BAMBOO-GUADUA FIBERS FOR COMPOSITES

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Abstract

Guadua angustifolia kunth (GAK) is a giant bamboo naturally found in South America. It is a renewable and sustainable material with very rapid growth. The GAK fibers are potentially suitable for reinforcement of composite materials because of its physical properties, good adhesion, and strength. This kind of composite has the potential to replace wood based products in the construction sector. In this study, GAK fibers were extracted and the mechanical properties of GAK fibers-PVC composites were determined. The GAK fibers were extracted with the kraft process. The composite samples were manufactured with PVC powder, and with different fiber lengths and volume fractions using an internal mixer. It was found the maximum temperature for processing the composite material and the effective length of GAK fibers for the condition of perfect adherence. It was found that the use of GAK fibers has a unique potential for reinforcing composite materials and the inclusion of small fibers proportions improves the composite stiffness and strength.

1 Introduction

The About 1250 species of bamboo are found in the world and these plants are known to have very high strength and they have been used for many years in several structural applications, as they grow up in several months. The fast growing rate of this plant is because the bamboo is a grass, not a tree. The rate of growing varies from 20 to 100 cm per day, and it depends on local soil and climate conditions that could affect bamboo's rhizome system. The fibers, which constitute the bamboo plant, have demonstrated to be a good choice for reinforcement material in polymeric composites because of the high mechanical properties and facility to obtain them. Guadua angustifolia kunth (GAK) is a giant bamboo naturally found in South America. It is a renewable and sustainable material with very rapid growth. The GAK fibers are potentially suitable for reinforcement of composite materials because of its physical properties, good adhesion, and strength. In the present study, different formulations of the composite PVC-GAK fibers were prepared, modifying the fiber length and volume fraction. The prepared specimens were tested in tension, compression, bending and impact. The mechanical behavior and properties of the composite were determined in order to compare with other materials using different types of fibers, and in this way explore the potential applications of the PVC-GAK fibers composite.

2 Materials and Methods

2.1 GAK Fiber Extraction and Properties

The bamboo specie used for the investigation was Guadua angustifolia from Cauca Valley, Colombia. This region is located to 1100 meters over the sea level and 22°C of temperature. The 4-year-old bamboo culms used are from the upper part of the plant with external diameters that varies from 4.5 to 10 cm and culm wall from 0.4 to 1.8 cm thick. Its material was cut in chips of 8 to 10 cm long, 0.5 to 3.0 cm wide and the thickness between 0.5 and 2 mm at the aim of better reagent soaked in the digestion. GAK fibers were extracted at the Environmental Laboratory of Universidad de los Andes. The kraft process employs sodium hydroxide (*NaOH)* and sodium sulfide (Na_2S). The digestion was performed with and effective alkali EA of 20%, a sulfidity S of 50%, and a hydro module HM of 4. The pH was adjusted washing the fibers with acetic acid. Once the fibers were extracted, they were cut and classified into three different sizes: long fibers 2.00-4.76 mm, medium fibers 0.25-200 mm, and short fibers 0.1-0.25 mm.

The mechanical characterization of the fibers was performed by means of tension and pull out tests. The tension tests were performed according to the ASTM C1557 standard, for the evaluation of the stresses, the cross sectional areas of the fibers were obtained based on the fiber weight, density and length. The pull-out tests were performed to determine the interfacial shear strength (IFSS) by means of the fiber adherence test. The fibers were also subjected to thermogravimetric analysis (TGA) according to the ASTM E1131.

2.2 Composite Formulations and Characterization

First, the GAK fibers were dried in a convection oven during 24 hours at 105°C. Then, the PVC-GAK fiber composite formulations were prepared using a dry mix at room temperature for three minutes in a high-speed mixer. Each of the composite formulations is named with a letter, indicating the fiber length (L-long, M-medium, S-short), and two digits indicating the fiber volume fractions (20%, 40%, 60%). The PVC specimens without fibers are tagged 000.

The mechanical properties of the PVC-GAK composites were determined by means of tension, compression, bending, and izod impact under the ASTM D638, D695, D790, and D256 standards, respectively.

3 Results and Discussion

3.1 Fibers pH

In order to neutralize the *pH* of the fibers, samples were prepared and washed with different concentrations of acetic acid, and *pH* readings were taken, and shown in Table 1

Table 1. Fibers pH measurement

		Valores pH		
Ensayo	**Cápsula**	**Ácido acético**	**Masa seca fibras, g**	**pH**
1	17	0.00%	10.0277	10.15
2	26	0.10%	5.0124	5.63
3	15	0.30%	5.0258	4.80
4	16	0.50%	10.0229	4.42
5	23	3.00%	10.0397	3.49
Ácido acético				2.97
Valor a pH neutro		0.07%		7.00

Based on this information a concentration of acetic acid of 0.07% was employed for washing the fibers in order to obtain a *pH*=7.

3.2 Thermogravimetric Analysis

The thermogravimetric analysis resulted in a degradation temperature of 250^0C as shown in Figure 1. This temperature ensures that the fibers will not be affected due to the the composite manufacturing temperature.

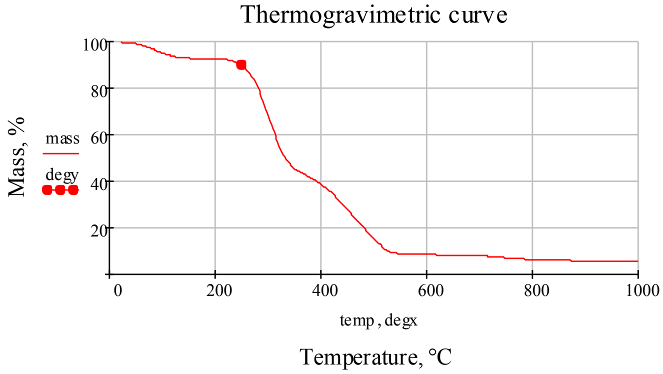

Figure 1. GAK fiber TGA

3.3 GAK Tension Tests Results

Tensile strength and modulus of elasticity of the GAK fibers are listed in Table 2. Average values are 233.6 MPA and 20.6 GPA for the strength and modulus respectively. These values are comparable to those of the glass fibers indicating the potential use of the GAK fiber as a replacement of synthetic fibers.

Table 2. Tensile test results.

Probeta	Esfuerzo máximo MPa	Elongación a carga máxima %	Módulo elasticidad MPa
F1	274.033	1.92%	19,018.395
F3	188.358	1.44%	20,475.862
F4	184.848	1.39%	20,913.779
F5	287.056	1.39%	21,932.722
Promedio	233.574		20,585.190
Desviación estándar	54.516		1,209.768
Promedio+desv. estándar	288.090		21,794.957
Promedio-desv. estándar	179.058		19,375.422

3.4 Fibers Pull-Out

Results of pull-out tests are listed in Table 3. The data obtained from the pull-out tests allow the preparation of a curve where the first local failure can be identified. It can be observed that for embedment lengths below 2 mm no force is necessary to extract the fiber from the PVC matrix. On the other hand, for the case of the embedment length of 5 mm, the stress required is higher than the fiber strength, indicating that this is the minimum length to guarantee a perfect bonding between the PVC matrix and the GAK fibers.

Table 3. Single fiber pull-out test results.

Single fibre pull-out test							
Test	W, gr	Lf, mm	d, mm	L, mm	F, N	σ, MPa	τ, MPa
----	0.0078	101.68	0.2641	1.0	----	----	----
----	0.0095	92.31	0.3059	1.5	----	----	----
1	0.0224	100.51	0.4502	2.0	3.082	19.361	1.090
2	0.0164	95.59	0.3950	2.5	6.382	52.078	2.057
3	0.0341	121.07	0.5061	3.0	18.748	93.189	3.930
4	0.0100	99.70	0.3020	3.5	16.055	224.096	4.834
5	0.0139	100.20	0.3552	4.0	23.504	237.204	5.266
----	0.0118	68.07	0.3971	4.5	----	----	----
W : masa fibra			Distancia entre mordazas: 73 mm			Humedad relativa: 48%	
Lf : longitud fibra			Longitud efectiva: 73 mm				
d : diámetro fibra			Velocidad ensayo: 1 mm/min				
L : longitud penetración			Periodo acondicionamiento: 200 h				
F : carga máxima			Temperatura ambiente: 23°C				

3.5 PVC-GAK Fiber Composite Mechanical Properties

Results of the tension, compression, bending and impact tests performed for the different formulations of the composites are shown in Figures 2 – 5.

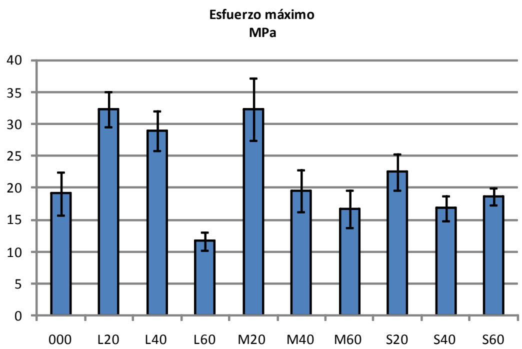

Figure 2. Composite tensile strength (MPa)

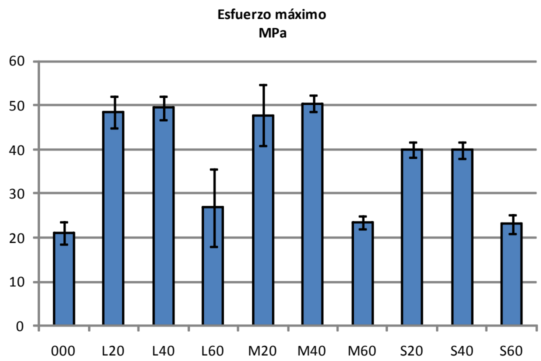

Figure 3. Composite Compressive Strength (MPa)

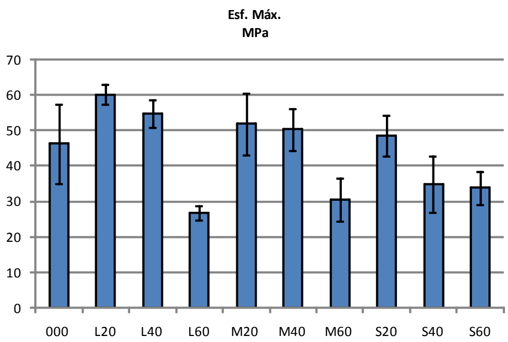

Figure 4. Composite bending strength (MPa)

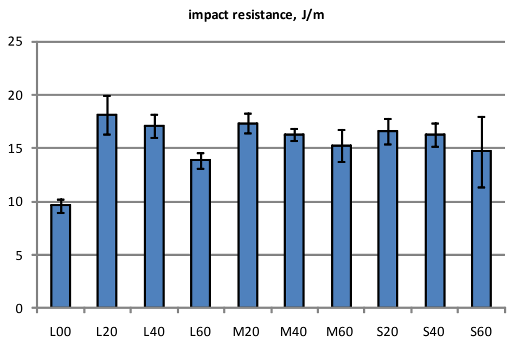

Figure 5. Composite Impact Strength (J/m)

According to the results, the inclusion of the GAK fibers in the PVC matrix increases the tensile and bending strength of the composites for all fiber lengths and volume fractions of 20% and 40%, while they decreases for fiber content of 60%. On the other hand, the inclusion of fibers increases the compressive and impact strength for all fiber lengths and volume fractions. The highest increments in mechanical properties are consistently obtained for long and medium fibers with a volume fraction 20%.

Tensile strength and modulus of elasticity of the PVC-GAK fiber and those of other commercial fiber-reinforced composites are comparable indicating that GAK-fibers are potentially adequate for composite reinforcement give the mechanical properties obtained.

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