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Mechanical Properties Analysis of Polypropylene Biocomposites Reinforced with Curaua Fiber

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Over the last few years, great interest has been shown by researchers in presenting alternative proposals for the design and fabrication of materials with good mechanical properties and low cost for a variety of applications. With this in mind, a study was carried out on the addition of curaua fibers in a polypropylene (PP) matrix. These were extruded in the pellets form with curaua fiber content of 5, 10 and 20% (mass percentage). An injector was used to make the test specimens from these pellets, which were then subjected to mechanical tests (tensile and three point bending), physical and thermal tests (fluidity index and HDT). As a consequence, it was noted that the incorporation of fibers in composites of PP with curaua resulted in an increase in the elastic modulus and tensile strength improving therefore the mechanical properties of these materials. Another important point was to check if there was an increase in heat deflection temperature as the fibers were added. As a result, it has been found that it is feasible to use these materials in industry, facilitating its recycling and improving its final mechanical properties.

Keywords: *biocomposites, mechanical properties, curaua fibers, polypropylene*

1. Introduction

As applications and services become more sophisticated, it is frequently necessary to find new materials which can meet all the expectations of the industry, especially when considering the cost, mechanical properties and recyclability of the material.

With this in mind, several researchers[1-7] made an effort to meet this demand. Taking this into account, the biocomposites materials render themselves as an alternative because of the possibility that they will be recyclable, thereby reducing environmental impact and cost of production.

When considering the biocomposites manufactured from natural fibers and thermoplastic matrix, it has already been established in the literature that with a suitable surface treatment of the fiber or using a graft copolymerization matrix[1-3,8] and by using an increasing percentage volumetric fiber[5,9] it is possible to use these materials in small and medium structures even if they are in the form of short fibers[4,6-7].

One of the natural fibers that is currently showing very promising results[10-13] is the curaua fiber, showing superior resistance in comparison to other more frequently used natural fibers such as sisal, jute, abaca, kenaf[5-9,14] and therefore its application in composite manufacturing shows much promise for the future.

It is important to mention that in none of the studies cited above was it found how the increase in curaua fiber content influences the properties of the biocomposites nor was it proven that there was an advantage and at what values there wouldn't be any structural advantage in using natural fibers

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Therefore, this paper proposes to manufacture biocomposites based on polypropylene (PP) and reinforced curaua fiber of percentages of 5, 10 and 20%, that are thermally and mechanically tested by performing a comparison between the results and the properties of the base material.

2. Material and Methods

Polypropylene homopolymer (KM-6100) was used as a raw material for the development of biocomposites which was supplied by Quattor Petroquímica S/A company at a density of 0.9 g/cm³ and curaua fibers which were provided (in natura) by the Pematec company, located in the city of Santarém, state of Pará / Brazil.

The biocomposite was developed using a process extrusion, pelletization and injection. The mechanical and thermo-mechanical performance of the biocomposite was determined using the uniaxial tensile test, three point bending and heat deflection temperature. The influence in viscosity of the biocomposite, due to the addition of natural fibers, was evaluated in melt flow index test.

2.1. Manufacturing process

The specimens were prepared by mixing polypropylene (PP) pellets with caraua fibers, where composites were obtained in the form of chopped fiber grains of mass percentages of 5, 10 and 20%. These values were chosen because of the processing capacity of the extruder. The used extruder is a twin screw co-rotating manufactured by IMACOM, model DR 30:40 with screw diameter of 30 mm and L/D = 40.

The extruder speed used was 210 rpm at a temperature average 180 °C.

Before the manufacturing of the curaua fibers biocomposites, they were washed with water to remove impurities, combed, chopped and dried in a kiln. Soon after, they were conditioned in aluminum trays.

The PP (polypropylene) biocomposites, were added during the manufacturing process into the screw conveyor and the chopped fibers through a lateral opening, between the screw and the extruder. Both continued moving towards the entrance of the extruder, where the melting and mixing of elements took place. On leaving the extruder in the shape of a "noodle", through two small holes they then made their way to a cooling tank where they were allowed to solidify. After this process, the noodles were sent to the pelletizing machine. The pellets were homogenized and conditioned in a kiln for a period of 24 hours prior to the manufacture of the test samples.

The polypropylene analyzed in the preparation of the test specimens was processed by the same method used in biocomposites. This procedure was implemented in order guarantee that materials possessing identical characteristics and processing could be compared.

After removing the humidity in a kiln, the grains were deposited in a funnel, then injected into a mold at a pressure of 500 bar, at an injection rate of 120 cm^2/s and working temperature of 180°C. A "ROMI" type injector was used and the complete cycle between injection and cooling was 30 s. The norm used in the process of molding and extrusion was ISO 527-2[15].

2.2. Analysis of the fluidity index (FI)

In order to check the degree of thermal degradation caused by the extrusion process it was necessary to analyze the melt flow of the material. This is important because it evaluates the performance of the polymer during processing and reprocessing the extruder, indirectly analyzing the decrease of the molar mass of the specimen to its degradation. The decrease in molar mass occurs with an increased fluidity index and may hinder the recycling of the material.

With this in mind, in addition to the analysis of the fluidity index of the aforementioned material, an evaluation of the "virgin" polypropylene was also carried out at this stage, which serves as a point of comparison for the analysis of degradation and recyclability of biocomposites.

The ASTM D 1238[16] norm was used for the analysis of the fluidity index using equipment manufactured by Digitrol, which has an accuracy of ± 0.001 g/min with a test temperature of 230° C.

2.3. Tensile and bending in three points testing

The tensile and three point bending test were carried out on a universal testing machine manufactured by SHIMADZU with a maximum capacity of 30T; it was used at a speed of 5 mm/min in the tensile test and 1 mm/min in the bending test. The norms for the procedure and dimensions of the test specimens were ISO 527-5[17] and ISO 178[18], for testing the tensile and bending respectively. At least eight test specimens were used for each evaluated case.

2.4. Analysis of Heat Deflection Temperature (HDT)

In addition to tensile and three point bending, tests were done to measure the Heat Deflection Temperature (HDT) of the materials, using ISO 75-1[19]. In this test the specimens are immersed in oil, and loaded with bending stress of 450 kPa, which applies a heating rate of 2° C/min. Hereupon, it evaluates the temperature at which the specimen reaches a deflection of 0.34 mm which is called heat deflection temperature. The equipment used for this test was HDT 300 VICAT - CEAST.

3. Results and Discussion

3.1. Analysis of fluidity index (FI)

As previously mentioned, an increase in fluidity index may hinder the recyclability of polypropylene or biocomposites, due to their decreased molar mass and consequent degradability. Thus, for the biocomposites analyzed in the present study, the use of natural fiber did not alter the fluidity index compared with virgin polypropylene (Table 1). This table also shows that polypropylene degrades after the extrusion process, given that its fluidity index increased from 0.32 to 0.51 g/min (increase of 59%). Moreover, the use of 20% curaua fiber lowered the index to 0.24.

This result demonstrates that despite the reduced molar mass (indirectly measured by this test) during the extrusion process, the addition of natural fiber compensates the decline in viscosity, thereby allowing its reuse.

3.2. Tensile strength test

The tensile strength test results of these biocomposites showed that test specimens of all the biocomposite specimens ruptured and only those of the polypropylene specimens did not. Furthermore, a slight difference occurred between the test specimen results of each case analyzed, except for the value of rupture deformation, which exhibited wide-ranging values.

The results between the biocomposites and polypropylene showed an increase in mechanical properties (strength and stiffness) and a rise in fiber percentage. This finding is presented in Table 2 and Figure 1, which show the mean behavior of these materials for each situation analyzed. According to these values, the most significant increment occurred for the 20% PP/curaua biocomposite compared to polypropylene, which obtained a 151% increase in modulus of elasticity (from 1.08 GPa to 2.72 GPa). In relation to strength, the greatest increase also occurred for the 20% PP/curaua biocomposite, with a 20% rise in maximum tensile strength (from 25.9 MPa to 31.2 MPa).

Table 1. Average values of the pellets submitted to the FI analysis.

Material	Fluidity Index (g/min)
Polypropylene "virgin"	0.320
Polypropylene	0.510
PP/Curaua 5%	0.371
PP/Curaua 10%	0.370
PP/Curaua 20%	0.240

Another important point related to Table 2 is the fact that the increase in strength (maximum stress) did not occur linearly, since maximum stress values were practically the same for biocomposites with 5 and 10% curaua fiber. This result may be related to the formation of stress concentration points on the fiber-matrix interface, thereby masking the greater strength and stiffness caused when an increase in fiber content is not sufficiently high.

The formation of stress concentration points was confirmed by microstructural SEM analysis in the final fracture region of the material (Figure 2), where areas with greater biocomposite deformation (dark area) are observed around the fibers.

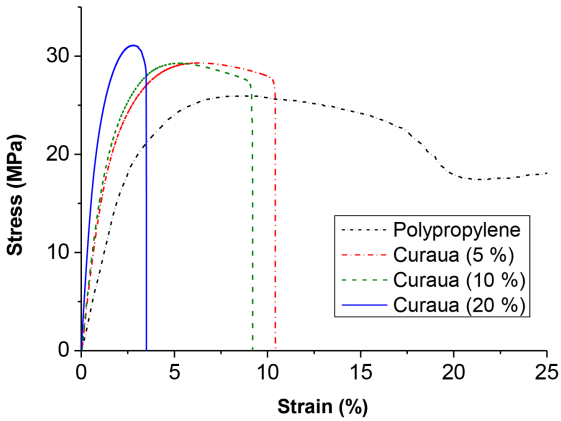


Figure 1. Average stress strain curves of polypropylene and biocomposites.

3.3. Three-point bend test

In contrast to tensile tests, none of the specimens ruptured during flexural testing, but all tests exhibited a maximum stress value. There was also little dispersion between specimens. An example can be seen in Figure 3 for the polypropylene biocomposite with 20% curaua fiber.

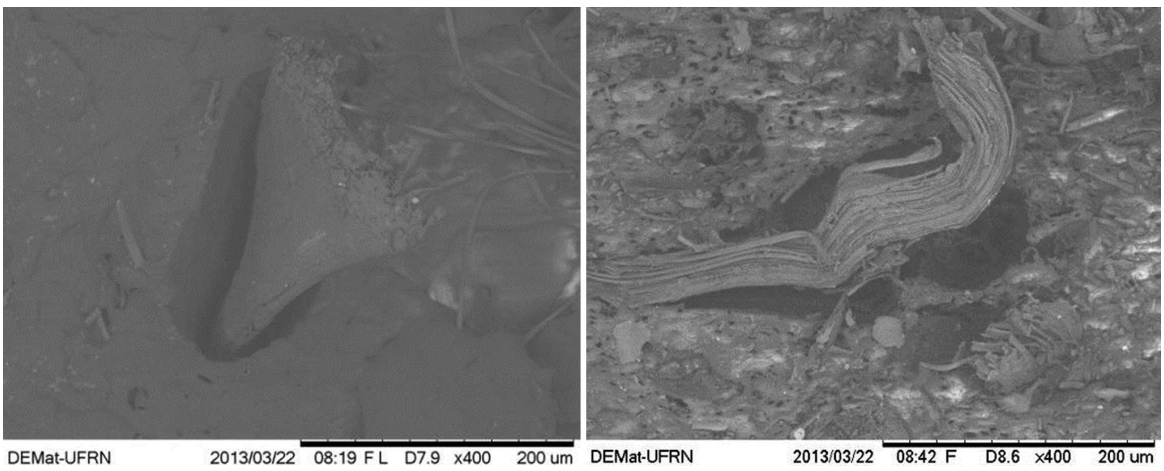
A comparative study between results showed an increase in strength and stiffness (Table 3 and Figure 4) with the addition of fiber to the biocomposite, as occurred in tensile testing. The difference was highest for stiffness (modulus of elasticity), with an increase of 105% (1.09 GPa in PP to 2.24 GPa in the biocomposite with 20% curaua fiber). A similar result was obtained by Raman et al.[20] for a PP composites reinforced with jute fibers.

With respect to strength, the increase was 23.2%, where maximum stress rose from 40.8MPain polypropylene to 50.3 MPa in the biocomposite with 20% curaua fiber.

It was also determined that the increase in strength (maximum tensile) and stiffness (modulus of elasticity) did not occur linearly, since fiber percentages of 5 and 10% exhibited similar mechanical properties. Once again, the effect of stress concentration caused by adding fibers to polypropylene may have masked the increase in the mechanical properties of the biocomposite.

3.4. Heat deflection temperature (HDT) test

Analysis of heat deflection temperature is important for thermoplastic applications (or thermoplastic-based materials) in industry, since its values determine, among others, the capacity of this material to withstand a sterilization temperature (around 121 °C), or whether it can be used in hot-filling processes of pasteurized products with working temperatures between 75 °C and 100°C.



(a) (b)

Figure 2. Scanning electron microscopy of (a) 5% PP/Curaua and (b) 20% PP/Curaua.

Table 2. Mechanical properties of polypropylene and the biocomposite obtained in the tensile test.

Material	Maximum Stress (MPa)*	Rupture Strain (%)*	Elastic Modulus (GPa)*
Polypropylene	25.94 (0.3)	——	1.08 (0.04)
PP/Curaua 5%	29.47 (0.5)	10.34 (2.2)	1.42 (0.05)
PP/Curaua 10%	29.35 (0.8)	9.11 (0.9)	1.54 (0.06)
PP/Curaua 20%	31.21 (0.2)	3.48 (0.3)	2.72 (0.03)

*The values in parentheses correspond to the standard deviation.

Table 3. Mechanical properties of polypropylene and the biocomposite obtained in the bending test.

Material	Maximum Flexural Stress (MPa)*	Flexural Modulus (GPa)*
Polypropylene	40.84 (0.5)	1.09 (0.04)
PP/curaua 5%	43.38 (0.7)	1.23 (0.05)
PP/curaua 10%	43.51 (1.5)	1.30 (0.06)
PP/curaua 20%	50.27 (0.3)	2.24 (0.03)

*The values in parentheses correspond to the standard deviation.

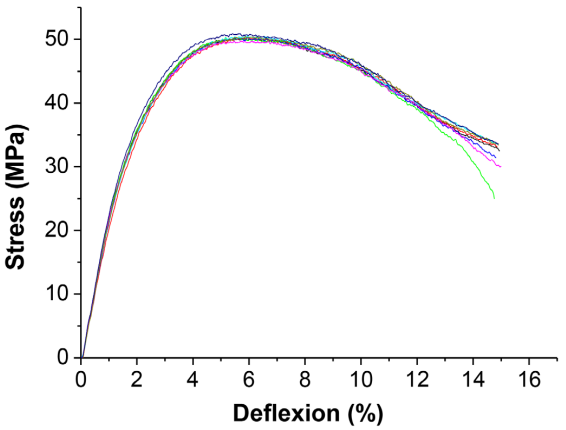


Figure 3. Stress deflexion curves of biocomposite with 20% of curaua fiber.

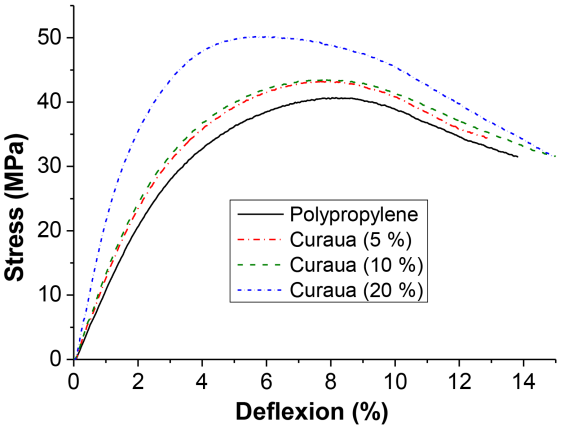


Figure 4. Average stress deflexion curves of polypropylene and biocomposites.

Figure 5 shows heat deflection temperature (HDT) values obtained for the biocomposites and polypropylene. Only 20% curaua fiber obtained a rise in HDT, increasing from 75.3 0176C (polypropylene) to 97 °C (increase of 28.8%).

This result is important, since it demonstrates that the use of curaua fiber improves the thermal stability of the composite, meaning it can be used in applications with higher temperatures. Jarukumjorn and Suppakarn[21] found a similar effect to that observed for the curaua fibers studied here, demonstrating that the addition of sisal fibers along with polypropylene P700J increases heat deflection temperature.

With respect to a possible industrial application, the results obtained for the biocomposite with 20% curaua fibers are also promising, since it can be used, for example, in the manufacture of containers for hot-filling pasteurization. However, if a sterilized product were to be used, a study with higher fiber percentages in the biocomposite would be needed.

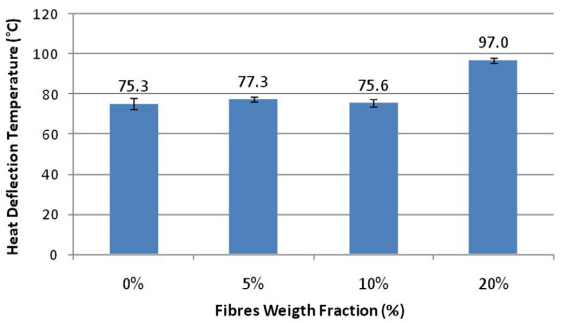


Figure 5. Heat deflection temperature of the curaua composites.

4. Conclusions

Based on the results obtained in the present study, the following conclusions can be drawn:

- The addition of curaua fibers in PP reduces the effect caused by thermal degradation of polypropylene during the extrusion process;
- In the three-point bend test the addition of curaua fiber had a greater effect on stiffness than on strength in the biocomposites;
- Only a 20% increase in curaua fibers had a significant effect on the mechanical properties analyzed, this was verified for both the tensile tests and for the three-point bending tests;
- In the HDT test the addition of curaua fibers increased the heat deflection temperature of the composite, improving its thermal stability and providing a quality material in high-temperature applications.

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