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Physical and mechanical properties of agglomerated panels made from bamboo fiber and vegetable resin

Martha L. Sánchez *, Luz Y. Morales, Juan D. Caicedo

Universidad Militar Nueva Granada Carrera, Facultad de Ingeniería, Programa de Ingeniería Civil Carrera 11, N. 101 80, Bogotá D.C., Colombia

HIGHLIGHTS

- Panels with bamboo fibers and vegetal resins were fabricated.
- An alkaline treatment was applied.
- A method of manual molding and a process of compaction by pressing were used.
- Physical and mechanical properties of the panels were determined.

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ABSTRACT

Agglomerated panels using bamboo fibers and vegetal resin were constructed and their physical and mechanical properties were evaluated. The fibers used were extracted from the top of bamboo culms of the species Guadua Angustifolia Kunth, preserved and treated according to the recommendations of the Colombian Technical Standard. As the matrix of the composite, a vegetal polyurethane derived from the plant called "higuerilla" was used. The physical and mechanical properties of the panels: density, absorption capacity, percentage of swelling, tensile, compression, and flexural strength, were determined according to the specifications of the American Society for Testing and Materials. For the manufacture of the agglomerate, the method of manual molding and a process of compaction by pressing were used. To guarantee the integrity and durability of the fibers and their adhesion to the matrix, an alkaline treatment was carried out. The experimental results were compared with results found in the reference bibliography. The results presented show the feasibility of using agglomerates made with Guadua fibers and vegetal resin for non-structural purposes.

1. Introduction

The growing concern about mitigating environmental pollution generated by the indiscriminate use of traditional materials has aroused interest in the study of new alternatives that allow the development of sustainable construction, promoting the use of natural resources of wide availability, whose employment contributes not only to reducing the environmental impact generated by conventional construction processes but also to improving the living conditions of a large part of the population of Latin America [1].

Among the natural resources that have found a wide range of applications in different sectors of engineering, mainly in the construction sector, are the lignocellulosic materials [1]. Lignocellulosic materials can be described as a natural, abundant, and renewable resource, usually derived from fibers of vegetal origin [2]. These materials consist mainly of three chemical components: cellulose, hemicellulose, and lignin, which are responsible for the mechanical and structural behavior of the plant, giving it good strength, stiffness, and durability.

At present, the use of plant fibers in various branches of modern industry is an area of interest for researchers focused on promoting the development of non-conventional materials. The wide availability, rapid renewal, economy, low weight, and high specific properties of vegetal fibers, as well as their biodegradable character and their high resistance to the abrasion, allow considering them to be a reasonable alternative when compared with fibers traditionally used as the dispersed phase in the manufacture of conventional composite materials [3,4].

Among the multiple applications of vegetable fibers as a building material is their use as reinforcement in the elaboration of

* Corresponding author.
E-mail address: martha.sanchez@unimilitar.edu.co (M.L. Sánchez).

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composites that use polymer resins as a matrix of materials [5–10]. For this type of application, results have been reported during the last few years in which relevant aspects such as the effect of the chemical treatment, the influence of the mixing percentages, and the physical and mechanical properties of the fibers on the behavior of the fiber-matrix interface as well as on the mechanical performance of this type of composite material have been shown.

Recent research has shown that the use of resins obtained from the processing of oils of vegetal origin as a matrix in the production of wood agglomerates can be an efficient solution that contributes to reducing the environmental impact generated by the use of phenolic resins [11]. These adhesives have been investigated. However, their application is not yet sufficiently widespread. Recently, results have been reported in the literature of the characterization of composite materials reinforced with vegetable fibers such as coconut fiber, banana, bamboo, sugarcane bagasse, etc., as well as vegetal resins as the matrix of the composite [12–22]. These investigations report novel results related to both the manufacturing processes and the evaluation of various physical and mechanical properties of these composites.

In the present paper, a procedure for the elaboration of agglomerated panels made from bamboo fibers randomly distributed in a resin of vegetal origin is presented. For the elaboration of the panels, the manual molding method and the method of compaction by pressing at room temperature were used. The evaluation of the physical and mechanical behavior of the panels was carried out through laboratory tests of their density, absorption capacity, dimensional stability, tensile strength, compression, and static bending. The results obtained were compared with experimental results found in the reference literature for panels made with other fibers and resins of vegetable origin.

2. Materials and methods

2.1. Properties of constituent materials

In order to obtain the fibers, the top of bamboo culms of the species Guadua Angustifolia Kunth, from the municipality of Guaduas, located in the north-west of the Department of Cundinamarca, Colombia, was used. This municipality has an altitude of 992 meters above sea level, an average temperature of 23.5 °C, and an average humidity of 61%. The culms used were between 4 and 6 years of age and were immunized according to the recommendations of Colombian Technical Standard NTC 5301 [23].

The material used as a matrix was a vegetal polyurethane resin derived from a plant known as "higuerilla", a bi-component formulated from the mixture at room temperature of a pre-polymer and a polyol, which gives the agglomerate high durability, good resistance to ultraviolet rays, and good adhesion. The properties of the resin were supplied by their provider and are shown in Table 1.

2.2. Fiber extraction

One of the fundamental stages in the process of obtaining of the fibers is the elimination of the lignin that bamboo possesses and the selection of an adequate method for the extraction of the fibers, avoiding their mechanical degradation. Lignin is an aromatic polymer with an amorphous structure that acts on the plant as a binder, giving the fibers stiffness and protecting them from attacks of microorganisms [2]. Nevertheless, in spite of the functions of the lignin in the plant, it is advisable to carry out its separation from the vegetal fibers in order to guarantee an adequate adhesion to the matrix in the composite materials.

Table 1
Properties of the vegetable resin.

Property	Component "A"	Component "B"
Physical condition	Liquid	Liquid
Color	Brown	Amber
Form	Viscose	Viscose
Boiling point	190 °C	313 °C
Melting point	−14 °C	−10 °C
Density at room temperature	1.25 g/cm^3	0.98 g/cm^3

The process of fiber extraction was performed by a combination of chemical and mechanical methods. For the removal of the lignin, an alkaline treatment was performed, which consisted of submerging strips of bamboo 2 cm wide and one meter long in a sodium hydroxide solution with a concentration of 20% m/v for a period of 96 h. This process was followed by washing and oven drying in order to obtain a constant mass. The effect of the treatment on the lignin removal process can be observed in Fig. 1.

In Fig. 1 it can be seen that by subjecting the material for a certain period of time to high concentrations of sodium hydroxide, the lignin and the hemicellulose are partially removed from the fibers. This increases its crystallinity and favors its adhesion to the vegetable resin. Nevertheless, it is important to take into consideration that the concentrations of sodium hydroxide employed and the time established for the carrying out of the treatment caused a mass loss of about 15% with respect to the initial mass of the material.

Another aspect of interest when evaluating the effect of alkaline treatment is the occurrence of changes in the color and morphology of the fibers. This color change may be associated with the breakdown of the chemical bonds that exist between the lignin and the extractable substances that are part of its chemical composition. Variations in the fiber morphology can be observed in Fig. 2.

For the mechanical extraction process, a crusher composed of a system of toothed rollers coupled to a motor-reducer that allows the production of long fibers was used, and they were later cut to lengths that varied between 1 and 2 cm. Fig. 3 shows the crusher used.

2.3. Physical characterization of Guadua fibers

For the determination of the physical properties of the fibers, three study groups were prepared. Each of the study groups consisted of 10 bundles of five fibers 5 cm in length, which were used in the determination of the moisture content, absorption capacity, and density of the material.

The moisture content was determined according to the oven-drying method, following the recommendations of ASTM D 4442-16 [24]. For the study, a Memmert type U40 oven with a maximum operating temperature of 300 °C and an uncertainty factor of ± 0.36 °C was used at a temperature of 100 °C, which provides great reliability in its operation. For the determination of the mass, a Sartorius ENTRIS4202I-1S balance with a resolution of 0.001 grams and a measurement range between 0 and 420 g was employed.

For the determination of the moisture content, the specimens were conditioned to the equilibrium moisture content, at which point they neither absorb nor release water. Once their moisture content had stabilized, the mass was determined in a natural moisture condition (A) and they were baked for 24 h. Upon reaching a constant mass condition, a new mass reading was recorded as mass B and the moisture content was calculated according to Eq. (1).

$$\%CH = \frac{A - B}{B} \times 100 \quad (1)$$

where:

%CH is the percentage of moisture content,