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Potential use of macambira fiber (*Bromelia laciniosa*) in geotextiles for geotechnical and environmental protection works

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ABSTRACT: The use of geotextiles made from synthetic manufactured materials, such as polypropylene and polyester, is already well known, well tested, and accepted for applications in geotechnical and geoenvironmental works. However, the application of natural vegetable textile fibers in this field is a relatively recent phenomenon. In this perspective, the present work aims to introduce macambira fiber (*Bromelia laciniosa*) as a potential alternative textile material for manufacturing geotextiles. Macambira fiber is abundant, renewable, biodegradable and low cost, in addition to presenting interesting physical-chemical and mechanical properties for application in geotechnical and environmental protection works. To achieve this, thermogravimetry (TG), Fourier transform infrared spectroscopy (FTIR), and tensile strength tests were carried out to evaluate the degradation, chemical composition, and strength of the macambira fiber. The results obtained in this research demonstrate that macambira fiber has characteristics and properties compatible with other textile fibers of the same nature that are already being used in geotextiles, such as jute fiber.

KEYWORDS: macambira fiber, geotextiles, natural textile fibers.

1 INTRODUCTION

The macambira (*Bromelia laciniosa*) is a plant belonging to the bromeliaceae family, genus Bromelia, and native to the dry areas of northeastern Brazil. Its structure consists of fine roots, a cylindrical stem, and long leaves distributed around the stem. In the textile context, macambira is a fiber extracted from the leaves of the plant of the same name and, therefore, should be classified as a natural vegetable fiber, or simply as a lignocellulosic fiber (Pimentel 2012). In the field of geotechnical and environmental engineering, its use is associated with erosion control and phytoremediation processes due to its fasciculate root system.

Geotextiles are textile products used in civil, geotechnical, and geoenvironmental engineering applications, serving functions such as reinforcement, separation, filtration, and drainage. They are typically composed of manufactured polymers, especially in applications requiring a long lifespan.

In this context, as a more ecological alternative, there is a growing use of geotextiles composed of natural polymers of lignocellulosic origin, such as jute, which, when converted into fabric, exhibits desired characteristics and necessary properties for geotechnical engineering projects (Mathur *et al*. 2011).

Lignocellulosic fibers are mainly composed of cellulose, hemicellulose, and lignin, and being of plant origin, they are biodegradable and hygroscopic. This hygroscopic property allows fibers of this nature to vary in weight under different relative humidity conditions. Another characteristic of lignocellulosic fibers is that they are excellent insulators of heat and electricity, although this property varies with changes in moisture content (Mathur *et al*. 2011).

Studies conducted by these aforementioned researchers have demonstrated the feasibility of applying geotextile blankets made from natural plant fibers in road projects. The results of this application are primarily related to the improved performance of structures and the reduction of construction and maintenance costs. The Institute mentions various uses for geotextile blankets made from jute fibers, such as riverbank protection, slope management, including hill slopes, control of surface soil erosion, slope stabilization, prevention of reflection cracks in asphalt pavements, and consolidation of soft soils. The potential of geotextiles made from jute fiber is increasingly appreciated by end-users due to its low acquisition cost and technical viability.

The use of geotextiles made from synthetic manufactured materials, such as polypropylene and polyester, is well-known, extensively tested, and accepted in the field to address soil behavior-related issues (Palmeira 2018). However, the application of natural vegetable textile fibers in this field is a recent phenomenon (Mathur *et al*. 2011). The demand for geotextiles grows each year, but it is estimated that only 2% of the total production comes from natural fibers (Wiewel & Lamoree 2016).

In this perspective, the present study aims to present the macambira fiber (*Bromelia laciniosa*) as a potential alternative textile material for use in geotextile blankets. This is due to its abundance and renewability as a natural resource, biodegradability, low cost, and interesting physicochemical and mechanical properties for application in geotechnical and environmental protection projects.

2 MATERIALS AND METHODS

2.1 *Preparation of the material (macambira fiber)*

The preparation of the material commenced with the collection of macambira plant leaves in the municipality of Ielmo Marinho, located in the Agreste Potiguar region, Brazil. The thorns were removed on-site during the collection to facilitate material preparation. Subsequently, the leaves were sorted by size, washed to remove dust and other inherent surface impurities from the leaves (Figure 1), and weighed using an OHAUS electronic scale, model AV8101CP, with a capacity of up to 8.1 kg, in the Laboratory of Construction Materials, Department of Civil Engineering, Federal University of Rio Grande do Norte (UFRN).

The leaves of the macambira ranged in length from 1.84 to 3.45 meters. During the extraction process, the leaves were split in half for technical reasons, aiming to facilitate processing and prevent entanglement in the machine, which could result in fiber loss and equipment damage.

Following the stages of collection, sorting, washing, and weighing of the leaves, the process of extracting macambira fibers commenced. For this purpose, a machine called a "defiberizer," developed at UFRN (Aquino 2006), was utilized. The extraction process involves introducing the leaves into the defiberizer, passing through the feeding system containing cylinders responsible for macerating the leaves and separating the fibers from other constituents. Subsequently, the fibers were exposed to sunlight until they dried. The drying progress of the fibers was monitored through mass stabilization control (Figure 2).

Figure 1. Leaves sorted by size and washed (Pimentel 2012).

Figure 2. Mass control of macambira fibers (Pimentel 2012).

2.2 Characterization of the material (macambira fiber)

2.2.1 Thermal analysis of macambira fiber

The thermal analysis of macambira fiber was conducted using the thermogravimetric technique (TG). This analysis aimed to measure the variations of mass of the fiber as a function of temperature. The tests were performed with a TA Instruments equipment, model SDT Q600 V20.9 Build 20. The analysis parameters were set for a heating rate of 10°C/min, starting at a temperature of 25°C and reaching 800°C under a nitrogen gas flow of 100 ml/min.

2.2.2 Chemical analysis of macambira fiber

The chemical analysis of macambira fiber was conducted using the Fourier-transform infrared spectroscopy (FTIR) technique. This analysis aimed at determining the chemical composition of the fiber. The FTIR tests were performed under three different conditions: i) with the fiber in its natural state; ii) with the fiber heated in the oven; and iii) with the fiber carbonized in the muffle furnace. The experiments were conducted using a SHIMASZU FTIR equipment, model A210044, belonging to UFRN. The determination of the composition was achieved by identifying the functional groups present in the chemical constitution of the material under analysis through the incidence of radiation, which absorbs the characteristic frequency of radiation in the infrared region.

2.2.3 Mechanical analysis of macambira fiber

The mechanical analysis of macambira fiber was conducted through a tensile test using the TA Instruments machine, model DMA Q800 CONTROLLED FORCE, belonging to UFRN. The tests followed the recommendations of ASTM D3379-75/1989, which standardizes the method for tensile testing of monofilaments. The equipment was programmed to operate with a force scale of 3N/min until reaching 16N, a load considered as the limit for fiber rupture. The experiments were repeated 15 times, with a new 15 mm length fiber sample positioned in the equipment for each repetition (Figure 3).

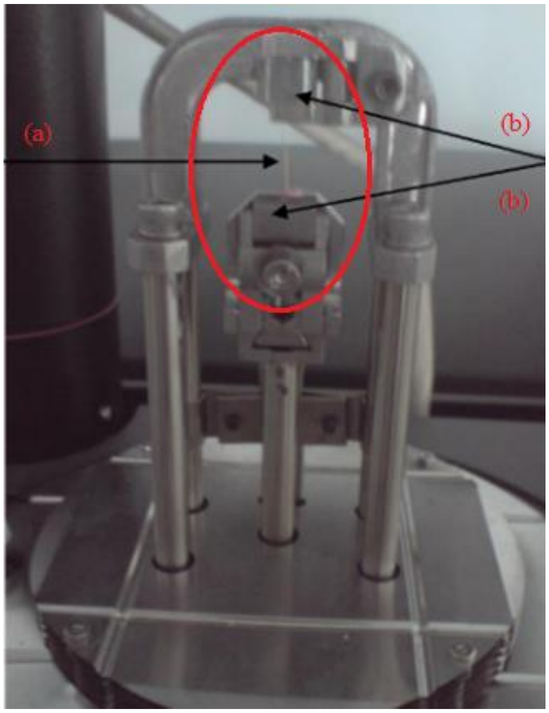

Figure 3. Tensile test of macambira fiber (a) Fiber (b) Machine Claws (Pimentel 2012).

3 RESULTS

3.1 Thermal analysis of macambira fiber

In the thermal analysis of macambira fiber (in natura) using the TG technique, it was possible to observe a mass decrease of 3.9% at 150°C, attributed to moisture loss. The fiber began to undergo degradation at 210°C, reaching its onset temperature of 280°C, when its elemental properties started to be lost. At 340°C, a significant portion of the fiber's organic composition was lost, and by 400°C, 65% of the material had already undergone degradation (Figure 4).

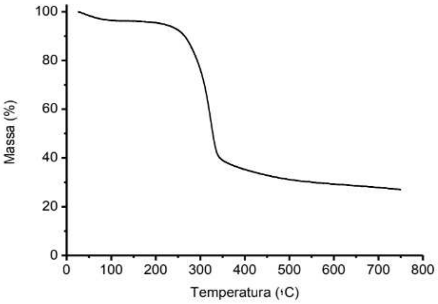

Figure 4. Thermal behavior of macambira fiber (Pimentel 2012).

3.2 Chemical analysis of macambira fiber

In the chemical analysis of macambira fiber using the FTIR technique, a change in the chemical composition of the material was observed when comparing different thermal treatment conditions applied to the macambira fiber. In the data presented in Figure 5, it can be observed that the fiber in its natural state exhibited a pronounced curve in the wavelength region between 3000 and 4000 cm⁻¹. For the fibers heated in the oven and carbonized in the muffle furnace, a drop in this curve was noted, indicating a decrease in radiation absorption in this region, which is associated with vibrations of hydrogen atoms bonded to oxygen (-OH-). Additionally, pronounced peaks were observed in the wavelength region between 1500 and 2000 cm⁻¹ as the fiber underwent thermal treatments. Absorption in this region is related to vibrations resulting from double bonds between carbon and oxygen (C=O).

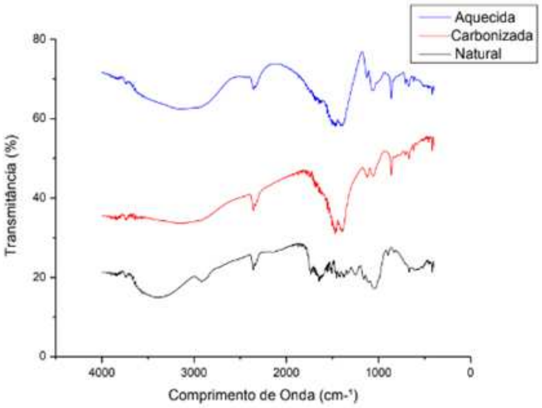

Figure 5. FTRI analysis of macambira fiber (Pimentel 2012).

3.3 Mechanical analysis of macambira fiber

The mechanical analysis of macambira fiber was conducted through a tensile test using the DMA machine. The average tensile strength was 171.44 MPa, with a standard deviation of 94.1 MPa. The average elastic modulus was 9.98 GPa, with a standard deviation of 4.86 GPa, and the average fiber cross-sectional area was 0.0293 mm².

According to a study conducted by Spinacé et al. (2009), sisal and curauá fibers exhibited tensile strengths of 264 MPa and 509 MPa, respectively, with standard deviations of 72 MPa and 109 MPa. The same author mentions that the lack of uniformity in the diameter along the length of plant fibers can influence the results of the tensile test. It is worth noting that the properties of fibers of this nature can vary considerably depending on the type of plant, the region where they are grown, and the part of the plant from which they are extracted (Bledzki & Gassan 1999).

As an example, the tensile strength of a specific macambira fiber throughout the test was 144.2 MPa. The fiber failed when subjected to a force of 2.8 N, exhibiting a deformation of 3.6% (Figure 6).

Following the tensile test, the fibers were analyzed microscopically (Figure 7). It was observed that the cross-sectional geometry of the fiber after rupture did not exhibit uniformity. This indicates that macambira fiber, like other lignocellulosic fibers, does not have a consistently cylindrical diameter, which may vary along its length.

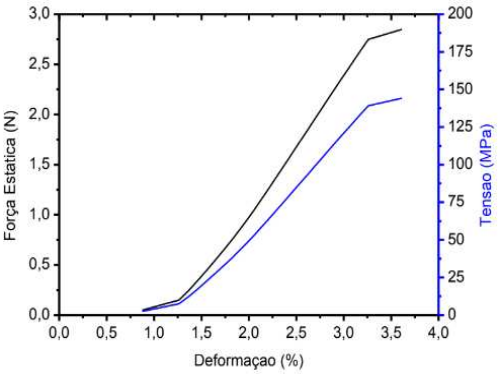

Figure 6. Tensile strength behavior of macambira fiber (Pimentel 2012).

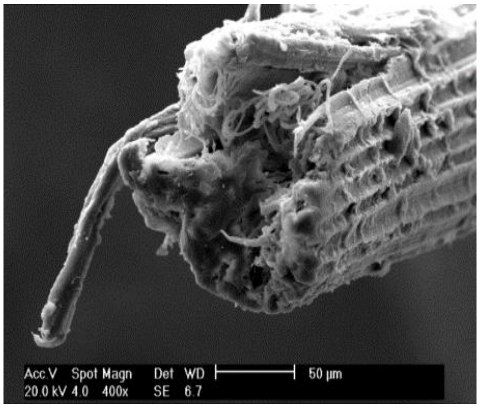

Figure 7. Image (MEV) of the cross-sectional view of macambira fiber after the tensile test (Pimentel 2012).

4 CONCLUSIONS

This paper presented a study on the potential use of macambira fibers to manufacture geotextiles and geomats. The main conclusion of this study is summarized below.

In the TG analysis, it was identified that the degradation temperature of in natura macambira fiber begins at 280°C. In the chemical analysis, the results obtained for macambira fiber are in accordance with the literature, presenting values equivalent to the main constituents of plant fibers. FTIR analysis revealed that thermal treatments can alter the characteristics of the fiber, making it drier and rougher. Changes in functional groups were also observed due to the breaking of intermolecular bonds in the fiber caused by temperature.

It was observed that the cross-sectional shape of the macambira fiber is not perfectly circular, and its diameter varies along its length. This characteristic directly affects the tensile strength of the fiber. The tensile strength of a specific macambira fiber throughout the test was 144.2 MPa. The fiber ruptured when subjected to a force of 2.8 N, exhibiting a deformation of 3.6%. According to a study conducted by Spinacé *et al*. (2009), sisal and curauá fibers exhibited tensile strengths of 264 MPa and 509 MPa, respectively, with standard deviations of 72 MPa and 109 MPa. Synthetic fibers, such as polypropylene, widely used in the manufacture of geotextiles, have a typical tensile strength between 550 MPa and 690 MPa (Castro *et al*. 2011), but are not biodegradable, since they need centuries to decompose in the environment.

In summary, macambira fiber stands out as an additional alternative among materials derived from renewable sources. It can be used in various ways and achieve satisfactory results depending on the application and purpose. Additionally, its sustainable use has the potential to promote social and economic development in regions where this plant is found.

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