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Characterization and Evaluation of Employment in Rigid Packaging of Polypropylene Composites with Bamboo Fiber

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The packaging industry is the industrial segment that, historically, is one of the largest consumers of polymers, highlighting the great use of polypropylene. Seeking to reduce the consumption of non-renewable raw materials in packaging, this work aimed to study the use of bamboo fiber in polypropylene composites with 15wt% and 25wt% of fiber. Also, the mechanical and thermal properties were evaluated. The density and fluidity of the composites were compared with the virgin polymer. Regarding the density of the composites, it was observed that this was not significantly affected by the addition of fibers. In the melt flow index of the composites, it was observed that the fluidity of the composite with 25wt% bamboo fiber was reduced by more than 50%. The fluidity of the composite with 15wt% fiber has not undergone considerable change compared with the data of the virgin polymer. In tensile analysis, the only property that increased with adding fibers to the polymer was the modulus of elasticity. The impact resistance analysis showed that the composites significantly increased impact resistance and energy absorption. It was concluded that the composites of PP with bamboo fiber showed potential application in the packaging industry.

Keywords: *Polypropylene, Composites with natural fibers, Bamboo fibers, Composites, Packaging.*

1. Introduction

With the increase in production and use of polymers worldwide, ways have been sought to reduce the consumption of polymeric raw materials, which, for the most part, are produced from non-renewable sources. One proposal is to replace part of the polymeric resin with a material of natural origin from a renewable source which can act synergistically with the Polymer, such as bamboo fibers being of renewable origin. The replacement of part of the Polymer with these fibers reduces the environmental impact of consuming scarce natural resources used to produce the Polymer and reduces the volume of plastic material. Thus, studies on the impact of using these fibers in different segments of the industry that are large consumers of plastic materials, such as the packaging industry, are highlighted.

The packaging industry is the industrial segment that is one of the biggest consumers of polymers. The European demand for plastics in 2019 was 50.7 million tonnes. By far, packaging and building & construction represent the largest end-use markets in Europe, corresponding to 39.6% (packaging) and 20.4% (building & construction)[1]. In 2019, Brazil's worldwide production of thermoplastic resins and processed plastics was 8.2 million tons and 7.1 million tons, respectively. In 2018, in Brazil, among the sectors that consume processed plastics, 34.8% correspond to sectors that use plastics with a short life cycle, that is, up to one year, within which packages fall[2], showing the strength and size of the segment in which ecologically sound options raw materials would have an immediate impact. Among the most used plastic materials, polypropylene (PP) represented an expressive 19.4% of the demand consumed in 2019 in Europe and a fifth of the demand consumed in Brazil, in 2020, in stratification by types of polymers. These volumes consolidate PP and the mechanical 's position as one of the most representative commodities in the plastic materials production and consumption industry. Furthermore, polypropylene's low density, resistance to chemical products, surface hardness, and the cost of the monomer direct the use of this Polymer in different industry segments, including the packaging industry[1-4].

Natural fibers act as fillers in polymers because they are low-cost materials and, in many cases, in their isolated forms, they do not stand out for their mechanical properties. However, together with polymers, in the form of composites, they can help increase materials' mechanical properties. Therefore, the need to reduce the use of plastic materials through materials from renewable sources, without impacting its performance, with polymer composites containing natural fibers[5].

In this scenario, replacing percentages of polypropylene in the formulas of plastic materials with more ecologically correct alternatives would significantly impact the industry, giving greater visibility to these more sustainable materials. Bamboo fibers are materials that can be indicated due to the range of options in the Brazilian territory. In addition, an increase in demand for these fibers will mobilize an entire

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production chain, and they are already used as materials in the construction and manufacturing industry[6].

Bamboo is a material that presents anisotropy; its properties vary according to how its fibers are arranged. Despite being denser than the woods most used in the national market, bamboo surpasses the properties of the vast majority of them. Given many existing species, with varied morphological compositions and distinct properties between the types of bamboo, it is interesting to specify the type of bamboo and how it is disposed of when performing technical comparisons[7].

Bamboo in the form of fiber is used for structural packaging and transporting heavy items since the mechanical properties of bamboo fibers allow physical protection according to the size and shape of the product, which can be either rigid or semi-rigid packaging[8].

Bamboo fibers have provided some response in producing recyclable, biodegradable, and sustainable materials. For example, the natural fibers yield composites with high strength-to-weight ratios as a function of the best properties of each component. In addition, researchers have found sustainable high-end quality industrial products that can be generated from raw materials like bamboo fibers[9].

Short bamboo fiber reinforced polypropylene composites were prepared by incorporating various chemically modified bamboo fibers loadings. At 50% volume fraction of the extracted bamboo fiber in the composites, a considerable increase in mechanical properties like impact, flexural, tensile, and thermal behaviour like heat deflection temperature was observed[7].

With its natural agricultural potential, Brazil offers an optimistic scenario for bamboo production, with a favorable climate and soil for the development of the plant, which has been studied by several researchers in Brazil and other countries. Furthermore, bamboo can be among the plant species that most contribute to sustainable development, adding to its diversity of applications (Associação Brasileira do Bambu, BambuBR). On September 9, 2011, Law No. 12,484 was published in the Federal Official Gazette, which provides for the National Policy for Incentives to Sustainable Management and Bamboo Cultivation, focusing on the development of bamboo culture in Brazil through government actions and private enterprises, seeking to value bamboo as an agro-forestry-cultural product capable of meeting ecological, economic, social and cultural needs.

Due to the increase in the environmental appeal of environmentally correct products, the aim is to reduce the consumption of raw materials using returnable packaging. Returnable and rigid packaging examples are transport boxes, such as plastic boxes used in street markets and supermarkets. Although the initial investment is higher than cardboard packaging, plastic boxes are distinguished by durability and mechanical integrity, ensuring protection for transported items[8,10].

Seeking to reduce the consumption of non-renewable raw materials and considering that the packaging industry is one of the segments that consumes the most polymeric raw materials in the world, the objective of this work was to study the use of bamboo fiber in composite materials. As a result, polypropylene composites with 15wt% and 25wt% bamboo fiber were produced, and the composites' mechanical properties, density, and fluidity were compared to the virgin Polymer. Furthermore, analysis of the composites was carried out in a Scanning Electron Microscope, and the application of composites obtained in the area of rigid packaging was analyzed. Finally, the injection of specimens and the tests to characterize their mechanical properties were conducted in the facilities of the Celanese do Brasil Ltda industry, located in Suzano, São Paulo state.

2. Materials and Methods

2.1. Materials

The polypropylene used was the trade name H 502HC from the Brasken industry, whose properties are shown in Table 1.

Bamboo short fibers were provided from a bamboo plantation farm in Tatuí, São Paulo state.

According to Nabinejad et al.[11], bamboo has a hydrophilic nature with high moisture absorption. The fibers were, therefore, oven-dried at 80°C for 24 hours. Figure 1 shows bamboo fibers after drying in an oven. After drying, the fibers were cut manually with scissors to homogenize the length.

2.2. Preparation of composites

Two polypropylene composites with different bamboo fiber mass percentages, 15wt% and 25wt%, were prepared. First, the fibers were manually mixed with virgin polypropylene, and the composites were obtained in a high-speed mixer,

Table 1. Properties of polypropylene H 502Hc according to the manufacturer.

Feature	Method	Units	Values
Melt Flow Rate (230 °C/2.16 kg)	D 1238	g/10 min	3.3
Density	D 792	g/cm^3	0.905
Flexural Modulus – 1% Secant	D 790	Mpa	1950
Tensile Strength at Yield	D 638	Mpa	38
Tensile Elongation at Yield	D 638	%	7
Rockwell Hardness (R Scale)	D 785	-	108
Notched Izod Impact Strength at 23 °C	D 256	J/m	25
Deflection Temperature under Load at 0.455 Mpa	D 648	°C	130
Deflection Temperature under Load at 1.820 Mpa	D 648	°C	68
Vicat Softening Temperature at 10 N	D 1525	°C	160

Source: Brasken Ltda

manufacturer M.H. Tecnologia, by incorporating the fibers into virgin polypropylene. After closing the chamber, the rotor was activated, homogenising the materials inside by shearing and friction. As a result, molten masses composed of Polymer and bamboo fiber were obtained, which, after cooling, generated solid agglomerates. These agglomerates were transformed into pellets in a knife mill Model MGHS 4/180, manufacturer SEIBT. Figure 2 shows the high-speed mixer's PP/fiber mixtures before and after homogenization.

2.3. Preparation of specimens

The specimens were moulded in an Arburg 420 C Golden Edtion injection molding machine. For comparative analysis, specimens were prepared of PP/bamboo fiber with 15wt% and 25wt% by mass of fiber and virgin PP.

Table 2 shows the temperature and pressure conditions for injecting virgin PP and the composite with 15wt% fiber.

In processing the composite with 25wt% fiber, excessive material leakage was observed in the injection molding machine nozzle, causing the mold injection channel to clog. Therefore, the temperature values were reduced, as shown in Table 3. As a result, the composite injection with 25wt% bamboo fiber presented more difficulty processing with a significant material loss.

Figure 1. Bamboo fibers after drying in an oven.

2.4. Tests and characterization

All tests were carried out with composites of PP with 15wt% and 25wt% of fiber and virgin PP.

Fluidity Index: fluidity analyzes were performed in a Tinus Olsen Plastometer (ASTM D1238-10)[12].

Density: the tests were determined with the aid of a Shimadzu scale model Aw20 with a precision of 4 decimal places (ASTM D792)[13].

Mechanical properties: Impact Resistance: the tests were carried out in INSTRON brand equipment, with the unnotched

Table 2. Parameters used in the injection process of virgin PP and PP/15wt% bamboo fiber.

Injection nozzle temperature	235 ° C
Temperature in zone 4	230 ° C
Temperature in zone 3	230 ° C
Temperature in zone 2	225 ° C
Temperature in zone 1	180 ° C
Hold pressure	20 bar
Injection pressure	400 bar
Injection speed	145 mm/s

Table 3. Parameters used in the PP/25wt% bamboo fiber injection process.

Injection nozzle temperature	225 ° C
Temperature in zone 4	225 ° C
Temperature in zone 3	220 ° C
Temperature in zone 2	220 ° C
Temperature in zone 1	180 ° C
Hold pressure	20 bar
Injection pressure	400 bar
Injection speed	145 mm/s

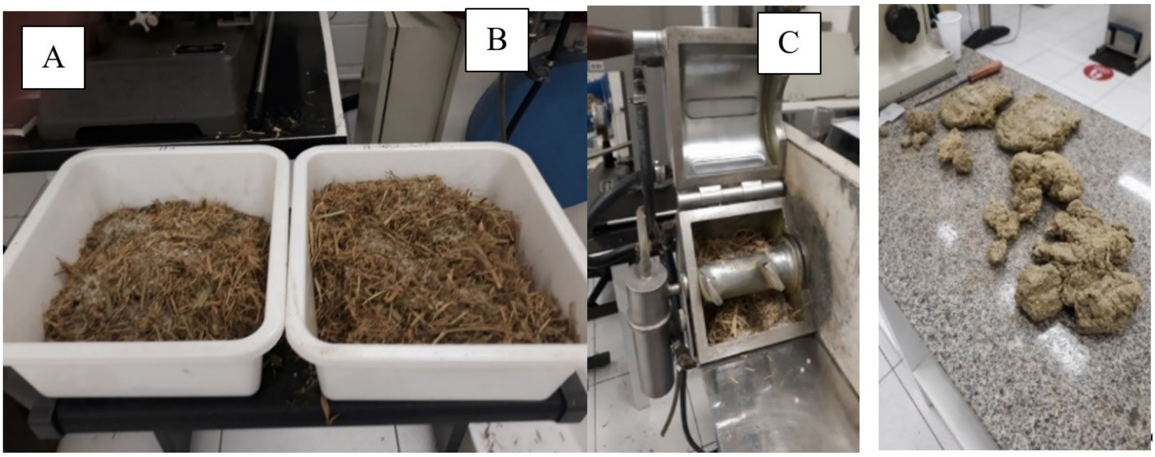

Figure 2. PP/fiber blends (A), high-speed mixer (B) and PP/fiber composite obtained in the high-speed mixer (C).

specimens and the notched specimens (ASTM D256)[14]. Ten specimens were tested for each test for all materials.

Three-point bending: the tests were performed in INSTRON brand equipment, 3367 series (ASTM D790)[15].

Tensile tests were performed in INSTRON brand equipment, 3367 series (ASTM D638-14)[16].

Analyzes in Scanning Electron Microscope (SEM): SEM images of the composites were obtained using a JEOL JSM 6510 microscope.

3. Results and Discussion

The results of the analysis of the fluidity indexes of the composite materials and natural Polymer are shown in Table 4. Virgin PP presented expected results according to the manufacturer's specifications. There was a similarity in fluidity results between virgin PP and the composite with 15wt% bamboo fiber, showing that adding this percentage by mass does not affect the mobility of the polymer chains in the composite. The difference between the melt flow index of this composite based on virgin polypropylene was 2.3%.

The composite with 25wt% fiber presented a reduction in the melt flow index of 55%. In addition, this bamboo fiber mass percentage significantly altered this material property, indicating that the fiber hinders the mobility of polymer macromolecules in the composite.

Table 5 shows the density values for both composites and virgin PP. The composite with 15wt% fiber showed an increase in density of approximately 2% compared to virgin PP, and the composite with 25wt% fiber increased by approximately 6.5%. Again, it is observed that the natural fiber did not significantly impact this property of the Polymer.

Table 4. Fluidity index results of composites and virgin PP.

Sample	Flow values (g/10 min)
PP virgin	3.42
PP 15% fiber	3.34
PP 25% fiber	1.54

Table 5. Density values of composites and virgin PP.

Sample	Density values (g/cm^3)
PP virgin	0.92
PP 15% fiber	0.94
PP 25% fiber	0.98

Tables 6 and 7 show the results of the impact resistance tests on unnotched and notched specimens, respectively.

Virgin polypropylene has higher values than composites. The reason is that the polymer matrix absorbs more impact and disperses energy. Olefins can present a ductile behaviour to impact a wide range of temperatures[17]. The samples made with PP with 15wt% bamboo fiber had 29% higher impact resistance properties than the composite made with 25wt% by mass of bamboo fiber. In this composite, the amount of fiber is more significant. As a result, there is a considerable reduction in mechanical property. The fibers are like large particles that can initiate failure mechanisms in the polymer chain, leading to failures during applied loads[18].

The composites' behaviour and virgin polypropylene showed a significant variation between the impact tests with and without the notch, as observed in Tables 6 and 7. In addition, the properties of composites with 15wt% and 25wt% of bamboo fiber obtained in the tests of notched impact values greater than 100% (impact resistance) compared to material without the addition of natural fiber tested with the notch.

It was also observed that the differences between the results of composites with 25wt% of fiber addition showed higher values of energy absorption and impact resistance; that is, the increase in bamboo fiber content in the Polymer was shown to be positive for the properties evaluated in the test. However, considering that the increase in properties was less than 10% between the composites, it can be considered that the two composites have similar impact resistance properties.

Table 8 shows the results of the 3-point bending strength tests for composites and virgin PP.

Virgin PP presented higher flexural strength and flexural modulus properties than the composite with 15wt% fiber content. However, it did not present a greater flexural modulus than the composite with 25wt% fiber.

In the comparison between virgin PP and the composite with 25wt% fiber, it is noteworthy that the modulus of the composite is slightly higher than the modulus of virgin PP, around 3%. The fibres' heterogeneity and their polymer arrangement may have affected this property. However, the difference can be considered irrelevant, showing no negative impact on the flexural modulus after adding 25wt% bamboo fiber to polypropylene.

The graphs obtained in the 3-point bending tests can be seen in Figures 3, 4, and 5.

Table 6. Impact resistance results, unnotched specimens.

Sample	A.B.S. (%) average	Re (kJ/m^2) average	Energy (J) average
PP virgin	96.42 ± 3.52	120.54 ± 4.40	4.821 ± 0.176
PP 15% fiber	20.40 ± 4.04	25.51 ± 5.07	1.020 ± 0.203
PP 25% fiber	14.510 ± 3.022	18.15 ± 3.78	0.151 ± 0.150

Table 7. Impact resistance results, notched specimens.

Sample	A.B.S. (%) average	Re (kJ/m^2) average	Energy (J) average
PP virgin	14.84 ± 1.91	2.32 ± 0.30	0.074 ± 0.010
PP 15wt% fiber	31.80 ± 2.98	4.98 ± 0.47	0.160 ± 0.015
PP 25wt% fiber	34.54 ± 3.05	5.41 ± 0.47	0.151 ± 0.150

In the analysis of the bending tests, the composite with 25wt% fiber content had 7% higher flexural modulus values than the composite with 15wt% fiber content. However, observing the data in Table 8 and Figures 3, 4, and 5, it is possible to state that composites have similar properties concerning bending strength.

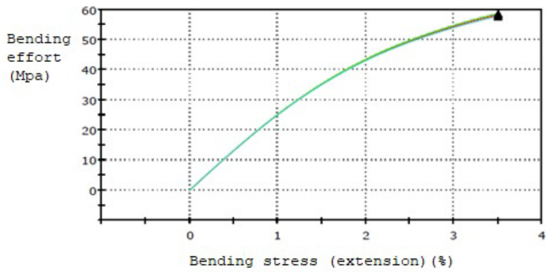

Figure 3. 3-point bending test for virgin PP.

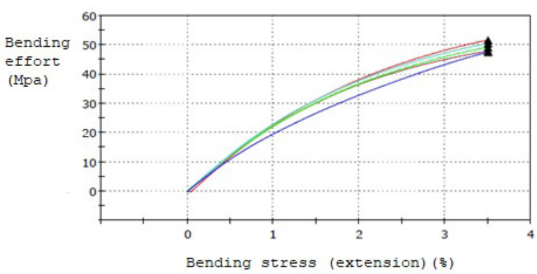

Figure 4. 3-point bending test for PP 15wt% fiber composite.

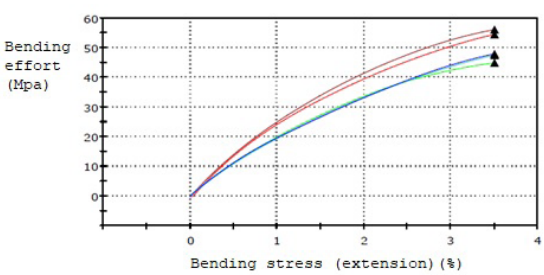

Figure 5. 3-point bending test for the composite PP 25% fiber.

Table 8. 3-point bending strength results.

Sample	bending strength	flexural modulus
PP virgin	58.20 ± 0.34	2580.0 ± 374.9
PP 15% fiber	49.3 ± 1.5	2486.0 ± 130.6
PP 25% fiber	50.20 ± 4.82	2670.0 ± 20.0

Table 9. Tensile test results.

Sample	Modulus of elasticity (MPa)	Tensile strength (MPa)	Maximum strain (%)
PP virgin	2341.85 ± 30.42	41.59 ± 0.12	5.64 ± 0.06
PP 15wt% fiber	2566.09 ± 96.39	32.01 ± 0.53	4.31 ± 0.22
PP 25wt% fiber	2826.81 ± 123.54	31.04 ± 0.97	3.38 ± 0.14

Table 9 shows the results of the tensile tests for virgin PP and composites.

The composites presented lower maximum tension and elongation values than virgin polypropylene. Compared to virgin PP, the composite with 25wt% fiber presented an increase of 20% in the modulus of elasticity, and the composite with 15wt% fiber presented an increase of approximately 9.5%.

It can be seen that the dispersed phase of composites composed of bamboo fibers provided an increase in the modulus of elasticity. As Fazita et al.[19] mentioned, it is possible to observe an increase in the modulus in composites that use fibers of natural origin in synthetic/polymeric matrix. The dispersed phase acts to increase some mechanical properties of the composite.

The graphs of the tensile tests (strain X strain) of composites and virgin PP can be seen in Figures 6, 7 and 8.

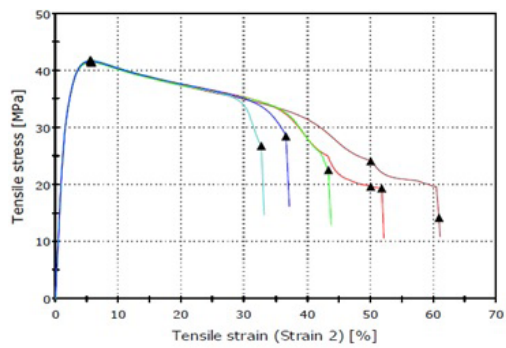

Figure 6. Tensile test for virgin PP.

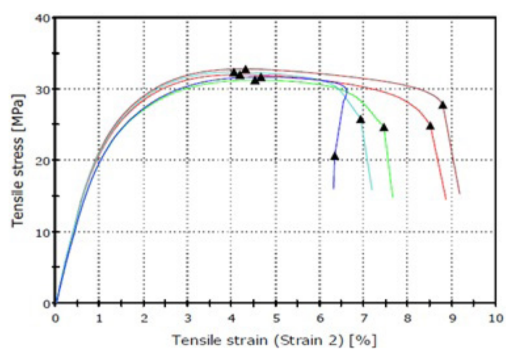

Figure 7. Tensile test for the composite PP 15wt% fiber.

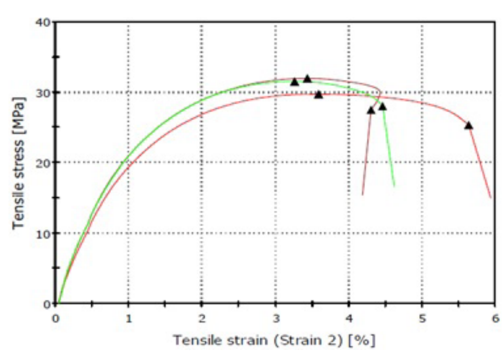

Figure 8. Tensile test for composite PP 25wt% fiber.

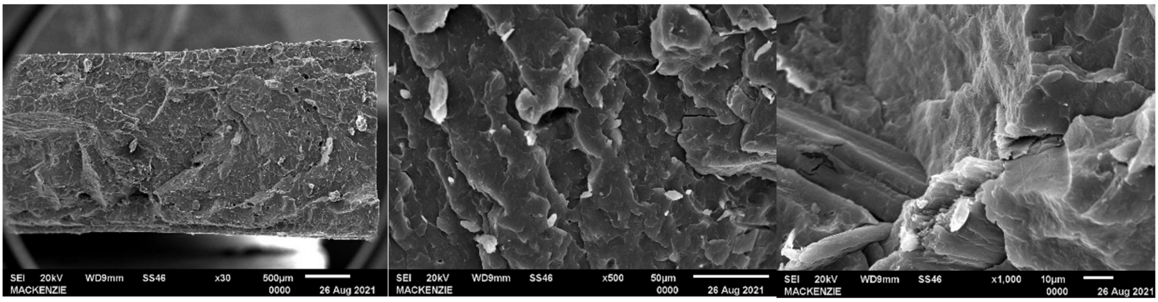

Figure 9. SEM image of the PP with 15wt% fiber (30, 500, and 1000 times magnification).

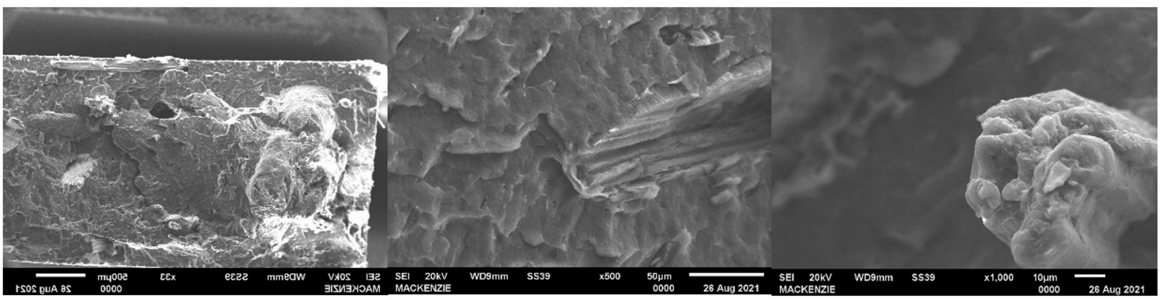

Figure 10. SEM image of PP with 25wt% fiber (33, 500, and 1000 times magnification).

The plastic phase for virgin PP is quite accentuated, unlike the results observed for composites.

The maximum tension of virgin PP is the highest of the three materials. For example, the composite with 15wt% bamboo fiber showed tension and maximum elongation values higher than those with 25% fiber. However, the composite with the highest fiber percentage had a higher modulus of elasticity than other materials.

According to Del Pino et al.[20], fiber content is the main factor affecting biocomposites' tensile strength. For example, epoxy resin composite with 25wt% curauá fiber, treated with NaOH, showed a 3-fold increase in tensile strength compared to the pure epoxy polymer.

PP composites analyses with 15wt% and 25wt% of fiber were performed using Scanning Electron Microscope (S.E.M.), shown in Figures 9 and 10.

Analyzing the images in Figures 9 and 10, it is observed that the fibres were adhesive to the Polymer. In addition, a small amount of voids between fiber and Polymer is also observed.

4. Conclusion

This research work was carried out to obtain polymeric composites formed by virgin polypropylene with 15wt% and 25wt% of bamboo fiber content by mass and to compare their mechanical and rheological properties with the properties of virgin polypropylene H 502 HC by Brasken Brand, aiming at the potential application of composites in the rigid packaging industry. The main objective was to obtain more sustainable packaging, reducing the amount of synthetic Polymer in the material's formulation.

In the Fluidity tests, it was possible to observe that the PP composite with 15wt% bamboo fiber showed similarity with the virgin PP, showing that the dispersed phase of the composite did not significantly impact this property. However, this result was not observed in the composite with 25wt% bamboo fiber, in which there was a significant decrease in fluidity.

Difficulties were observed in injecting the composite with 25wt% bamboo fiber. The high fiber content in the composite generated excess gases and leakage at the injector nozzle, indicating that the high fiber content directly impacted the injection phase, needing to reduce the temperature profile.

The results of densities of the composites did not show significant differences. Therefore, the composites will not present negative results in applications where weight can be an obstacle.

The impact tests without notch confirmed that the virgin Polymer had more significant properties than the composites under these conditions. However, when performing the test with the notch, it was possible to observe that the composites showed a significant increase in impact resistance and energy absorption, which proved to be the most promising for the application of composites in the manufacture of rigid packaging such as boxes.

The 3-point bending test showed that the composites had lower bending properties than virgin polymer. Although concerning the tensile tests, as the virgin Polymer had a more accentuated plastic behavior, only the modulus of elasticity of the composites showed an increase in values. The composite with 25wt% of fiber presented the highest values in the modulus of elasticity.

According to the results obtained, PP composites with bamboo fiber showed application potential to reduce the consumption of raw materials from non-renewable sources. However, it must be considered that there was difficulty in processing the composite with a high bamboo fiber content (25%).

For future work, thermal characterizations of composites and formulation with different contents are recommended to verify the percentage by mass of bamboo fiber that presents interesting properties for use. Another point to go further is the comparison of raw fiber, as used in this work, and fiber after chemical treatment to improve compatibility with polypropylene. The alkaline treatment had shown an effective increase in adhesiveness between phases, allowing composites with high tensile strength to be obtained.

5. Acknowledgments

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6. References

1. Plastics Europe. Plastics – the Facts 2020: an analysis of European plastics production, demand and waste data [Internet]. 2020 [cited 2022 July 12]. Available from: https://plasticseurope.org
2. ABIPLAST: Associação Brasileira da Indústria do Plástico. Perfil 2020: a indústria de transformação e reciclagem de plástico no Brasil [Internet]. 2020 [cited 2022 July 12]. Available from: http://file.abiplast.org.br/download/perfil_2011.pdf
3. Sarfat MS, Setyaningsih D, Fahma F, Indrasti NS. Potential of polypropylene nanocomposite reinforced with cellulose nanofiber from oil palm empty fruit bunch as sustainable packaging: a review. IOP Conf Ser Earth Environ Sci. 2021;749(1):012044. http://dx.doi.org/10.1088/1755-1315/749/1/012044.
4. Hashemi J, Smith WF. Foundations of materials science and engineering. 6th ed. New York: McGraw-Hill Education; 2018.
5. Espinach FX. Advances in natural fibers and polymers. Materials. 2021;14(10):2607. http://dx.doi.org/10.3390/ma14102607.
6. Md Shah AU, Sultan MTH, Jawaid M, Cardona F, Abu Talib AR. A review on the tensile properties of bamboo fiber reinforced polymer composites. BioResources. 2016;11(4):10654-76. http://dx.doi.org/10.15376/biores.11.4.Shah.
7. Chattopadhyay SK, Khandal RK, Uppaluri R, Ghoshal AK. Bamboo fiber reinforced polypropylene composites and their mechanical, thermal, and morphological properties. J Appl Polym Sci. 2011;119(3):1619-26. http://dx.doi.org/10.1002/app.32826.
8. Alavi S, Thomas S, Sandeep KP, Kalarikkal N, Varghese J, Yaragalla S. Polymers for packaging applications. 1st ed. Oakville: Apple Academic Press Inc.; 2014.
9. Muhammad A, Rahman MR, Hamdan S, Sanaullah K. Recent developments in bamboo fiber-based composites: a review. Polym Bull. 2019;76(5):2655-82. http://dx.doi.org/10.1007/s00289-018-2493-9.
10. Leppänen S. Requirements for environmentally sustainable packaging in the forest products value [thesis]. Helsinki: Aalto University; 2021 [cited 2022 July 12]. Available from: https://aaltodoc.aalto.fi/handle/123456789/108217
11. Nabinejad O, Debnath S, Beh JK, Ali MY. Mechanical performance and moisture absorption of unidirectional bamboo fiber polyester composite. Mater Sci Forum. 2018;911:88-94. http://dx.doi.org/10.4028/www.scientific.net/MSF.911.88.
12. ASTM: American Society for Testing and Materials. ASTM D1238-10: standard test method for melt flow rates of thermoplastics by extrusion plastometer. West Conshohocken: ASTM International; 2010.
13. ASTM: American Society for Testing and Materials. ASTM D792-20: standard test methods for density and specific gravity (relative density) of plastics by displacement. West Conshohocken: ASTM International; 2020.
14. ASTM: American Society for Testing and Materials. ASTM D256-10: standard test methods for determining the izod pendulum impact resistance of plastics. West Conshohocken: ASTM International; 2018.
15. ASTM: American Society for Testing and Materials. ASTM D790: standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials. West Conshohocken: ASTM International; 2010.
16. ASTM: American Society for Testing and Materials. ASTM 638-14: standard test method for tensile properties of plastics. West Conshohocken: ASTM International; 2014.
17. Calafut T, Maier C. Polypropylene: the definitive user's guide and databook [Internet]. Norwich: Plastics Design Library; 1998 [cited 2022 July 12]. Available from: https://lib.ugent.be/catalog/ebk01:111056552542894
18. Bakar MBA, Ishak ZAM, Taib RM, Rozman HD, Jani SM. Flammability and mechanical properties of wood flour-filled polypropylene composites. J Appl Polym Sci. 2010;116:2714-22. http://dx.doi.org/10.1002/app.31791.
19. Fazita NMR, Johary N, Abdul Khalil HPS, Norazli N, Azniwati AA, Mohamad Haafiz MK. Parameter optimization ***via*** the Taguchi method to improve the mechanical properties of bamboo particle reinforced polylactic acid composites. BioResources. 2021;16(1):1914-39. http://dx.doi.org/10.15376/biores.16.1.1914-1939.
20. Del Pino GG, Bezazi A, Boumediri H, Kieling AC, Garcia SD, Torres AR, et al. Optimal tensile properties of biocomposites made of treated Amazonian Curauá fibres using taguchi method. Mater Res. 2021;24(2, Suppl. 2):e20210326. http://dx.doi.org/10.1590/1980-5373-mr-2021-0326.