Morphological, Physico-Mechanical and Thermal Properties of Banana Plant Fibers (*Musa sapientum*)

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SUMMARY

Environmental consciousness and increasing awareness of green technology have stirred the entire gamut of industry to move towards new materials instead of using conventional synthetic polymeric fibers. They are both a responsible and a sustainable choice. Natural fiber can be a good substitute as they are available in fibrous form at low cost. The work presented here deals with banana fibers (Musa Sapientum) which are extracted from the stem of the banana plant. The microstructure, physical and mechanical properties are investigated. The diameter and density of the fibers are 0.15 mm and 1.36 g/cm^3 respectively. Tensile test results show that tensile strength is in the range of 345-520 MPa. The fracture mode of fibers after tensile testing are investigated through Scanning electron microscope images (SEM). Thermogravimetric analysis (TGA) shows that thermal stability of banana fiber is up to 252°C.

INTRODUCTION

Most of the developing countries have rich reserves of fiber: agricultural and natural. Environmental researchers focused their attention towards the effective utilization of natural lignocellulosic fibers due to their availability, biodegradability, mechanical properties, human friendly nature and low cost. The industrial use of vegetable fibers as composite material reinforcements, started at the beginning of the 20th century with large scale manufacturing of sheets, tubes and pipes for electronic purposes (paper or cotton to reinforce sheets, made of phenol- or melamine formaldehyde resins). For example,

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aeroplane seats and fuel tanks were made up of natural fibers with a small amount of polymeric binders [1]. Several researchers reported the use of natural fibers such as sisal, banana, jute and coir as reinforcements in composite building panels [2-5]. In India, potential yield of fiber has been estimated to be 2.2 million tons annually. Banana fibers are extracted manually from the banana stems which are usually discarded in the land after banana cultivation. About 37 kgs of stem, yields about 1 kg of quality fibers. Extracted banana fibers can be used in the paper industry due to its high cellulose and low lignin content [6].

The structure- property relationship of various fibers have been described, and the problems arising during processing of the composites and their solutions have been discussed [7]. The ultimate tensile strength, initial modulus and breaking strain of banana fibers, as a function of various fiber diameters, fiber length and crosshead speed [8] have been reported. The tensile and thermal properties of varieties of banana fiber have been studied. The experimental results show that untreated fiber has more tensile strength than treated fibers [9]. The nature of stress strain curve and fracture at different strain rates of the banana fibers has been analyzed by SEM [10]. The micro structural, physical, chemical and mechanical properties of the *Sansevieria Cylindrica* fibers have been analyzed and studies reveal that tensile strength of fibers does not appear to be a function of the gauge length [11]. Banana fiber exhibits the highest content of ash, cellulose, and carbon compared to coir and bagasse [12]. The present study investigates the micro structural, physical, mechanical and thermal properties of banana fibers obtained in natural form without any alkaline modification.

EXPERIMENTAL

Banana Fiber Material Extraction

Banana fibers for this investigation are collected from YMCA at Marthandam, Kanyakumari district, Tamilnadu, India. These fibers are mainly obtained from the stem of the edible fruit bearing plant of species *Musa Sapientum*, by hand scraping or retting. The fleshy parts of the pseudostem are removed with a semi sharp knife. After that, it is dried in the sunlight for five hours. The fibers extracted for this study is shown in **Figure 1**.

Figure 1. *A sample of dry banana fiber after extraction*

Physical Properties of Fiber

The methodology used to determine the fiber diameter and its physical properties like density (mass/unit volume) and denier (mass/unit length) are presented here. Fiber diameters have been studied through image analyzer. It is the average of three dimensions taken at various locations along the length of the fiber. Density of fiber is measured by using True density meter SMART PYCNO 30. This measurement is done by measuring the pressure difference between the volume of sample cell and the reference cell. A known quantity of helium gas under pressure is allowed to flow from a precisely known reference volume (V_R) into a sample cell containing powdered fiber sample [13]. The method of calculating the density of banana fiber sample is as follows:

Density of fiber (ρ) = Sample weight / Sample volume measured (V_P) (1)

$$V_P = V_C - V_R\,[(P1/P2) - 1] \quad (2)$$

Where,

V_C is Volume of Sample cell (13.12 cm^3)

V_R is Volume of Reference cell (7.21 cm^3)

$P1/P2$ is pressure ratio between volume of sample cell and reference cell

Denier is the measure of the linear mass density of fiber. Denier of the fiber is determined by weighing accurately 100 fibers of 10 cm each. Three such measurements were performed, and then average weight of 1000 cm (100 x 10 cm) fibers was measured using the Equation (3).The denier, which is the weight in gram of 9000 meter length of the fiber, was computed using the following formula:

$$\text{Denier } (N) = W \times l/L \quad (3)$$

where,

W is Weight of the fiber in gram

l is Length of the fiber in meter

L is System length (9000 m)

Mechanical Properties

In this study, fiber bundles were separated into single fibers and then were tested in dry condition under tensile loading at gauge length of 70 mm using INSTRON universal testing machine type 55R6021 as per ASTM D 3822-01. Tensile test was carried out at a crosshead speed of 10 mm/min. The measurements were recorded for 20 samples. The cross section of the fiber was calculated from the diameter which was measured by the image analyzer, assuming a cylindrical fiber. The microstructres of the fibers before and after fracture, were analysed by the scanning electron microscope (SEM).

Thermal Analysis

Thermogravimetry analysis (TGA) and derivative thermogravimetry (DTG) techniques were used to study the thermal behavior of banana fibers. The measurements were taken using horizontal differential type thermo balance TG/DTG EXSTAR 6200 in nitrogen atmosphere (200 ml/min) in a temperature range of 30-900°C at a heating rate of 40°C/min. Also, differential scanning calorimetry analysis has been performed by DSC Q20 V22.4 build 116. Fiber samples of approximately 6 mg were placed in the aluminium pan, sealed and introduced into the heating cell of the calorimeter. Thermal scanning is done at 10°C/min and is heated from 0 to 400°C under constant nitrogen atmosphere.

RESULTS AND DISCUSSION

Fiber Diameter, Density and Denier Measurement Evaluation

Thirty fibers were chosen randomly from a bundle of banana fibers. It was found that fiber cross-sections are roughly circular in shapes. **Figure 2** shows the image used for the measurement of fiber dimensions. The range of fiber diameters was from 0.03 to 0.36 mm. The average diameter of fibers used for this study was approximately, 0.15±0.0749 mm. The SEM micrograph of cross section of banana fibers is shown in **Figure 3**. The structure of

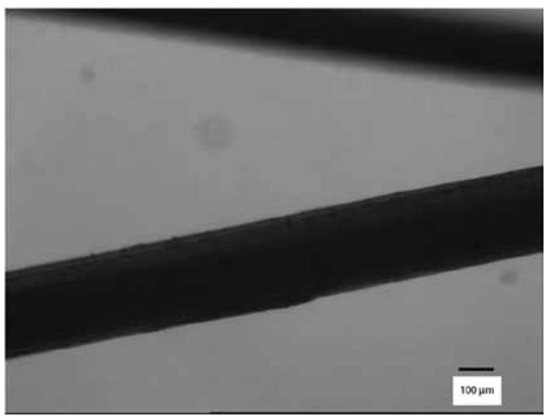

Figure 2*. Image of banana fiber through image analyser (10 x)*

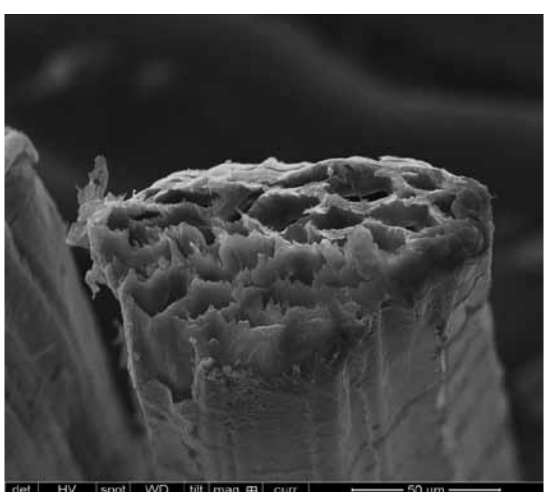

Figure 3*. Micrograph of cross section of fiber*

banana fiber consists of four types of cells (xylem, phloem, schlerenchyma and parenchyma) arranged in a particular fashion. These cells overlap along the length of the fiber and are bonded together by pectin and other non cellulosic compounds which give strength to the bundle. The shape of the cells is circular to polygonal with rounded corners and the walls of the cell are thin and uniform [14].

The density and denier values are 180 g/m and 1.36 g/cm^3 respectively. This density is suitable for light weight application such as sound insulation and thermal insulation panels. Banana fibers having lower values of denier are considered as fine fiber materials.

Tensile Strength

Figure 4 shows the stress strain curves of the untreated banana fiber. The curve shows that there is a brittle fracture with a sudden drop in load when fiber failure occurs. Single filament tensile test results of small brittle natural fibers are difficult to analyze due to the high scatter of values observed. This scatter is related mainly to three factors: test parameters/conditions, plant characteristics and area measurements [15]. Banana fibers have exibited variability in tensile testing which is the characteristic of all natural fibers. Slight differences in their microstructure could also result in some

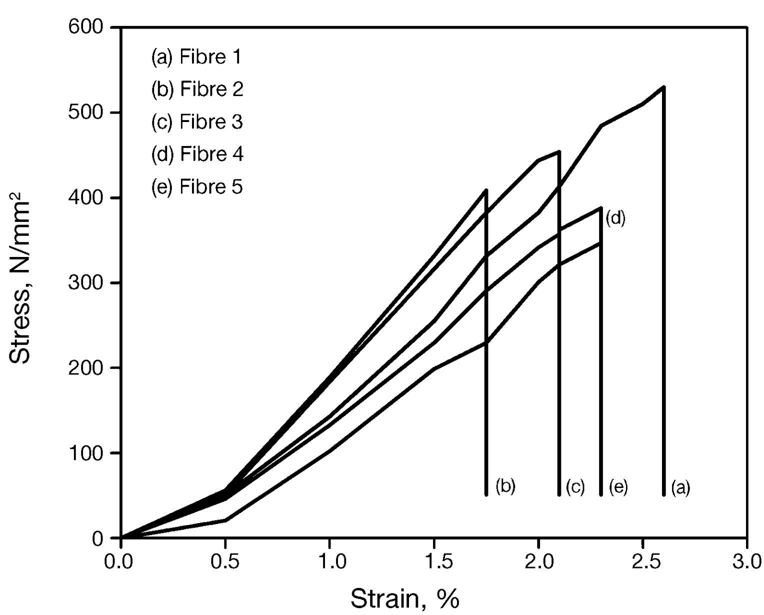

***Figure 4**. Stress strain curves of banana fiber*

variability. The tensile strength values, Young's modulus and elongation at break are 345-520 MPa,1.7-2.6% and 17 GPa respectively. **Figure 5a-b** shows the SEM micrographs of untreated banana fiber before and after fracture, in tension testing. The SEM analysis reveals that the nature of fracture in banana fibers due to tensile force is brittle with the absence of fibril splitting. The fracture has occurred due to the variability in the strength of the individual fiber cell [16].

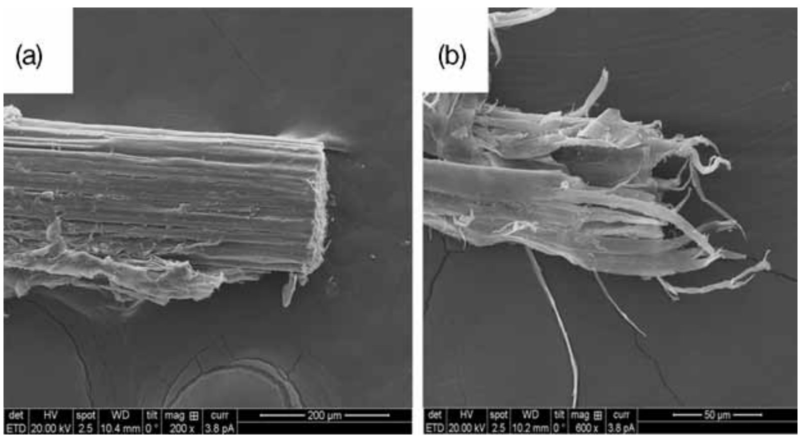

***Figure 5**. SEM micrograph of banana fiber: (a) before fracture (b) after fracture in tension*

Thermal Analysis of Fiber

Figure 6 shows the TGA and DTG (1st derivative) curves of the fiber. Three main steps in the loss of mass can be identified from the figure. Initial mass loss up to 100°C is related to the water loss associated with the moisture present in the fiber. Due to the hydrophilic nature of the fiber, it is difficult to eliminate completely, the water present in the fiber during drying [17]. Secondly the banana fiber exhibits thermal stability between 100°C and 252°C. Hence, for the banana, 252°C is the maximum temperature up to which, this can be utilized. From 252°C to 386°C there is a considerable mass loss due to the degradation of cellulose present in the fiber. Further, above 386°C, degradation of fiber takes place due to the breaking of the bonds of the protolignin [18-19]. The traces of thermo gravimetric and derivative thermo gravimetry analysis are characterized by three parameters such as initial decomposition temperature (IDT), final decomposition temperature (FDT) and percentage of mass loss. Single step degradation is observed in banana fibers. Initially, 10% of mass loss is observed between the temperature 50 and 100°C. Major mass loss of

70% is observed in the temperature range of 200 to 400°C. The fiber loses its maximum mass at the temperature of 360°C. These results are shown in **Table 1**.

Table 1. Results of TGA/DTG of fiber

Sample	IDT °C	FDT °C	T_{max} °C	Mass loss %
Banana fiber	272	378.98	358.23	70

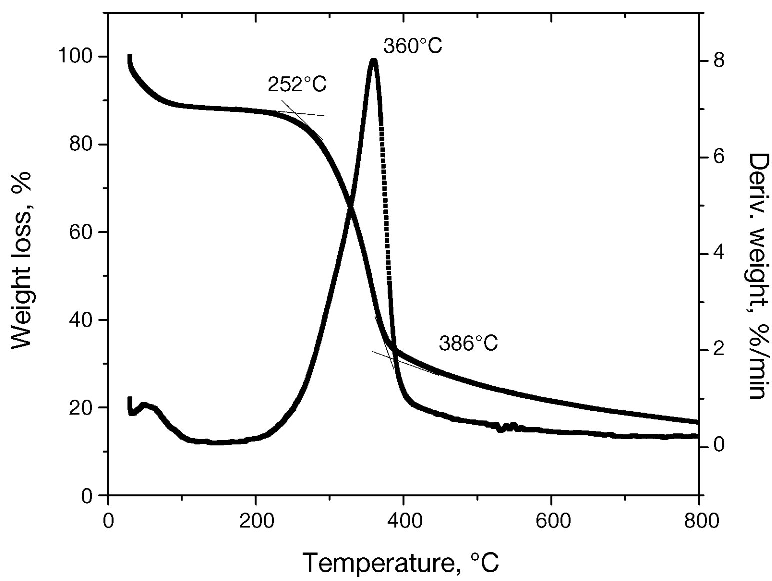

***Figure 6**. TGA/DTG curves of banana fiber*

Differential scanning calorimetry study in **Figure 7** reveals the presence of two major inflection points: one is between 25 and 150°C, at 103°C and the other between 325 and 375°C, at 363°C. The first point could be correlated to the breakdown of cell debris and evaporation of water molecule associated with the cellulosic fiber [9]. The peak around 363°C could be related to the decomposition of cellulose which is in agreement with mass loss obtained in this range in TGA analysis of the banana fiber.

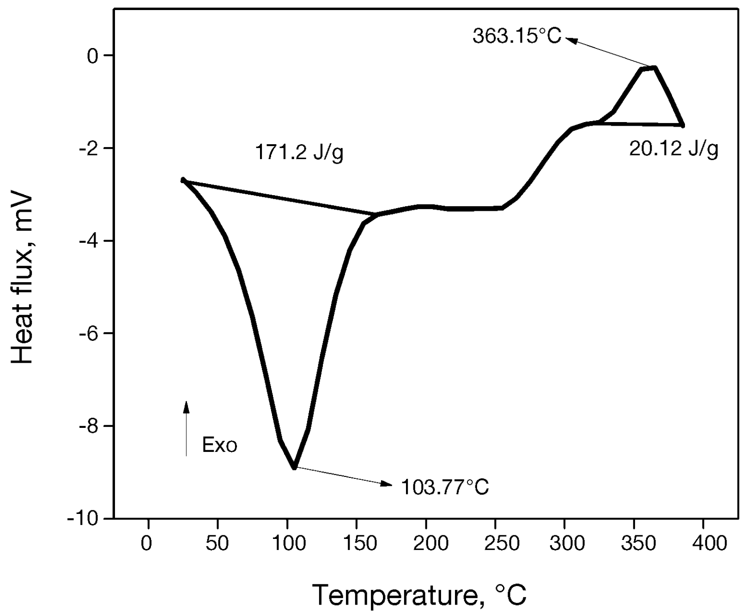

Figure 7. *DSC curves of banana fiber*

CONCLUSIONS

The following major conclusions are drawn from the results. The fiber diameter measured through image analyzer shows high variability, which is common in lignocellulosic fibers. Banana fiber exhibited variability in tensile strength which is quite characteristics of natural fiber. The SEM analysis reveals that the nature of fracture in banana fibers is due to tensile force. Moreover, it is brittle with the absence of fibril splitting. The fracture has occurred due to the variability in the strength of the individual fiber cells. Due to its high thermal stability, it could be effectively used in the thermal insulation industries. At present, banana fiber is considered a waste and its industrial potential is untapped. Hence, banana fibers can be a good choice as reinforcement in the manufacture of bio-composites.

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