distinct temperatures; hemicellulose decomposes at a lower temperature range (220–315°C) than cellulose (300–400°C), whereas lignin decomposes across a

whole wide temperature range (150–800°C) [30–33]. As shown in Tables 3–6, the TGA and DTG features imply dehydration weight loss and three stages of degradation weight loss and explore the maximum temperature and maximum weight losses of the fiber.

As illustrated in Table 3, when untreated (water retting) highland bamboo fiber is dehydrated, 1-year-old bamboo fiber has the maximum temperature (207.9°C) and weight loss (12.1%), which is related to the plant's higher moisture content at this age, than 2 and 3 years. In the case of the first degradation stages, the maximum temperature (387.6) was 3-year-old bamboo fiber, and the maximum weight loss (46.9%) was the 1-year-old bamboo fiber. At this stage, all of the fiber's major components (cellulose, hemicellulose, and lignin) were decomposed at various temperatures. As a result, more weight loss indicates that more of these components have been removed. The second stage of degradation occurs in the cellulose and lignin decomposition temperature range. Bamboo fibers that are 2 years old get the most weight loss (29.53%), and bamboo fibers that are 3 years

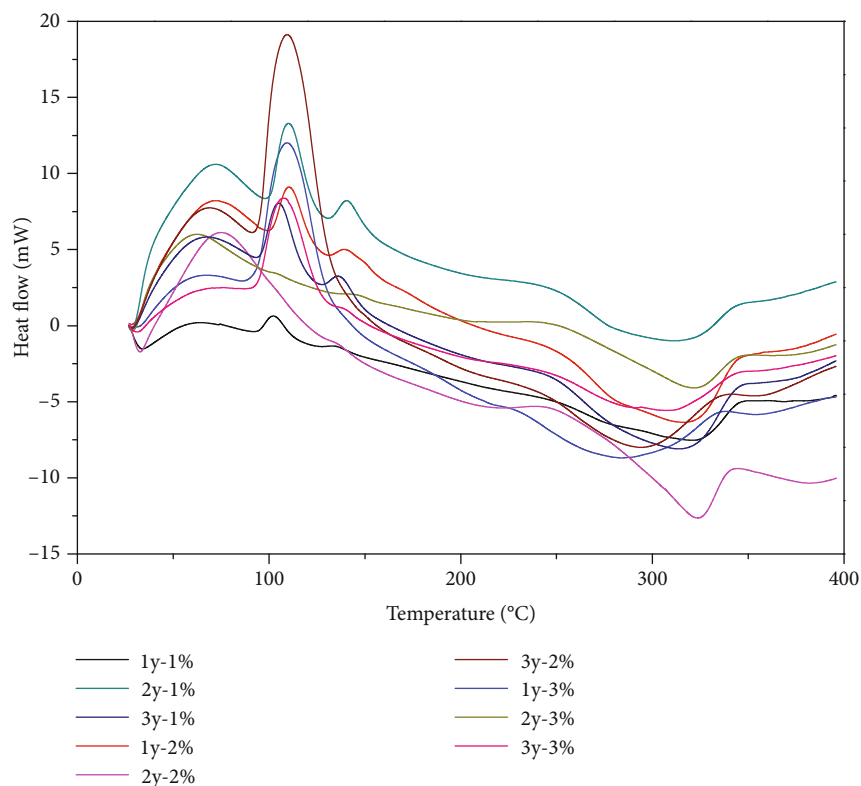


FIGURE 9: DSC analysis of untreated and alkali-treated highland bamboo fiber.

TABLE 8: DSC data analysis of highland bamboo fiber at different alkali concentrations and ages.

	Peak temperature (°C)	Peak height (mW)	Area (mJ)	Delta (J/g)	Onset temperature (°C)	End temperature (°C)
1 year—1%	316.66	-3.8945	-1833.9	-84.51	27.41	350.1
1 year—2%	110.51	9.23	1510.6	68.73	8.9	135.6
1 year—3%	109.41	13.1	-256.7	-12.1	90.2	133.6
2 years—1%	110.03	12.63	3929.1	163.1	91.72	134.5
2 years—2%	76.6	7.5	940.4	66.2	27.9	342
2 years—3%	62.97	6.11	1642	68.13	31.1	350
3 years—1%	105.03	8.54	-20.04	-0.95	87.4	126.4
3 years—2%	109.6	19.7	1363.2	60.6	91.08	134.8
3 years—3%	107.85	8.66	-426.8	-1923	90.76	130.13

old have the highest temperature (586.6°C). Finally, the temperature ranges of all years old bamboo fiber are within the decomposition temperature range of lignin in the third degradation stage. The 1-year-old bamboo fiber destroyed more lignin (15.1%) at this stage, whereas the 3-year-old bamboo fiber had the highest decomposition temperature.

Table 4 shows, in the dehydration stage of 1 wt%/vol NaOH concentration alkali-treated highland bamboo fiber, 3-year-old bamboo has the highest temperature (195.7°C) and the most weight loss (10%) in the 1-year age; in this stage, 3-year-old bamboo fiber has the highest temperature but the least weight losses (8.6%). Table 4 shows that 3-year-old bamboo fiber underwent lignin decomposition in addition to dehydration. 356.2°C and 46.2% are the peak temperature

and weight losses of 1-year-old bamboo fiber, respectively, in the first degradation phases. All of the fiber's major aspects (cellulose, hemicellulose, and lignin) were degraded at different temperatures at this point. As a result, greater weight reduction implies that more of these components have been eliminated. The cellulose and lignin decomposition temperature range is where the second stage of degradation takes place [31, 32]. One-year-old bamboo fibers lose the most weight (12.6%), whereas three-year-old bamboo fibers have the highest temperature (566°C). The decomposition temperature range of lignin in the third degradation stage is within the temperature range of all years old bamboo fiber. At this time, the 3-year-old bamboo fiber degraded more lignin (22.8%) and has the highest decomposition temperature (785°C).

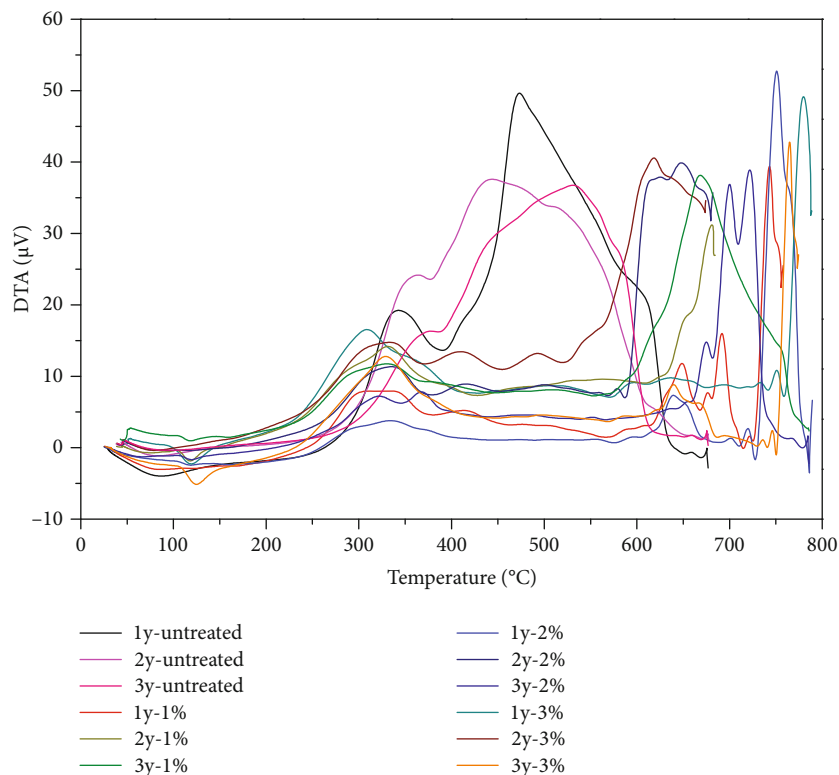


FIGURE 10: DTA analysis of untreated and alkali-treated highland bamboo fiber.

As demonstrated in Table 5, 1-year-old bamboo fiber has the highest temperature (203°C) and weight loss (18.5%) during the dehydration stage of 2% alkali-treated highland bamboo fiber, which is due to the plant's higher moisture content at this age than 2 and 3 years. The 1-year-old bamboo fiber had the highest temperature (367°C) and the 2-year-old bamboo fiber had the most weight loss (33.5%) during the first degradation phases. All of the fiber's primary components (cellulose, hemicellulose, and lignin) were degraded at different temperatures at this point. As a result, greater weight reduction implies that more of these components have been gone. The cellulose and lignin decomposition temperature range is where the second stage of degradation takes place. Two-year-old bamboo fibers lose the most weight (10.8%), whereas three-year-old bamboo fibers have the highest temperature (642°C). The temperature ranges of all years old bamboo fiber are inside the lignin degradation temperature range in the third deterioration stage. The 2-year-old bamboo fiber had decomposed more lignin (12.1%) at this point, whereas the 1-year-old bamboo fiber had the highest decomposition temperature (787°C).

Due to the plant's higher moisture content at this age than 2 and 3 years, 1-year-old bamboo fiber has the maximum temperature (184.8°C) and weight loss (11.7%) during the dehydration stage of 3% alkali-treated highland bamboo fiber, as proven in Table 6. Three-year-old bamboo fiber had the highest temperature (358.3°C) and weight loss (40%) during the first stages of degradation. At this point, the main components of the fiber (cellulose, hemicellulose, and lignin) were all decomposed at various temperatures. As a result, more weight loss means that more of these components have

been removed. The second stage of degradation occurs in the cellulose and lignin decomposition temperature range. Bamboo fibers that are two year old lose the most weight (12.2%), whereas bamboo fibers that are one year old have the highest temperature (641.8°C). In the third degradation stage, the temperature ranges of all years old bamboo fiber are within the lignin decomposition temperature range. Although the 1-year-old bamboo fiber had the highest decomposition temperature (787.85°C), the 3-year-old bamboo fiber had decomposed more lignin (10%) at this stage.

The maximum temperature is the temperature at which a material loses the most weight and decomposes the fastest, as well as a major indicator of its thermal stability [33]. The temperature with of untreated (water retting) and different concentrations of alkali-treated highland bamboo fibers are shown in Table 7. For one and two years, the maximum temperature and weight losses occurred in untreated bamboo fiber, whereas for three years, the maximum temperature and weight losses occurred in 3% concentration alkali-treated and untreated bamboo fiber, respectively. The first degradation stage is responsible for the greatest weight loss since it overlaps with the disintegration of all the fiber's principal components (cellulose, hemicellulose, and lignin).

When compared to TGA and DTG, the DSC study yielded slightly different results. The data were analysed in such a way that it was possible to see the phase change of various materials, which might be exothermic (dip) and/or endothermic (peak), and the energy consumption property is shown by DSC curves [34]. The large endothermic peak for all alkali-treated highland bamboo fiber is related to the removal of water in DSC measurements [35]. The peak

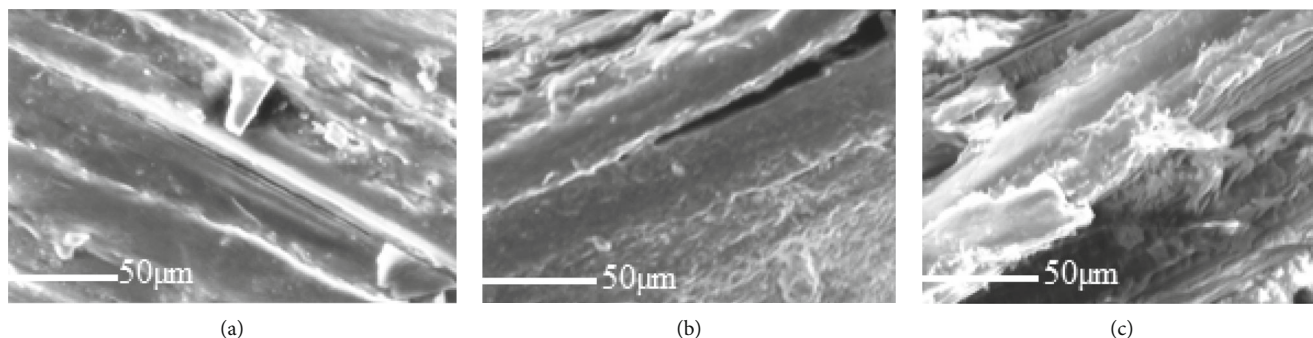


FIGURE 11: SEM image of (a) 1%, (b) 2%, and (c) 3% alkali-treated highland bamboo fiber micromorphology at $50\ \mu\text{m}$ magnification.

temperature for all samples occurred in the temperature range of $62.97\text{--}316.66^\circ\text{C}$, according to the raw data, as shown in Figure 9. Due to the work of expansion caused by the creation of gas, weight loss is usually an endothermic action [36]. All plots show a similar tendency, and their result is illustrated in Table 8. One year, 1 wt%/vol bamboo fiber exhibits an exothermic peak attributable to phase change, whereas others have an endothermic peak, which is a result of evaporation of bound water molecules. The DTA experimental studies, as explored in Figure 10, support this investigation.

3.3. Morphological Analysis. The surface appearance of randomly distributed one-year-old alkali-treated highland bamboo fibers with varied NaOH concentrations was shown in Figure 11. As the NaOH concentration grew, the diameter of individual bamboo strands shrank (Figure 11). The loss of hemicellulose and lignin matrix, as well as microfibril aggregations following alkali treatment, may have caused the fiber dimension change. Bamboo fiber from *Neosinocalamus affinis* exhibited a similar behavior [34]. When compared to the 1% and 2% NaOH bamboo fibers, the 3% NaOH treated fiber resulted in greater wrinkles on the surface of the bamboo fibers. This is because the microfibril aggregates have changed from a randomly interwoven to a granular structure. The removal of hemicellulose, lignin, and other surface contaminants enhances the surface morphological roughness as the alkali concentration is increased. Because they provide good interfacial bonding between the polymer matrixes, these rough surfaces have more advantages in the fabrication of composite materials [35]. After treatment with high alkali concentrations, the partial loss of cellulose produces a drop in fiber strength. As a result, a high-concentration alkali treatment can weaken single cellulose bamboo fibers [36].

4. Conclusions

Untreated (water retting) and alkali-treated bamboo fibers of various ages and concentrations were properly generated in this investigation, and their thermal characteristics as a function of age and alkali concentrations were examined. The following conclusions can be derived from the findings:

- (i) All of the samples have about identical FTIR spectra, showing that no additional functional groups had been introduced to the cellulose molecules. The O–H stretching and H-bonded broad absorption band in the region decrease as the alkali concentration rises.
- (ii) When untreated (water retting) highland bamboo fiber is dehydrated, 1-year-old bamboo fiber has the maximum temperature (207.9°C) and the greatest weight loss (12.1%), which is owing to the plant's higher moisture content at this age, than 2 and 3 years.
- (iii) For one and two years, the maximum temperature and weight losses occurred in untreated bamboo fiber, but for three years, the maximum temperature and weight losses occurred in 3% concentration alkali-treated and untreated bamboo fiber, respectively. The first degradation stage is responsible for the greatest weight loss since it overlaps with the disintegration of all the fiber's principal components (cellulose, hemicellulose, and lignin).
- (iv) One year, 1 wt%/vol bamboo fiber exhibits an exothermic peak attributable to phase change, whereas others have an endothermic peak, which is a result of evaporation of bound water molecules.

Alkali treatment affected the cell wall's surface appearance and microfibril aggregates.

The results of this study indicate that highland bamboo fibers have good thermal stability and surface appearance properties but pretentious by alkali treatment. Hence, the newly developed composite material from this fiber can be used for textile and energy production structural parts.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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