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Residual composite materials with applications in the industry of the construction

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Abstract

Ecological awareness as an ethical obligation is conceived. A product, a prototype or a process must culminate efficiently when incorporated into a production chain; its life cycle will depend, therefore; of its use, reuse and recycling. This project presents an industrial vision in conjunction with agriculture. For this, a general problem of interaction between products (agribusiness chain of the banana plant and reuse of conventional polymeric waste) that work within the same context has been addressed. Colombia has climatic conditions that weigh this country as one of the major producers in the banana zone. Today Colombia is recognized for its quality and for its exports, which reach a figure of 1,578,112 Tons of Banana as of December 31, 2017, and amount to 86.99 million boxes of approximately 18.14 Kg. Once the fruit is harvested, it is packed and exported; at the end of this process, the leaves and stems of the plant become waste. This residue called pseudostem has a mass percentage of about 51% with respect to the total plant. In economic terms, 1,667,000 metric tons per year correspond to this waste, an important economic factor in regions where bananas are high, as is the case in Risaralda. In response to this situation, we find that the banana pseudostem is a low-cost fiber, which increases its mechanical strength when mixed with medium density polymers. These characteristics allow mixing cellulosic residues with residual polymers such as polypropylene, the incorporation of load and reinforcement elements in thermoplastics has been a common practice in the plastics industry whose purpose is the reduction of production costs of molded products, and the improvement of thermo-mechanical properties of polymers. In this context, new materials are proposed based on the mixture of polypropylene and fiber with percentages of 10%, 20% and 30%. For these materials, the process variables were evaluated based on obtaining the pellets by extrusion and finally the samples to which the mechanical properties were estimated. On the other hand, the 3D design of the potential application in roof tiles for construction is reported and it is concluded that at 20 % fiber the degradation. There is a good consistency of pellets, but there is a drastic detriment of traction.

Keywords: Banana stem, polypropylene, roof tile.



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1. Introduction

The need to develop and commercialize materials containing plant fibers has grown to reduce environmental impact and achieve sustainability. Large quantities of lignocellulosic materials are generated worldwide from various human activities. Lignocellulosic materials are composed of cellulose, hemicellulose, lignin, extracts and ashes. Recently, these constituents have been used in different applications; In particular, cellulose has been the subject of numerous works on the development of composite materials reinforced with natural fibers with improvements in mechanical, physical and thermal properties. In the context of innovation, these lignocellulosic materials have been applied in efficient and sustainable systems due to the growth of global environmental awareness. Cellulose fibers provide strength, and lignin, another hydrophobic biopolymer, acts as an adhesive to bond the fibers in a matrix near the surface.

Fibers constitute a renewable resource throughout the world, especially in the tropics. According to the Food and Agriculture Organization Survey, Tanzania and Brazil produce the largest amount of sisal. Abaca and hemp are produced by the Philippines. The largest jute producers are India, China and Bangladesh. At present, the annual production of natural fibers in India is approximately six million tons compared to world production of around 25 million tons. In low pressure lamination, the use of glass fibers is almost a monopoly. In recent times, the lack of competitiveness of fiberglass reinforced plastic components in applications where resistance characteristics are not essential, has led molders to seek a reinforcement that provides the necessary properties while reducing the cost. This has resulted in a growing interest in the reinforcement of natural fibers. Therefore, the diversification of natural fibers in traditional markets not only strengthens the activity in the area of substitutes for wood and molded products, but also preserves forest resources that help maintain our ecological balance.

Biocomposite material has been synthesized from banana fiber, where the fibers of the banana pseudostem were treated with acetic anhydride, epichlorohydrin and the mixture of acetic anhydride and epichlorohydrin. These treatments directly influence the mechanical properties of these compounds especially with 10% NaOH. Also, SEM studies showed that the chemical treatment of banana fibers changes the surface topography of the fibers. These treatments are important depending on the inconveniences that may arise in the use of these materials, such as: moisture absorption, loss of adhesion or detachment in the fiber / matrix interface, water diffusion, reduction in dimensional stability, resistance limited to biological attacks and weathering agents. These material degradation factors have led researchers to impart hydrophobicity to the fiber surface; by alkaline means and the use of coatings that improve fiber adhesion.

In the degradation aspect, lignin with UV exposure is affected by absorbing short visible wavelengths. UV exposure also damages the lignin binder, leading to the separation of cellulose fibers and surface erosion in these systems. Energy UV photons have enough energy to disrupt chemical bonds. After the interruption of the initial chemical state, polymers are likely to react with oxygen and / or water vapor causing additional changes. If these materials are used in construction as ceilings, it should be noted that the energy content of direct sunlight that normally affects a roof is approximately 1 kW m^2 (1 kilowatt per square meter). There is a long wave compensatory radiative cooling effect of approximately 60 W m^2 , because the effective temperature of the radiant sky is below the air temperature. If the roof is insulated at the bottom, the heat dissipation through the roof is mainly caused by convection to outside ambient air and thermal radiation emission. The convection coefficient for heat transfer is approximately $12 \text{ W m}^2 \text{ K}$ to $20 \text{ W m}^2 \text{ K}$, and the highest values occur during wind conditions, where the radiative transfer coefficient for a surface with high thermal emittance is approximately $6 \text{ W m}^2 \text{ K}$. This infers that the increase in the temperature of a black roof (reflectance 0.05) in full sunlight is approximately $34\text{-}50 \text{ }^\circ \text{C}$, warmer than ambient air.

Various types of matrix resins such as phenolic resins have been used as coatings, unsaturated polyester, and epoxides have been used in the manufacture of fiber composites such as jute. Unsaturated polyester resins are widely used as composite matrices due to their low cost, low viscosity and optimum strength. However, they are prone to microcracks and secondary adhesion failures due to their low toughness, lower fiber adhesion and a high volume of contraction during the curing process. Therefore, improvements in polyester properties are highly desirable to improve its toughness by interpenetrating polymer techniques. In this method, a hybrid polymer network can be formed through crosslinking reactions, that is, copolymerization of styrene unsaturated polyester resin and polyaddition between terminal hydroxyl groups of polyester and isocyanate groups. This method is suitable for the interlocking of both resins that improves the impact resistance of hybrid polymer networks.

To improve hydrophobicity, synthetic binders and reinforcing fibers have been added. The clot (dry latex) of *Euphorbia royleana* has been used to replace the polyester resin as a natural binder in the polyester banana fiber compound. The influence

of different volumetric fractions of the clot on the compound has been studied. It has been observed that with the increase in the clot fraction the flexural property of the polyester banana fiber compound increases. The flexural strength increases by 25% and the flexural modulus increases by 15% to 40% of the clot weight fraction. This study presents the possibility of preparation of composite materials using Euphorbia latex clot and raises the use of these polymers in partition walls, tiles, car interior linings, etc. as a substitute for cellulosic systems such as wood. In other studies, endosperms of roasted tamarind seeds have been used for the preparation of the tamarind seed gum solution. The tensile strength of the prepared composite material showed water resistance as a function of temperature, ending the study with the manufacture of low-cost housing using sisal fiber and tamarind seed gum. The thermal factor can lead directly to the degradation of the materials. The rise in temperature can accelerate harmful chemical reactions, cause the loss of volatile components and soften some polymers. Temperature changes, whether gradual or sudden (rain on a hot day), cause stress due to differential thermal expansion. In fact, even a monolithic material, such as a sheet of glass, experiences stress that can cause fractures if heated to a non-uniform temperature. The nitrogen that makes up most of the atmosphere (78% by volume) is not very chemically reactive. However, the reaction with oxygen (21%) and water vapor (0.3-3%) can cause the formation of several oxides and hydroxides. For example, corrosion products of metallic iron include FeO, Fe₂O₃, Fe₃O₄. Also, smaller gaseous atmospheric components such as: CO₂, SO₂ and NO₂, formed by combustion dissolve in water and form acids. These acids can promote corrosive chemical reactions.

In this research work, the authors report the synthesis of a new material made up of polypropylene and fiber obtained from banana stalk. Our interest is to find the best process variables that allows the stabilization of the composite material, the obtaining of pellets by extrusion and the construction of mixtures used to evaluate the mechanical properties. Likewise, one of the potential uses of the material is in the construction of tile from residual material, which is why the 3D design of the prototype will be included in the results.

2. Experimental details

2.1. Performance of tiles 3D

Development of the 3D injection mold model for conventional tiles measuring 250 mm x 350 mm, using wireframe 3D.

2.2 Banana fiber treatment

The residue of the banana pseudostem is physically obtained by agreement with the banana grower associations of Risaralda (Colombia). The pseudostem was cut into 30 cm sections, washed with water and dried in the sun. The fibers are obtained by treatment with 10% sodium hydroxide to remove waxes, pectins and resins contained therein, and then they will be manually defibrated. Cellulose will be obtained through the procedure reported in the literature (Andrade, 1998), it will be carried out in triplicate for each of the residues. The final pH of the chlorination stage (9.2 and 8.4) as well as the NaOH concentration (20 and 25%) during alkaline hydrolysis was varied, in order to determine the effect of these variables on cellulose properties. The fibers were dried at room temperature. Subsequently dried in a vacuum oven. Subsequently these materials will be mixed polyethylene with a 10 (PP- FB 10%), 20(PP- FB 20%) and 30 (PP- FB- 30%) percent in relationship to banana fiber and it characterized by thermal and rheometric properties.

2.3. Thermal characterization of the material

The thermogravimetric (TGA) and differential scanning calorimetry (DSC) analyses were performed on a TGA/DSC 2 STAR System thermogravimetric analyzer, Mettler Toledo. The samples (10 ± 0.5 mg) were placed in alumina crucibles at a heating rate of 20 °C/min using a nitrogen purge at a flow rate of 100 mL/min. In the case of TGA, the analysis was performed from room temperature until 600 °C. The DSC analysis was done at temperature range between 30 and 300 °C.

2.4. Development of composites pellets

Manufacture of static ultrasonic mixing head in accordance with the technical specifications recorded in the plans generated from the design area of the CDT - ASTIN. Tuning of a static ultrasound mixer head in single-screw extruder. Experimental performance of the extrusion process taking into account the following criteria: Variable concentration, constant concentration: DCP 2 phr, HBPAM 10 phr, AM 10 phr, recycled polypropylene, setting of the process parameters: mixing zones: 4 and 0

units; feed rate: 0.5% and 5% feed (~ 60 g / h and 200 g / h); frequency and wavelength (25-40 KHz and 80-100 V, respectively). Establishment of constant process parameters: spindle speed 50 rpm, temperature profile from 175 ° C to 220 ° C with gradual increase of 5 ° C, **table 1**. In the table 2 are showed the qualitative torque parameters for the development of composites pellets.

| Site | Function | Length (D) |
|--------------|-----------------------|---------------|
| 0 | Support | ----- |
| A | Feed | 10 D |
| B | Mixers to 30° | 1.5 D |
| C | Mixers to 90 ° | 1.5 D |
| D | Transport | 6 D |
| E | Mixers to 60° | 1.5 D |
| F | Transport | 9 D |
| G | Mixers to 60° | 0.75 D |
| H | Mixers to 60° | 2.25 D |
| I | Extrusion | 7.5 D |
| Total length | | 40 D |

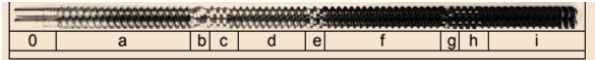


Table 1. Variables of the plastics processing

| Mixture 1 (PP- FB 10%), mixture 2 (PP- FB 20%), mixture 3 (PP- FB 30%) | | | | | | | | | |
|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Temperature performance (° C) | | | | | | | | | |
| Z1 | Z2 | Z3 | Z4 | Z5 | Z6 | Z7 | Z8 | Z9 | Z10 |
| 155 | 160 | 165 | 170 | 175 | 180 | 185 | 190 | 200 | 200 |
| Spindle speed: 150 rpm | | | | | | | | | |
| Simple hopper speed: 10 %, 9.033 g/min | | | | | | | | | |
| Double hopper speed: 0.9 %, 1.003 g/min | | | | | | | | | |

Table 2. Qualitative torque parameters

3. Results and discussion

3.1. Performance of titles 3D.

In the **figure 1**, the development of three tile models was presented. Within the design stage, a verification of tile assembly system was carried out, in order to observe in a tangible way whether the proposal was fully functional or should enter the modification process. The program Wireframe 3D allowed performance in 3D, which gives a vision of the purpose of the synthesis of the new material. A real application in environmentally friendly tiles.

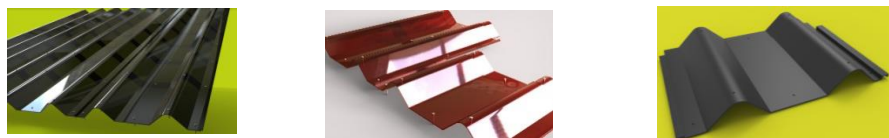


Figure 1. Design of tile prototypes in 3D

3.2. Thermal characterization of the material.

The **figure 2** corresponds to TGA and DSC analyses, for propylene, **figure 2a**, in relationship to the mixed PP- FB 30%, **figure 2b**. In the range of 240 °C – 400 °C, the thermal properties of the material improve in the presence of banana fibber. The melting point of polymeric material increases (line blue), which will allow better extrusion and degradation. For the TGA analysis, the degradation in polypropylene- fibber is in 10% in correlation with polypropylene simple.

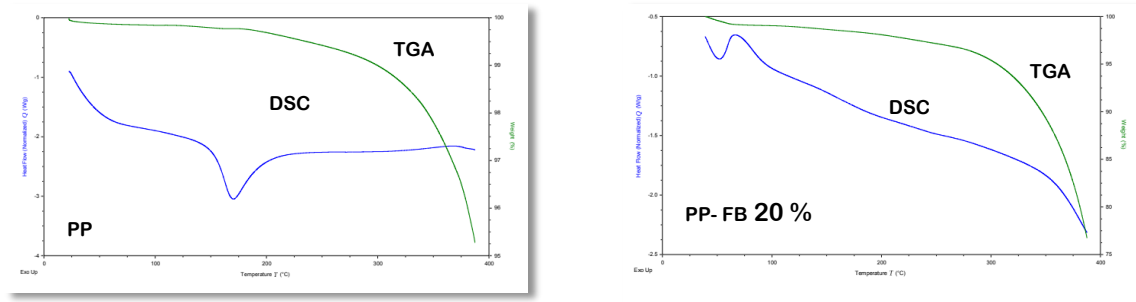


Figure 2. TGA and DSC of a). PP (polypropylene) and b). PP- FB 20 %.

3.3. Extrusion of the pellets

After having carried out the respective investigation of the materials to be used, the experimental process proposed in the methodology is applied in order to obtain (3) mixtures, and in this aim, subject them to mechanical test such as traction to determinate the best properties in process. In the table 3, it is showed the process output variables, in where the mixture with 20 % of fibber is the best material processable by the extruder for the development of pellets.

Table 3. Process output variables

| Mixture | Quantitative | | | | Qualitative |
|---------|------------------------|---------------------|-------------|---------------------|-------------|
| | Average pressure (Bar) | Average Torque (NW) | Mass nozzle | Amount obtained (g) | |
| 1 | 9.7 | 60.6 | 179.7 | 200 | Regular |
| 2 | 9.7 | 67.7 | 175.7 | 180 | Good |
| 3 | 11.4 | 72.5 | 176.4 | 335 | Regular |

3.4. Mechanical properties

In accordance with the **figure 3** and **4** at a higher load of fiber in the mixture, there is a loss of toughness and flexibility. Thus, achieving that the material is much more fragile and has less impact resistance. It was also deduced that, at a lower load of fiber, greater effort to break by traction. It is necessary to make the parallel of the mixed with fiber with that of 100% polypropylene to be able to observe the behavior and change of properties of the same. In this aim, determine which is more pertinent to be applied depending on the context, in this case to the development of a tile. It should be noted that only the specimen obtained with the pellets with the best process condition at 20% was chosen.

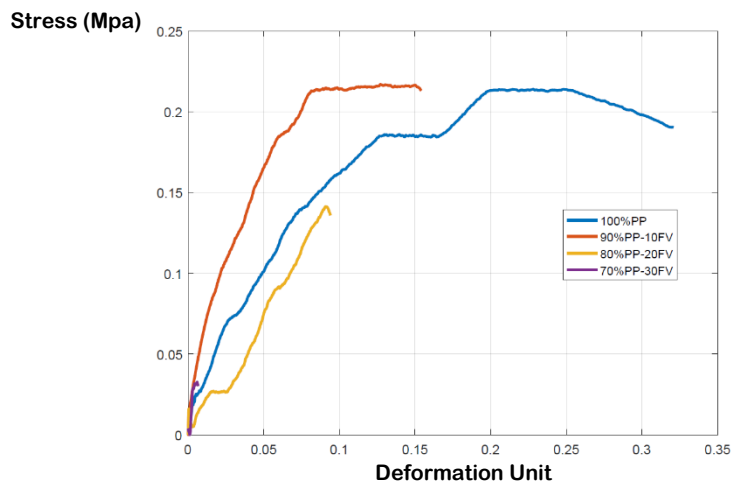


Figure 3. Mechanical properties in mixtures of polypropylene and banana fiber, stress curve Vs. Deformation.

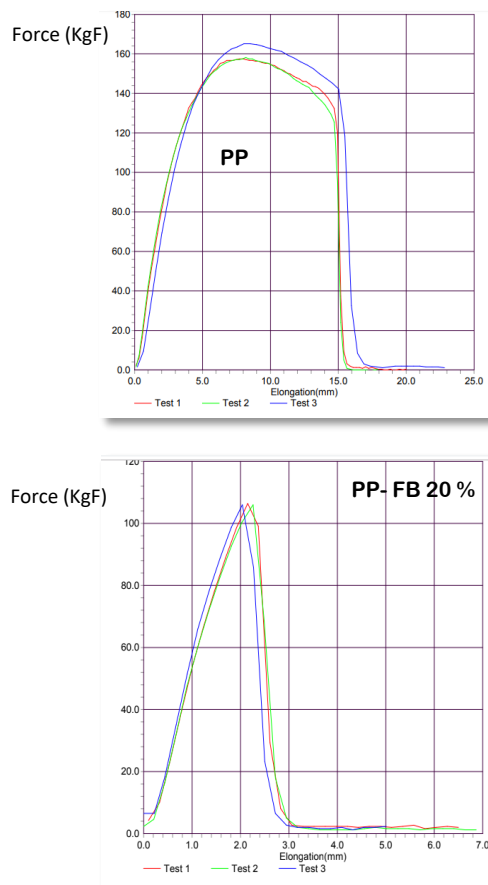


Figure 4. Traction module for a). PP and b). PP-FB 20%.

Conclusions

It is possible to reuse banana fiber with other thermoplastics under certain chemical procedures suitable for a good result, and thus be applied to a product. During the processes of TGA and DSC it was possible to identify the temperature support to which the materials can be subjected; between 240 to 400 ° C to be able to obtain the pellets in a uniform and consistent way without reaching degradation. However, the material developed in this project showed that, it generates a reduction of toughness of approximately 50% inferred from the area under the stress-strain curve compared to the polypropylene simple. In conclusion, it is necessary to improve the mechanical properties of mixtures in subsequent investigations that lead to the development of better materials with properties equal to those offered by the market.

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