Determination of Density of Nigerian bamboo fiber as an Engineering property using maceration method

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Abstract

The production of engineering products and services using engineering materials and skills is imperative. The materials used for this production must possess some properties that may be qualitative or quantitative. Density is both physical and qualitative property of any material especially in engineering. Density becomes important when there is need to design where weight and distribution of weight are critical. In this study the determination of density of Nigerian dry bamboo fiber as an engineering property using maceration method was carried out. Fresh bamboo was obtained from the Nigerian environment and oven dried to remove the moisture content. The extraction of the fiber was done by simple maceration method. The density of the extracted fiber was determined using the displacement method (Archimedes principles) for the volume and the weight for the mass. The mass-volume ratio gave the value of the density from the dry bamboo fiber extracted by maceration method. The value was found to be slightly less than that of water.

Key words: Density, Maceration, Bamboo fiber, Natural fiber, Nigerian, Property.

INTRODUCTION

Density is one of the most fundamental physical properties of any material. It is the ratio of an object mass to its volume. Because most designs are limited by either size and or weight, density is an important consideration in many calculations.

Density is a function of the mass of the atoms making up the materials and the distance between them. Massive, closely packed atoms characterize high density materials such as Tungsten or Neptunium. In contrast light, relatively distant atoms compose low density materials such as Beryllium or Aluminum. Density on a macroscopic level is also a function of the microscopic structure of a material. A relatively dense material may be capable of forming a cellular structure such as foam which can be nearly as strong and much less dense than the bulk material. Composites including natural constituents such as wood and bone, for example, generally rely on microscopic structure to achieve densities far lower than common monolithic materials [5].

The density of a material can be a crucial factor in determining the material that is best suited for an application [1]. The density can be used to determine the relative weights of materials. This is an extremely important factor to consider if the material in question will be used to construct the frame of an aircraft. A lighter weight material will ultimately translate to greater payload capacity and decreased fuel consumption.

A more important aspect of the density of the material is the role it plays in calculating its specific strength. The specific strength is simply the strength-to-weight ratio of the material [1]. The specific strength of a material is given by the tensile or yield strength divided by the density of the material. A material with a high specific strength will be suitable for applications such as aircraft and automobiles. This means that the material has a light weight with the aforementioned benefits, but it also has a high strength. Both of these factors are important in such safety conscious applications.

The density, and thus the specific strength, of a material can be calculated in a number of different ways. The simplest method is to determine the dimensions of a given material specimen and use an applicable formula to determine the volume of the specimen.

Once the volume of the specimen is known the mass can be measured with a balance. The density (ρ) is then the mass divided by the volume.

The specific strength also requires a measure of the tensile and/or yield strength of the material. This can be done using a tensile test machine. In this method the sample would be stretched until it fails with a computer calculating the stresses at failure. A separate measurement can be performed to obtain this data but published tensile/yield strength values for most engineering materials is readily available [1], [3], [9].

Natural fibers have low density and high specific properties. The specific properties of these fibers are comparable to those of traditional reinforcement. A number of investigations have been carried out to assess the potentials of natural fibers as reinforcements in polymers. Nowadays, natural fiber reinforced polymer composites are increasingly being used for various engineering applications due to their numerous advantages. Natural fibers have been used to reinforce materials for over 3,000 years, more recently they have been employed in combination with plastics. Many types of natural fibers have been investigated for use in plastics including flax, hemps, jute, straw, wood fiber, rice husk, wheat, barley, oats rye, cane (sugar and bamboo), grass reeds, kenaf, ramine, oil palm empty fruit bunch, sisal, coir, water hyacinth, pennywort, kapok, paper-mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus. They have the advantage of renewable resources and low cost [9].

Natural fibers are increasingly used in automotive and packaging materials, in some countries of the world that are solely agricultural dependent for instance Pakistan, Malaysia etc, thousands of tons of different crops are produced but most of their waste do not have any further useful utilization. These agricultural wastes include wheat husk, rice husk and straw, hemp fiber and shells of various dry fruits [10].

In Nigeria the scenario is not different as wheat husk, rice husk and straw, palm trees, bamboos, raphia, pineapple leaves etc. are lying waste in different agricultural fields. These agricultural wastes can be used to prepare fiber reinforced polymer composite for commercial purposes.

Among the various natural fibers, bamboo finds widespread use in housing construction around the world, and is considered as a promising candidate for housing material in

ISSN 2229-5518

underdeveloped and developed countries. Being a conventional construction material many decades past, bamboo fiber is a good candidate for use as natural fibers in composite materials. Many studies focused on bamboo fiber is due to the fact that it is an abundant natural resources with overall comparative, mechanical properties advantages to those of wood. Bamboo is found in diverse climates, from cold mountains to hot tropical regions. They are found across East Asia Northern Australia, West India and the Himalayas. They also occur in sub-Saharan Africa including Nigeria and in the Americas from the mid-Atlantic United States South to Argentina and Chile.'

The properties of natural fibre depends mainly on the nature of the plant, locality in which it is grown, age of the plant and extraction method used. Natural fibres are enjoying rapid growth due to their many advantages when reinforced with plastics such as light weight, reasonable strength and stiffness [12]. Among all chemical treatment applied to natural fibres the most used is alkaline treatment, also called mercerization. The alkaline treatment promotes the removal of partial amorphous constituents such as hemicelluloses, lignin, waxes, and oil soluble in alkaline solution and therefore reduces the level of fibre aggregate, making the surface rougher [13],[4].

Bamboo is one material that has good economic advantages, it reaches its full growth in just few months and reaches its full growth in just a few years, and it is also one of the fastest renewable plants with a maturity cycle of 3 to 4 years.

Although the utilization potential of this material for a number of applications has been explored, such superior mechanical properties have not been adequately well drawn for polymer-based composite.

The mechanical properties of different natural fibers such as sisal, vakka, banana, bamboo are compared and it is found that the bamboo fibers have much higher tensile and flexural properties than other fibers [8]. Bamboo fibers have emerged as a renewable and cheaper substitute for synthetic fibers such as glass and carbon, which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, flexibility and modulus, and are comparable to those of glass fiber.

Bamboo can be used for reinforcement such as the whole bamboo, section, strips and the fibers. These various forms of bamboo have been used in applications such as low rise construction to resist earthquake and wind loads, bamboo mats composite in combination with wood for beams and shear wall in low rise construction in addition bamboo fiber can be used as reinforcement with various thermoplastic and thermoset polymer[6].

Although in fiber reinforced polymer a judicious selection of matrix and the reinforcing phase can lead to a composite with a combination of strength and modulus comparable to or even better than those of conventional metallic materials, their physical and mechanical properties can further be modified by addition of a solid filler phase to the matrix body during the composite preparation. In view of the importance of density in engineering material it become pertinent to determine the density of a newly developed Nigerian long bamboo fiber [11].

MATERIALS AND METHODS

Matured bamboo stems and blemish free (Fig. 1) were cut from Nigerian environment. The moisture content of the bamboo was determined using gravitational method and the average moisture content was calculated to be 20% as shown in Tables 1 and 2.

The nodes of the bamboo were sawed off using a saw. The nodes were discarded while the bamboo stem was manually reduced to size. The bamboo chips were further reduced to matches 'stick sizes'.

ISSN 2229-5518

The length of the reduced bamboo stick was measured using a meter rule and the average length was determined to be 51mm as shown in Fig. 2.

The bamboo sticks were transferred to the laboratory where they were weighed by placing them on an electric weighing scale (Toledo Mettle Pan), the weight was read as 700g.

The weighed sticks were transferred into an enamel bowl. Hydrogen peroxide was measured in a beaker, and then transferred into the enamel bowl. Glacial acetic acid was also measured with a beaker and transferred into the enamel bowl containing hydrogen peroxide and bamboo sticks.

Fig. 1: Raw dry bamboo

Fig. 2: Bamboo reduced to match stick (51mm length)

The ratio of hydrogen peroxide to glacial acetic acid was estimated as 1:1 with a total volume of 2.5L each, making a combined volume of 5.0L. The chemical reaction of the solution is as shown in equation 1

$$C_2H_4O_2 + 3H_2O_2 \rightarrow 2CH_3OH + 2H_2O + 2O_2 \qquad (1)$$

The mixture of bamboo chips and reagents in the enamel bowl was stirred with a ladel. The oven temperature was read from the thermometer inserted into the oven to be 103°C after three hours.

At the expiration of three hours, the oven was switched off and the bowl was removed from the oven, the contents of the bowl (extracted fiber) was washed with tap water and put back into the oven at a temperature of 65°C for 6 hours and the fibers were dried.

TABLE 1: DETERMINATION OF MOISTURE CONTENT OF BAMBOO

Table of results	Sample A	Sample B
Weight of empty can and lid	42.049g	45.552g
Weight of can, lid and sample	85.034g	84.550g
Weight of air dried sample	42.985g	38.998g

TABLE 2: DRYING OF SAMPLES AT 105°C TO CONSTANT WEIGHT

Samples	Initial weight (g)	1 hour	2 hours	3 hours	4 hours
Sample A	85.034	76.728	76.584	76.570	76.570
Sample B	84.550	76.694	76.674	76.553	76.553

Weight of dried sample A = 76.570g

Weight of dried sample B = 76.553g

Weight of sample A = 76.570 – 42.049 = 34.521g

Weight of sample B = 76.553 – 45.552 = 31.001g

Weight of moisture content on sample A = 42.985 – 34.521 = 8.464g

Weight of moisture content on sample B = 38.998 – 31.001 = 7.997g

M.C% A = 8.464/42.985 = 19.69%

M.C% B = 7.998/38.998 = 20.509%

TABLE 3: PARAMETERS FOR DENSITY MEASUREMENT

Weight of fibre (g)	Initial Volume of liquid(cm^3)	Final Volume of liquid(cm^3)
2.2323	60.0	64.0

Using the formula for density

Density =A/D-C- - - - - - - - - - (2)

A= Mass of sample (g)

C= Initial volume of the liquid (cm^3)

D=Final volume of the liquid (cm^3)

Density=2.2323/64.0-60.0

=2.2323/4

=0.5581g/ cm^3

RESULTS AND DISCUSSION

The result of the experiment is shown in Tables 1, 2 and 3. Table 1 shows the different weights of the empty can and lid, can, lid and samples and the dried sample which is the weight of the bamboo. Different samples of A and B were considered for comparative advantage and analysis. The temperature of 105°C was made constant for convenience which is slightly above the boiling point of water. The samples were subjected to this temperature for different intervals of 1, 2, 3 and 4 hours each. It was observed that at constant temperature of 105°C, for between 3 and 4 hours there was no significant change in the weight of the sample (dry bamboo) and it was realized that the bamboo sample was dried. The percentage of the moisture content was also determined for the samples and was found to be about 20%. Table 3 shows the data of the fiber which was obtained in the course of determining the density of the Nigerian bamboo. The bamboo fiber was already extracted using the maceration method as shown in Figure 3. The density value was determined using the relation in equation 1 and the value obtained for the fiber extracted from Nigerian bamboo was found to be 0.5581g/cm^3. From literature according to [6] they reported that the density of bamboo generally is between 0.6-1.1g/cm^3. The value of density obtained in this experiment shows a relationship with that reported by [6]. This result is also in agreement with [11] who reported that the chemical composition of natural fiber may differ with the growing condition and test method even for the same kind of fiber, other factors that can control the properties of natural fibres even within the same specie include among others; area of growth, climate, age of the plant and the processing method. Also [12] reported again that the properties of natural depends on the nature of the plant, locality in which it is grown, age of the plant and extraction method used.

As stated earlier the quantity of the bamboo was known after weighing upon processing of the bamboo of the known weight, a weight of fiber was also produced and it was found that 700g of bamboo yielded 338g of long bamboo fiber representing 48% the output of the material. The chemical ratio of the solution shows the following relationship.

$$C_2H_2\,O_2 + H_2O_2 \xrightarrow{\text{Heat}} CH_3OH + H_2O \text{ - - - - - } \quad (3)$$

Acetic acid + hydrogen peroxide peracetic acid

$$C_2H_2\,O_2 + H_2O_2 \xrightarrow{\text{Heat}} CH_3OH + H_2O \text{ - - - - - } \quad (4)$$

Equations (3) and (4) show the reaction that took place during the maceration method where one part of glacial acid was mixed one part of hydrogen peroxide producing peracetic acid and water.

The water from this equation is in the form of steam. The peracetic acid is bright colourless liquid that has a piercing odour. The product of this equation cannot be reuse for further processing of the new long bamboo fiber. Rather it could be used for other purposes such as disinfectant, cleanser, water purification etc.

The other product of the equation of the chemical reaction is methyl alcohol or methanol which is also a colourless liquid with a characteristic pungent odor. This product of the reaction can be used as fuel, organic synthesis especially formaldehyde (methanol). It is poisonous and inflammable it is also called wood alcohol and its chemical name is methyl alcohol. Apart from the methyl alcohol that the chemical reaction generates, it also produces carbon dioxide (CO_2). This product can be used as greenhouse gas, for production of odorless low melting point. It is a colorless and it is light at a pressure of 5.1 atmospheres. It is also used as refrigerant, fire extinguishers etc.

CONCLUSION

Bamboo as a non-forest wood product (NFWP) has been a good replacement material for timber in construction due to its lightweight, good flexibility, low cost and tougher character. The tensile strength is also known to be good. Among the advantages of bamboo fiber listed above, its use as a reinforcement for composites fabrication becomes pertinent. When lightweight products are aimed at, reinforcement can be achieved by adding natural fiber-bamboo especially in transport application as in the case of aircraft, here weight is a critical design factor and density is often considered, which has informed this investigation. Therefore the density of Nigerian dry bamboo fibre was found to be 0.99458kg/m^3. This density calculated can be compared to the published values.

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