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PHYSICAL-MECHANICAL EVALUATION OF A HYBRID SISAL FIBRE/BANANA STEM FIBRE/BIO EPOXY BIOCOMPOSITE AS A REPLACEMENT ALTERNATIVE TO CONVENTIONAL MATERIALS

Bladimir Ramón V., Gonzalo Moreno C. and William Mora E.
Department of Mechanical Engineering, University of Pamplona, Colombia
E-Mail: baramon12@unipamplona.edu.co

ABSTRACT

This work develops a hybrid composite material using a bio-epoxy resin matrix reinforced with natural sisal and banana stem fibres. The vacuum-assisted resin infusion technique uses to define the appropriate proportions to guarantee the adhesion of the reinforcement. With the physical-mechanical characterisation of the density of 1041 Kg/m^3, a flexural resistance of 160.43 MPa, and Young's modulus of 2.17 GPa, the adhesion evaluated using SEM images (scanning electron microscopy) and shows separation between resin and reinforcement less than 10μm. With these properties, using the Granta Edu Pack tool, conventional materials such as polypropylene(PP), polyester, cellulose acetate, polystyrene (PS), Acrylonitrile Butadiene Styrene (ABS), cardboard and wood were found, with similar properties, and the hybrid biocomposite can replace that.

Keywords: hybrid composite, natural fibres, reinforcement, mechanical properties.

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INTRODUCTION

Natural fibres have gained great relevance in developing new materials mainly due to their abundance, low cost, low carbon footprint in their processing, and biodegradability [1]. Hybrid biocomposites are generally manufactured from a combination of natural fibres in a polymer matrix that may or may not be of natural origin, seeking to enhance the properties of the compound by complementing the properties of one material with those of the other, achieving better material performance [2].

Some of the fibres that have commonly been used as reinforcement are bamboo, sugar palm, bagasse, wood, kenaf, jute, hemp, pineapple leaves, sisal, jute, coconut fibre, silk fibres, and cotton, all lignocellulosic fibres that they contribute not only in mechanical properties but in care of the environment due to their biodegradability [3]. Natural fibres can replace the traditional reinforcement in composite materials where a high strength-to-weight ratio is required, which allows them for various industrial applications, especially in the automotive industry [4].

This work focuses on fabricating and characterising a bioepoxy polymer matrix hybrid composite material reinforced with natural banana and sisal fibres. The physical-mechanical properties found are density and flexural strength. In addition, the behaviour of its structure is reviewed by scanning electron microscopy to determine the level of fibre-matrix adhesion. With the properties of density and modulus of elasticity, a selection of possible conventional materials that can be substituted to make them more friendly to the environment is made.

MATERIALS AND METHODS

Materials

Banana fiber

Banana cultivation in Colombia corresponds to approximately 50% of the planted area in the country, with about 500 thousand cultivated hectares [5]. The cut plant is considered waste; this causes contamination of soils, and groundwater, the proliferation of bacteria and diseases due to its open decomposition without any control [6]. The dried banana peels come from the department of Córdoba, municipality of Tuchín. 200x200 mm sheets were used.

Sisal fiber

Two native species of sisal are cultivated in the Colombian Andean zone: *Furcraea cabuya* and *Furcrae macrophylla.* It is considered the second most crucial fibre after cotton. [7]. There are nine (9) producing departments with a planted area of approximately 16,990 hectares, and the production is focused on elaborating sacks, cords, biomats and handicrafts [8]. The sisal fabrics were obtained from a colhilados company in San Gil, department of Santander.

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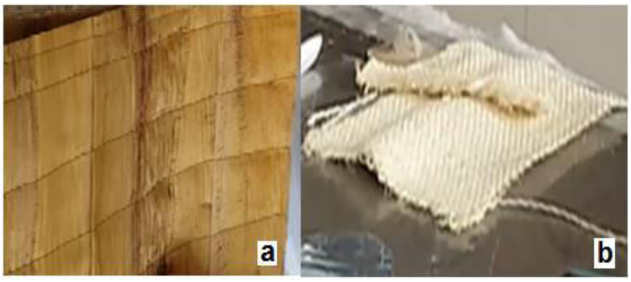

Figure-1. Natural fibres used a) Banana, b) Sisal.

Bioepoxy resin

Entropy Resins supplied the matrix referenced SuperSapTM100/1000, a two-component liquid epoxy system designed explicitly for Wet lay-up and curing at room temperature. It is a bioresin made up mainly of by-products of bio origin from industrial processes, such as wood pulp or biofuel production [9].

Methods

Elaboration of the material

With negative pressure, the vacuum-assisted resin transfer method was used to drive resin into the laminate. The banana fibre and sisal were previously dried. After placing inside the mould and sealing it, a vacuum of -0.8 bar was applied to suck the resin. The process was carried out at the University of the Basque Country at an ambient temperature of 20ºC, using a SuperSap® INF Hardener catalyst with a 100:33 resin/hardener mix percentage. The curing time was 8 hours.

Physical-mechanical characterization

The density of the material was determined using the ASTM D 792 standard using a PCE-LS 500 analytical balance. The flexural mechanical tests were performed according to the ASTM D7264 standard to determine the composite material's maximum strength, strain and flexural modulus. The simple bending test at three points was carried out in the materials laboratory of the University of Pamplona on the universal testing machine SHIMADZU UH-I Model 600 KN series with a feed rate of 1mm/min and an ambient temperature of 18°C; under these conditions, five specimens were tested.

Scanning Electron Microscopy (SEM)

This assay was carried out in the microscopy laboratory of the Universidad de los Andes, Bogotá. The equipment used was a state-of-the-art JEOL microscope, model JSM 6490-LV, operating in high and low vacuum modes. For the preparation of the samples, the specimens were covered in a bath of (gold/carbon) to allow the material's electrical conductivity; a voltage of 20KV and high vacuum insulation were used. The SEM images obtained correspond to the fracture of the tested specimens.

Selection by GRANTA-EDUPACK

The selection of materials that can be substituted with the obtained hybrid compound was made, considering the flexural modulus and density results.

RESULTS

Elaboration of the Material

The sandwich-shaped material's banana and sisal reinforcement distribution was done in layers. For the plantain-fique-plantain configuration, two plantain slices with 44.06 g and 24.26 g fique tissue were used (Figure-2a). Next, the assembly and execution of the infusion process were carried out (Figure-2b), and curing was carried out for 8 hours. The composite material obtained is observed in Figure-2c.

Figure 2. The manufacturing process of the Banana/sisal/bioepoxy composite. a) Determination of the weight in the reinforcement, b) mould for infusion and c) laminate obtained.

From the laminate obtained, five specimens are cut for the flexural test of 120mm in length, 13mm in width, and 4mm in thickness, as defined in the ASTM D7264.

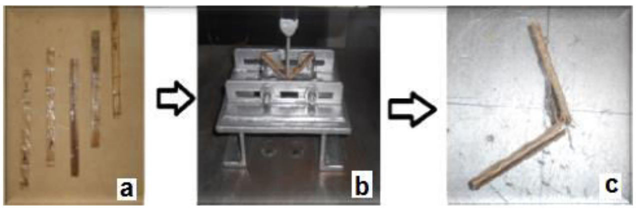

Figure 3. Bending test. A) specimens, b) 3-point bending, c) failed specimen.

The results of the density and Flexural test are presented in Table-1.

Table-1. Flexural mechanical properties of the composite.

Density(Kg/m³)	Flexural strength (MPa)	Maximum strain(%)	Flexural Modulus (GPa)
1041	160.42	4.05	2.17

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Comparing these results with some hybrid composite materials developed with natural fibres and polymeric matrix, good behaviour of the mechanical properties of the banana/sisal/bioepoxy composite material is identified, especially in stress, as shown in Table-2.

Table-2. Comparison of properties with other composites reinforced with natural fibres.

Composite	Flexural strength (MPa)	Flexural Modulus (GPa)	Ref.
Sugar palm/glass fibre/ thermoplastic polyurethane	13 - 31	0.28 - 0.5	[10]
Coir/silk/unsaturated polyester matrix hybrid composites	37 - 43	-	
Banana/sisal/epoxy matrix hybrid composites	21.6 - 57.5	-	
Sisal/silk/unsaturated polyester matrix hybrid composites	33.5 - 46.2	-	
PALF/OTL/epoxy matrix hybrid composites	16.4 - 44.4	2.04 - 4.82	
Epoxy resin / waste marble dust / tamarind shell particles (50/35/15)	38.5	10.9	[11]
Mango seed shell short fiber reinforced composite	57	-	[12]
Hybrid sisal fibre/banana stem fibre/bio epoxy	160.4	2.17	

In the Table, the developed material presents more excellent resistance to flexion than the other hybrid composites evaluated in other investigations. This strength can be used in structural components subjected to moderate loads.

Scanning Electron Microscopy

Figure-4 shows the characterisation by scanning electron microscopy for the hybrid material of banana slices, fique with bioepoxy resin. After the mechanical characterisation test, they show the morphology, adhesion and fracture type.

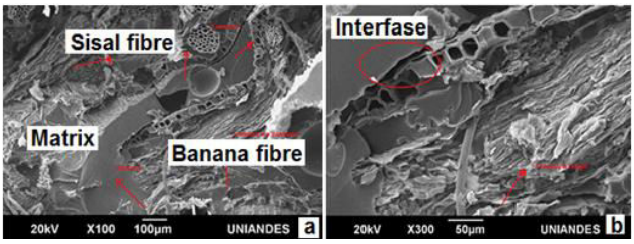

Figure-4. Banana/sisal/bioepoxy composite SEM at a) 100X and b) 300X.

Figure-4a shows the phases present in the hybrid material (banana-sisal-bio epoxy) and its morphology. The lumen of the banana fibre is very similar to that of the fique fibre because both are vegetable fibres. The banana one presents a linear configuration while the fique is circular; the matrix, the reinforcement and the interface between them are observed.

In Figure-4b, a brittle fracture can be highlighted in the specimens tested due to the structure that presents the cut and the fibre-matrix adhesion, which in this case is considered reasonable since the interface value is close to 10 microns, which also positively influences its mechanical behaviour.

Selection Uses Granta-EDUPACK Software

The selection was made in a bubble graph where limits for flexural modulus and density were determined. Figure-5 shows three high-use polymeric materials in this range (Light Blue) with similar properties to the obtained composite.

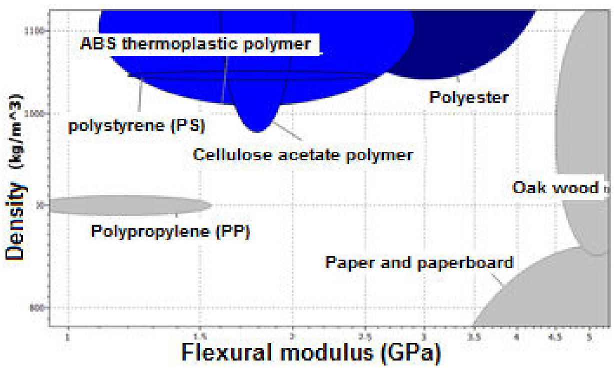

Figure 5. Selection by flexural modulus vs density.

The conventional materials with the closest properties are ABS, Polystyrene and cellulose acetate polymers. This similarity makes it possible to develop components frequently made with these materials but using the epoxy-banana-sisal composite. Some specific cases would be the manufacture of tool knobs or handles (cellulose acetate); electronic equipment covers (Polystyrene), panels and interior equipment for vehicles (ABS). Materials of natural origin, such as wood and

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cardboard, are further away from the evaluated properties; however, replacing them with composite in some decorative applications is possible. Figure 6 shows excellent flexural behaviour compared to the possible materials that can be substituted according to the selection by module vs density.

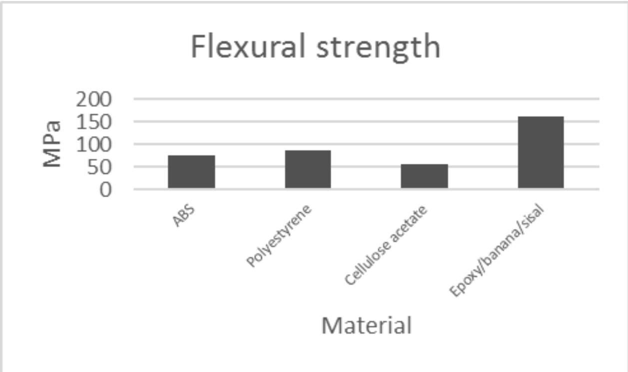

Figure-6. Comparative flexural strength composite with conventional polymers. [13], [14].

These results validate the possibility of replacement in components of daily use or industrial type.

CONCLUSIONS

The hybrid material is easily replicable through the vacuum-assisted resin transfer process; this is an advantage over manual impregnation methods that do not guarantee adequate adhesion and can generate delamination.

The density and resistance of the material give it an advantage over some hybrid compounds developed and polymeric materials derived from petroleum, taking into account that it is more friendly to the environment.

Scanning electron microscopy allows us to see a good adhesion between the reinforcing fibres and the matrix with an interface of approximately 10 microns, positively influencing the mechanical properties.

The selection of materials that can be replaced was made by density and flexural modulus, resulting in some natural and artificial polymeric materials. The closest to the characteristics were polystyrene, cellulose acetate and ABS, which have industrial applications where the compound can perform efficiently.

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