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Viabilities for obtaining, manufacturing and applying composites using bamboo powders and ophthalmic lens waste

Viabilidades para obtenção, fabricação e aplicação de compósitos usando pó de bambu e resíduos de lentes oftálmicas

Viabilidad de obtener, fabricar y aplicar composites utilizando polvos de bambú y lentes oftálmicos de desecho

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Abstract

The objective of this research was to obtain composites using petioles bamboo and ophthalmic lens waste powders and polyester resin. Such materials have no defined application, they are produced in large quantities and their waste is discarded irregularly in landfills. Bamboo and ophthalmic lens rejects powders were produced, with particle sizes of 2.07 mm and 1.14 mm, respectively. Preliminary tests were carried out to determine the maximum quantities of each material to be mixed with the polyester resin matrix, in order to guarantee the good processability of the new material produced. The mass quantities used were 10 and 15%

bamboo, 15 and 40% tailings and a hybrid composition with 5% bamboo and 20% tailings, to obtain the desired composites. The composite plates were manufactured by the cold compression wet molding process in closed mold. Several tests were carried out to characterize the composites that were produced. It was found a decrease in the mechanical strength of the composite in comparison to the matrix, concluding that the bamboo powders and ophthalmic lens waste had a filling load function in the composites produced. The most expressive result of the composites was in the impact resistance, corresponding to 0.55 J/cm2 for OLWP 40% higher in 39.6% in relation to the polyester resin matrix. As a practical application, table and bench tops were manufactured with the most economically and ecologically viable composite, 40% OLWP.

Keywords: Composites; Bamboo and ophthalmic lens waste powders; Polyester resin; Environmental sustainability.

Resumo

O objetivo desta pesquisa foi obter compósitos utilizando pecíolos de bambu e pós de resíduos de lentes oftálmicas e resina de poliéster. Esses materiais não têm aplicação definida, são produzidos em grandes quantidades e seus resíduos são descartados irregularmente em aterros sanitários. Foram produzidos pós de bambu e rejeitos de lentes oftálmicas, com granulometria de 2,07 mm e 1,14 mm, respectivamente. Testes preliminares foram realizados para determinar as quantidades máximas de cada material a ser misturado à matriz de resina de poliéster, a fim de garantir a boa processabilidade do novo material produzido. As quantidades de massa utilizadas foram 10 e 15% de bambu, 15 e 40% de rejeitos e uma composição híbrida com 5% de bambu e 20% de rejeitos, para obtenção dos compósitos desejados. As placas compostas foram fabricadas pelo processo de moldagem por compressão a frio em molde fechado. Vários testes foram realizados para caracterizar os compósitos produzidos. Foi constatado um decréscimo na resistência mecânica do compósito em relação à matriz, concluindo que os pós de bambu e os resíduos de lentes oftálmicas tiveram função de carga de enchimento nos compósitos produzidos. O resultado mais expressivo dos compósitos foi na resistência ao impacto, correspondendo a 0,55 J / cm2 para OLWP 40% superior em 39,6% em relação à matriz de resina poliéster. Como aplicação prática, tampos de mesa e bancada foram fabricados com o composto mais econômica e ecologicamente viável, 40% OLWP.

Palavras-chave: Compósitos; Pós de resíduos de bambu e lentes oftálmicas; Resina de poliéster; Sustentabilidade ambiental.

Resumen

El objetivo de esta investigación fue obtener composites utilizando pecíolos de bambú y polvos de residuo de lentes oftálmicos y resina de poliéster. Estos materiales no tienen una aplicación definida, se producen en grandes cantidades y sus residuos se descartan de forma irregular en vertederos. Se produjeron polvos de bambú y desechos de lentes oftálmicos, con un tamaño de partícula de 2,07 mm y 1,14 mm, respectivamente. Se realizaron pruebas preliminares para determinar las cantidades máximas de cada material a mezclar con la matriz de resina de poliéster, con el fin de garantizar la buena procesabilidad del nuevo material producido. Las cantidades de masa utilizadas fueron 10 y 15% de bambú, 15 y 40% de relaves y una composición híbrida con 5% de bambú y 20% de relaves, para obtener los composites deseados. Las placas compuestas se fabricaron mediante el proceso de moldeo por compresión en frío en un molde cerrado. Se llevaron a cabo varias pruebas para caracterizar los composites producidos. Se encontró una disminución en la resistencia mecánica del composite en relación a la matriz, concluyendo que los polvos de bambú y los residuos de lentes oftálmicos tenían una función de carga de llenado en los composites producidos. El resultado más expresivo de los composites fue la resistencia al impacto, correspondiente a 0,55 J / cm2 para OLWP 40% superior en 39,6% en relación a la matriz de resina de poliéster. Como aplicación práctica, los tableros de mesa y de banco se fabricaron con el compuesto más económico y ecológicamente viable, 40% OLWP.

Palabras clave: Composicion; Polvos de residuos de bambú y lentes oftálmicas; Resina de poliester; Sostenibilidad del medio ambiente.

1. Introduction

Compounds are a great tool for the development of new materials, reusing materials that were previously deposited in landfills and dumps, such as expanded polystyrene (EPS), polypropylene, PVC, polyethylene, marble, granite, steel and wood powder, seeking, with a union of two or more products, new properties and applications ((Meira de Souza, Santos, Cavalcante, Meira de Souza, & Costa, 2017), (Gomes, De Souza, De Souza Filho, & Santos, 2015), (Souza, 2019), (Oliveira, 2017), (La Mantia & Morreale, 2011), (Costa, 2017) and (Pech-May et al., 2018)).

Bamboo is already widely used in nature for home building and in fibers for the production of compounds, but it presents the disadvantage of being little miscible in the matrix resins ((Guimarães Junior, Novack, & Botaro, 2010) and (Taborda-Rios, Cañas-Mendoza, &

Tristancho-Reyes, 2017)). Bamboo is a useful floral product for various segments, from handicrafts to civil construction ((K. Buckingham et al., 2011), (K. C. Buckingham, Wu, & Lou, 2014) and (Yuen, Fung, & Ziegler, 2017)) describes that the world area of bamboo was estimated at 31.3 million hectares in 21 countries, with China and India being the countries that use it the most. In Brazil, about 258 species were cataloged, with a reserve of 18 million hectares on the border between Peru and Brazil ((INBAR, 2018), (Agricultura, 2015), (Mota, Pereira, Damacena, & Santos, 2017), (Rosa, Paes, De Alcântara Segundinho, Vidaurre, & De Oliveira, 2016), (Ribeiro et al., 2006) and (Torres, 2015)).

The rejects of ophthalmic lenses come from several operations, from the raw lens to the lens placed on the glasses with thinning and finishing processes that generate waste. (Cury & Saraiva, 2018) showed that in one year 5.5 million lenses are produced in a French factory installed in the industrial pole of Manaus. These residues are a mixture of various types of plastics, thermoplastics and thermosets, used for the production of ophthalmic lenses, with emphasis on polymethylmethacrylate (acrylic), polycarbonate, glass and other plastics used in the production of resin lenses.

The use of bamboo to obtain composite materials is widely presented in the literature, with supremacy for fibers, as a structural reinforcement. For ophthalmic lens waste, attempts were made to find articles for obtaining composite materials without success, which demonstrated that the use of these residues was an unprecedented study.

The use of plastics present in the used waste is present in the literature of composites, however in the matrix function, highlighting acrylic and polycarbonate, which differs from our study that uses waste as a load giving them an ecofriendly destination. The following are some studies on the use of bamboo in fibers or particulates, with only one using polyester resin, with bamboo in fiber, and some more recent studies on the production of ophthalmic lens waste.

(Wang et al., 2019) demonstrated the feasibility of obtaining and manufacturing a composite using bamboo powder and isotactic polybutylene-1 polymer (iBP) with the addition of Silane (KH570).

(Taborda-Rios et al., 2017) characterized composites with bamboo fibers and polyester resin, for three mass proportions, demonstrating a decrease in tensile strength and an increase in the elasticity modulus, proportional to the amount of fibers.

(Bahari & Krause, 2016) compared the bamboo/PVC and wood/PVC composites and proved the superiority of bamboo/PVC over wood/PVC.

(Chiu et al., 2016) used bamboo fiber to manufacture a composite with urethane diacrylate matrix for the prototyping segment.

(Kajikawa & Iizuka, 2015) studied obtaining wood-plastic composites (WPC) with bamboo powder through the injection molding process, proving their feasibility.

(Zhou, Yu, & Chen, 2015) studied a composite with bamboo powder and polypropylene, prioritizing the analysis of the bond between matrix and water absorption.

(Kharaev, Bazheva, & Chaika, 2007) presented an article on the use of polycarbonate in composites, highlighting its diversity due to its transparency properties, high resistance to acids and mechanical effects, high thermal resistance, good electrical insulation properties and biological inertia.

(Kausar, 2018) highlighted the importance of the thermoplastic polycarbonate polymer for its high performance in the construction, automotive, aerospace, computer, power generation and telecommunications industries, however it highlighted the limitations of its strong hydrophobicity and high viscosity in fusion.

(Bao, Li, Fu, & Chen, 2016) demonstrated that polymethyl-methacrylate (acrylic) plays an important role in many industrial processes such as the production of synthetic rubber, surface coatings, adhesives, additives in paper and textiles and many other products, which are currently being sought. alternatives for their production with renewable resources to replace oil-based sources.

(Ruivinho, 2010) estimated, for Portugal, a production of 221.6 tonnes of dry residues, with 70.6 tonnes of polycarbonate, a material with greater mechanical resistance than other constituents of ophthalmic lenses and 151 tonnes of other polymeric resin residues.

(Gomes, Godoi, De Souza, & De Souza, 2017) showed that an ophthalmic lens industry in Paraíba generated 1300 kg of type II waste, containing plastics from the manufacture of the lenses and the surfacing process, machining the material for the proper gradation. Initially, it was thought about the reuse of lens residues through the melting of the tailings powder, but it was realized that it was a mixture of materials, thermoplastic and thermoset, making it unfeasible.

The objective of this research was to obtain composites using petioles bamboo and ophthalmic lens waste powders and polyester resin. After obtaining the bamboo and ophthalmic lens rejects powders, we started to produce the composites: C1 and C2 - polyester resin + bamboo powder (PR + BP); C3 and C4 - polyester resin + ophthalmic lens waste powder (RP + OLWP) and CH5 hybrid - polyester resin + ophthalmic lens waste powder + bamboo powder (RP + BP + OLWP). In the process of obtaining the composite, the maximum proportions, in mass of the powders in relation to the resins were defined. Depending on the saturation levels, difficulty in manual processing of the mixture, the composites to be studied were chosen, in addition to the matrix.

In the characterization process, mechanical resistance to traction, flexion and impact, apparent density, water absorption capacity, thermal properties of conductivity, diffusivity, resistivity and specific volumetric heat and thermogravimetric analysis, a microscopic analysis and resistance to aging were studied.

2. Materials and Methods

This study is a research classified as applied, regarding the purpose; quantitative, in relation to the approach; hypothetical-deductive, in relation to the method and experimental, as to the procedures.

2.1. Materials

Polyester resin (PR) was chosen as matrix due to its lower acquisition cost, easy processability at low temperatures, reduced risk of handling and good aesthetics. The bamboo powder of the species Bambusa Vulgaris Schrad (BP) and the powder of ophthalmic lens reject (OLWP) were used as fillers. The composites obtained were characterized for two configurations: non-hybrid (PR + BP and PR + OLWP) and hybrid (PR + BP + OLWP).

The bamboo powder was obtained by cutting the stems of the dry sticks using a circular saw. The dust generated by the cutting operation was collected for further processing on a metal sieve. After sifting the obtained powder, the weighing and storage step was carried out in plastic containers to reduce the possibility of increasing the moisture in the material.

Ophthalmic lens waste was collected in a lens processing laboratory that performs the cutting and treatment processes. More than 10 kilograms of material were collected, in the form of mud, as the lenses were cut in a machine that used water to decrease the temperature, minimizing the appearance of cracks. To eliminate water, the waste was placed in a solar oven for two hours under good solarimetric conditions. The powders used to obtain the composites, BP and OLWP.

2.2. Methods

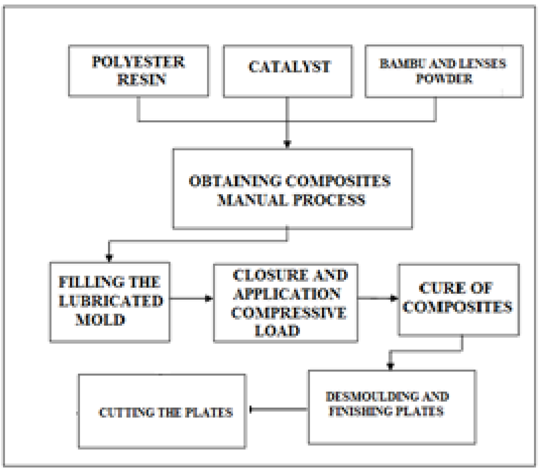
A granulometric analysis following the Norm (NBR NM 248, 2018) was performed, determining that the bamboo and tailings powders had particle sizes of 2.07 mm and 1.14 mm respectively. After processing the powders, the composites were obtained through mixing with polyester resin (PR).

The mass amounts of resin and powders were determined, that is, the amount of powder that would provide good processability through the manual mixing process. The fluency of the composites was also tested in the mold spill. Experimentally, a maximum of 15% for BP, 40% for OLWP and 5% of BP and 20% of OLWP forming the hybrid compound. It was noticed that using higher percentages than the ones described the processability of the composites was compromised, as there were difficulties in homogenizing the material and in its fluency when it was deposited in the molds.

After defining the maximum mass percentage of the powders in the resin, formulations were chosen to obtain the specimens of each composite for further characterization: Resin - 1.0 PR + 0.0 BP + 0.0 OLWP; C1 and C2 - 1.0 PR + 0.10 BP and 1.0 PR + 0.15 BP; C3 and C4 - 1.0 PR + 0.15 OLWP and 1.0 PR + 0.40 OLWP and CH5 - 1.0 PR + 0.05 BP + 0.20 OLWP.

The formulation with only polyester resin was chosen for comparison in relation to composites. The flowchart in Figure 1 shows the main stages of the processes for obtaining and manufacturing the specimens of the PR and BP and OLWP composites for the characterization tests.

Figure 1. Steps in the process of obtaining and manufacturing composite plates to remove samples for characterization tests.



Source: Authors.

For the manufacture of composite plates for mechanical tests, two metal molds with dimensions according to specific standards were used. Mold 01 for traction and flexion, with 200 mm X 200 mm X 8 mm and mold 02 for impact with 120 mm X 120 mm X 10 mm. For the thermal tests, the 03 metal mold with 50 mm internal diameter and 50 mm height was used. For the compression of the molds, a hydraulic press with a capacity of up to 15 tons was used.

The volume of the molds defined the masses of resin and BP and OLWP using a precision scale. The manufacturing process used to manufacture the composite plates was that of closed molding by cold wet compression. Then, the carnauba wax was applied to the mold and it was expected to dry. Soon after, the resin, BP and OLWP and the catalyst were weighed.

In a one liter disposable container 400g of resin was added to mold 01, 200g to mold 02 and 150g to mold 03, adding 2% by mass of the catalyst. This solution was mixed manually and then the powders were added in the proportions of each composition.

After homogenization, the composite was poured into the molds, filling them. There was a 10 to 15 minutes wait until the mixture reached the ideal viscosity to close the molds and apply a two-ton compressive load. After 24 hours, the plates were demolded. Finally, the burrs and protrusions from the compression process were removed using sandpaper, and the specimens were cut with a bench-top electric saw, meeting the measures required by each standard.

The characterization of composites comprised tensile, bending, impact, bulk density, water absorption, thermal properties, aging, thermogravimetric analysis (TGA) and scanning electrical microscopy (SEM) tests. Each test was performed according to the ASTM standards. The tests were carried out in a room with controlled temperature and humidity ((Gomes et al., 2015), (Souza, 2019), (Almeida et al., 2017), (Guimarães Junior et al., 2010), (Lee, Odlin, & Yin, 2014), (Li, 2004), (Rosa et al., 2016) and (Zakikhani, Zahari, Sultan, & Majid, 2017)) . Table 1 shows the dimensions, number of samples and the standards for each test.

Table 1. Dimensions and quantities of samples, tests and standards.

TESTS	Lenght (mm)	Width (mm)	Thickness (mm)	Qty. (un/for.)	Standards
TRACTION	200	25	8	6	ASTM D3039/ D3039M-17
FLEXION	200	25	8	6	ASTM D7264/ D7264M-15
IMPACT	100	10	10	6	ASTM D6110-18
DENSITY	25	25	8	6	ASTM D792-13
ABSORPTION	25	25	8	7	ASTM D570-98
THERMAL PROPERTIES	ϕ50	50	-	6	ASTM D5930-17
AGING	200	25	8	1	ASTM D1435-13
TGA	5	5	3		ASTM E2550-17
SEM	8	8	8	1	-

Source: Authors.

Table 1 presents a summary of the specifications of the specimens used for each test, in terms of dimensions and quantities, also showing the technical standards used for each test.

It was used a universal SHIMADZU machine model AGS-X 300 in the traction and flexion tests. In the impact test, an analog pendulum of the LEIPZIG machine of 0.937 kg length of the rod 220 mm. In the density test, a Gehaka DSL 910 digital densimeter.

The absorption test was performed for three aqueous media (distilled water, seawater and oil), for 60 days. In the thermal properties test, a portable analyzer kit from Decagon Devices model KD2 Pro was used. In the aging test, the samples were placed on a covering slab and were exposed to environmental conditions for one year, being weighed and photographed before and after exposure to make an analysis of the degradation occurred.

The Thermogravimetric Analysis (TGA) was performed with a simultaneous thermogravimetric and calorimetric analyzer from TA Instruments model SDT Q600, in an atmosphere of synthetic air at 50 mL/min, heating rate of 10 ºC/min and final temperature of 700°C.

In the SEM test the Hitachi Scanning Electron Microscope model TM 3000 was used, and the fracture surfaces of the samples subjected to traction were analyzed to evaluate the load/matrix interface and, consequently, the distribution of cement in the resin after impregnation and the formation and damage propagation.

The proposed applicability for the composite was the manufacture of handmade furniture at a lower cost than the conventional ones on the market. A set of coffee table and bench were manufactured, using composites with higher percentages of powders, PB and PRLO and PVC tubes for the table and metal tubes for the bench. The steps of the manufacturing processes of the coffee table and bench tops using composites C2 and C4 are shown in the Figure 2.

Figure 2. Stages of the manufacturing processes of the center and bench tops using C_2 and C_4.

Source: Authors.

Figure 2 shows the procedures for obtaining the composites and manufacturing the bench and table tops produced as applicability of the composites.

3. Results and Discussion

3.1. Density

Table 2 shows the average results of the density test for composites and polyester resin matrix.

Table 2. Results of density test for composites and polyester resin.

MATRIX/COMPOSITES	Density(g/cm^3)
R – 1.0R + 0.0BP + 0.0OLWP	1.240±0.10
C_1 – 1.0R + 0.1BP	1.185±0.08
C_2 – 1.0R + 0.15BP	1.173±0.07
C_3 – 1.0R + 0.15OLWP	1.195±0.09
C_4 – 1.0R + 0,40OLWP	1.221±0.10
C_{H5} – 1.0R + 0.05RB + 0.20OLWP	1.180±0.08

Source: Authors.

Table 2 shows the comparative behavior between the densities of the polyester resin matrix and the composites, to evaluate the mass of the composites in relation to the resin. This parameter is very important because it is associated with the lightness of the material, a very important property for engineering applications.

All composites showed lower densities than the resin. As the density of PB is very low, 0.15g/cm3, there was a decrease in the density of C1 and C2, which was not only greater due to the low mass load introduced into the resin. The density drop in composites C1 and C2 in relation to the resin was not significant.

The comparative analysis between C2 and C3 showed C2 with lower density due to the higher density of the OLWP, 0.5 g/cm3, in addition to the higher packaging of OLWP that produced an increase in density. However, the increase was insignificant, around 2.0%. The increase in density for C4 over C3 was only 2.0%. In the hybrid composite, there was a decrease in relation to the resin of less than 5.0%.

Composites with BP, C1 and C2, proved to be more viable in terms of density, with a better result for C2, however those that used OLWP, due to the higher packing factor in the resin, could be more viable in terms of mechanical strength, in addition to economically feasible due to the highest possible OLWP load on the resin. In terms of density, the composites showed an insignificant decrease in relation to the resin, not producing a considerable decrease in mass, an important property for the use of composite materials.

3.2. Mechanical Strength

The Table 3 shows the average results of the mechanical strength tests for polyester resin and composites.

Table 3. Avarage results of mechanical strengh tests for composites and matrix resin.

MATRIX/COMPOSITES	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J/cm²)
R – 1.0R + 0.0BP + 0.0 OLWP	30.7±1.60	60.0±2.10	0.282±0.013
C_1 – 1.0R + 0,1BP	16.7±1.23	31.3±1.14	0.323±0.017
C_2 - 1,0R + 0.15BP	13.3±1.10	32.2±1.24	0.333±0.015
C_3 – 1.0R + 0.15 OLWP	15.8±1.18	35.8±1.54	0.367±0.029
C_4 – 1.0R + 0.40 OLWP	11.2±1.10	28.2±1.15	0.55±0.034
C_{H5} – 1.0R + 0.05BP + 0.20 OLWP	16.6±1.24	36.3±1.68	0.457±0.031

Source: Authors.

Table 2 shows the comparative behavior of the mechanical properties of composites and matrix resin, to determine whether the fillers used were filling or reinforcing.

There was a significant decrease in the tensile and flexion strengths of the composites in relation to the polyester resin matrix, with a greater decrease in tensile strength and a significant increase in the impact absorption energy. The composite with the best performance in traction, flexion and impact was the CH5 hybrid. OLWP composites showed greater viability due to being able to work with a much larger amount of waste, which would reduce the cost of fabricating structures.

In the comparative analysis between the two loads in the proportion of 15%, there was little significant supremacy of C2, around 5% in traction and in flexion, there was a supremacy of C3, of 11.2%, due to its higher density, caused in part by the greater packaging of the OLWP in relation to bamboo.

The lower packing factor of BP in relation to OLWP explains the greater strength of composites with tailings, which can also be seen in the modules of elasticity, tension and flexion. All composites presented modulus of elasticity lower than resin, for both efforts. The relationship between density and mechanical strength was proven, with the highest density prevailing for this important property.

The composites obtained have little viability in relation to TS and FS, since the drop in relation to the resin was very significant, not being indicated for medium and high requests, and can only be used for low loads, once again demonstrating that the loads used were filling.

All composites presented impact absorption energy rates higher than the polyester matrix resin, demonstrating that the placement of BP and OLWP increased the tenacity to the impact of the new materials obtained, in accordance with (Margem, Monteiro, Neto, Rodriguez, & Soares, 2010).

The composites with the best results were C4 and CH5, with higher percentages of OLWP. All composites showed good viability for uses for impact absorption applications. It was the mechanical property of best result for composites and such powders can be qualified for this specific property as reinforcement loads, instead of filler loads, as happened for RT and RF. As probable applicability, it could be produced plates for the absorption of vibrations in machines and tools, as for example as bases for pumps instead of iron and steel.

3.3. Thermal resistance

The Table 4 presents the average results of the thermal resistance test for composites and polyester resin matrix.

Table 4. Average results of thermal resistance tests for resin and composites.

MATRIX/COMPOSITES	k (W/m.K)	c (M.J/m^3.K)	d (mm^2/s)	R (ºC.cm/W)
R – 1.0R+0.0BP+0.0OLWP	0.218±0.015	2.12±0.11	0.103±0.04	459.07±5.17
C_1 - 1,0R+0,1BP	0.202±0.012	1.80±0.09	0.112±0.05	495.57±6.13
C_2 - 1,0R+0,15BP	0.172±0.010	1.53±0.06	0.112±0.05	582.23±6,79
C_3 - 1,0R+0,15OLWP	0.194±0.011	1.91±0.09	0.102±0.04	516.03±5.18
C_4 - 1,0R+0,40OLWP	0.157±0.011	1.57±0.08	0.100±0.04	636.03±5.98
C_{H5} - 1,0R+0,05BP+0,20OLWP	0.190±0.012	1.92±0.10	0.100±0.04	527.03±6.16

Source: Authors.

Table 4 shows the comparative behavior of the thermal properties of composites and matrix resin, to demonstrate whether the composite could be used as a thermal insulator

The thermal behavior of the composites was better than that of the resin in relation to the thermal conductivity for possible applications as insulators. The best result came from C4, which also showed the highest economic viability. There was a decrease in thermal conductivity with the increase in the load of BP and OLWP, demonstrating that such loads have k lower than that of the resin. Comparing the composites with the same load ratio, C2 and C3, there was a supremacy of C3 equal to 11.4%.

The behavior of composites with BP was good and could be much better if the mass load was higher, as in C4, which cannot happen, due to the compromised processability of the composite. The behavior of the hybrid composite CH5 was good in relation to K, proving to be competitive with the other composites and having K lower than the resin by 12.8%.

For all composites, the thermal diffusivity was practically the same, demonstrating that the heat wave has practically the same speed of propagation in the composites, with loads of BP and OLWP.

The C4 composite was the one that brought together the best thermal properties. It is the most viable for thermal insulation applications and it is the most viable in the economic aspect, as has already been highlighted. The hybrid composite proved to be competitive with the resin and with the other characterized composites. Despite these auspicious results, obtaining in k composites less than 0.20W/m.K, competitive with PVC, for example, a widely used plastic material, there is no feasibility of using composites as insulators, as there are more efficient materials for this purpose.

3.4. Natural aging

The Table 5 shows the results of the natural aging test on composites and polyester resin.

Table 5. Results of natural aging test on composites and polyester resin.

MATRIX/COMPOSITES	Mass (g) 28/08/18	Mass (g) 01/09/19	Mass loss (g)	Mass loss (%)
R – 1.0R+0.0BP+0.0OLWP	49.398	49.275	0.123	0.25
C_1 – 1.0R+0.1BP	54.417	54.123	0.294	0.54
C_2 – 1.0R+0.15BP	64.603	64.286	0.317	0.49
C_3 – 1.0R+0.15OLWP	54.193	54.030	0.163	0.30
C_4 – 1.0R+0.40OLWP	50.477	50.334	0.143	0.28
C_{H5} – 1.0R+0.05BP+0.20OLWP	63.841	63.623	0.218	0.34

Source: Authors.

Table 2 shows the comparative behavior between composites and matrix in the aging test, to assess the resistance of these materials to the weather.

As supported by the literature on composite materials, polyester resin has considerable resistance to bad weather, as attested by (Souza, 2019). Once again, this statement was proven with a mass loss of only 0.25% in one year of exposure. All composites tested, with loads of BP and OLWP, showed excellent results in relation to mass loss due to non-accelerated aging, demonstrating significant resistance to the weather.

Composites C1 and C2 showed greater losses due to the fact that bamboo fibrils have a greater capacity for absorbing water and moisture, however little significant around 0.5%. Composites C3, C4 and CH5 showed the best results with a loss of less than 0.35%. The best performing composite was C4, with a loss close to that of the resin, even subject to severe conditions in the northeast region, intense global solar radiation, high ambient temperatures, little rain and high humidity.

Another effect perceived in the samples of resin and composites subjected to the natural accelerated aging test was in color. The samples after aging showed a yellowish appearance, denoting degradation. This color change was probably caused by exposure to ultraviolet radiation from the sun's rays, since it persisted even after cleaning the samples. In order to be able to state whether this exposure resulted only in aesthetic changes or if the material properties were affected, it would be necessary that the specimens after being removed from the test site be subjected to new tests to evaluate and, if necessary, quantify this degradation.

3.5. Water and oil absorption

Table 6 shows the degrees of absorption of distilled water, seawater and oil for polyester resin and composites.

Table 6. Avarage results of absorption tests for composites and resin.

MATRIX/COMPOSITES	Distilled water	Seawater	Motor oil
	Absorption (%)	**Absorption (%)**	**Absorption (%)**
R – 1.0R+0.0BP+0.0OLWP	1.06±0,09	1.04±0,08	1.00±0,07
C1 - 1,0R+0,1BP	3.15±0,17	3.08±0,15	1.69±0,10
C2 - 1,0R+0,15BP	3.81±0,19	3.64±0,18	2.44±0,16
C3 - 1,0R+0,15OLWP	1.50±0,11	1.44±0,10	1.11±0,10
C4 - 1,0R+0,40OLWP	2.28±0,15	2.15±0,17	1.72±0,12
C5 - 1,0R+0,05BP+0,20OLWP	3.25±0,16	3.19±0,16	1.99±0,14

Source: Authors.

Table 2 shows the comparative behavior between composites and matrix in the absorption test in the distilled water, seawater and motor oil, for possible applications in these aqueous media.

The test was carried out without resin coating on the sample cutting surfaces, offering easier diffusion of water and oil to the interior of the samples. As expected, there was very low water and oil absorption for the polyester matrix, around 1.0%, as evidenced by numerous scientific works available in the literature on composite materials ((Souza, 2019) and (Marinho, Do Nascimento, Nisgoski, & De Domenico Valarelli, 2013)).

Composites with BP showed a higher level of absorption, since bamboo fibers are more hydrophilic than resin. However, even with this characteristic, the water absorption capacity was slightly above 3.0% for aqueous water media and 1.0% for oil.

OLWP composites showed better results with increased water and oil absorption capacity with increased tailings load. Compared to resin, the composite with the best result was C3, with increases of 41.5 for distilled water, 38.5 for seawater and 11% for oil. The hybrid composite showed a significant elevation level in relation to resin; however, it proved to be more viable than the composites with PB load because such wastes are of plastic materials less susceptible to interaction with water and oil.

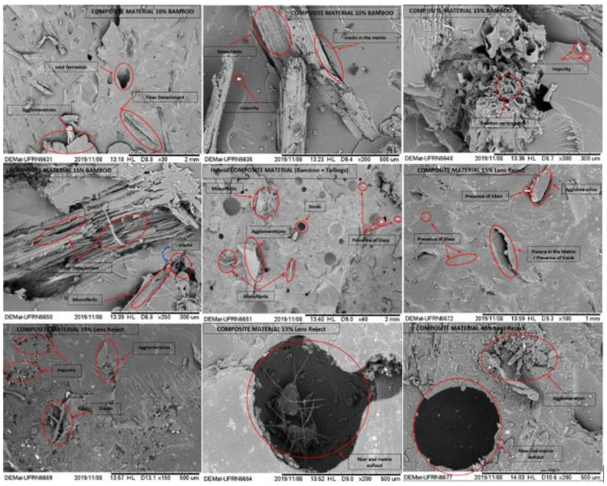
In seawater, composites showed a slightly lower absorption level than in distilled water, with a greater difference reaching 6.0%, which demonstrates the good feasibility of application in this medium for composites and represents an interesting option for applications in marine environment.

In the oil environment, the composites showed good results with C3 being only 11% lower than resin, and having much lower absorption levels than for the two other tested media, evidencing its probable viability for this medium, opening up possibilities for use in petroleum applications.

3.6. SEM

Figure 3 shows the microscopy images for samples of composites C1, C2, C3, C4 and CH5 and polyester resin.

Figure 3. Microscopy images for composites e resin samples.



Source: Authors.

Figure 3 shows the microstructure of the composites produced in order to be able to analyze the efficiency of the manufacturing process of the plates from which the specimens were removed for the characterization tests.

As expected, because they are particulate, the composites showed a decrease in mechanical properties in relation to the matrix. Greater care was taken in the manufacturing process of the slabs to avoid the presence of contaminants, obtaining a very homogeneous mixture between the two materials, minimizing the occurrence of voids and agglomerates, which could lead to additional reductions in mechanical strength. SEM images showed micro cracks, fragile fractures, the presence of impurities and many voids and agglomerates.

It was evidenced the presence of voids and impurities, the occurrence of cracks in the matrix and the formation of agglomerates in all composites, defects associated with deficiencies in the manufacturing process of the composite plates, from which the samples were removed. It is noteworthy that the process was manual, artisanal and that the samples were removed by cutting with a circular saw. Such defects induced fragility to the composites, evidenced by their low tensile strength, also reflected in flexion.

The defects became clearer in C2, in which there was an increase in the mass percentage of bamboo fibers by 50%, causing an even greater decrease in TS compared to the matrix. This decrease was associated with less adherence between fibers and matrix, translated by the detachment of fibers, denoting that the effort was not transferred from the matrix to the load. The presence of impurities and the occurrence of voids showed the need to optimize the manufacturing process for composite boards.

The low fiber-matrix adhesion translated by the low mechanical resistance could be improved with a fiber treatment to reduce the content of substances, such as lignin, which makes it difficult for the fibers to impregnate the resin, according to (Marinho et al., 2013), which claim that the physical and mechanical properties of bamboos correlate with their chemical and anatomical properties, highlighting the lignin content and the thickness of the cell walls.

The same defects seen for composites C1 and C2 were also evidenced in composites C3 and C4, highlighting the pullout of material as a result of the non-transfer of the matrix effort to the OLWP load and the presence of agglomerates, which translated to non-complete homogenization of the resin and filler mixture.

In some images, the presence of glass residues was highlighted, a constituent of OLWP, with greater profusion in C4, which has a higher percentage of OLWP. The most common defects in C4 produced greater mechanical fragility than the other composites produced and characterized.

The hybrid composite CH5 presented a similar behavior with a significant presence of voids, highlighting the presence of agglomerates, with the two loads becoming evident, which demonstrated the inhomogeneity of the composite generating mixture. Also noteworthy is the presence of glass particles, a component of the OLWP. Despite the defects found, the hybrid composite showed the best mechanical behavior.

3.7. Thermogravimetric analysis (TGA)

The graphs in Figure 4 contain the TGA and DTG curves that allow identifying in how many steps thermal degradation of the composites and polyester resin occurs.

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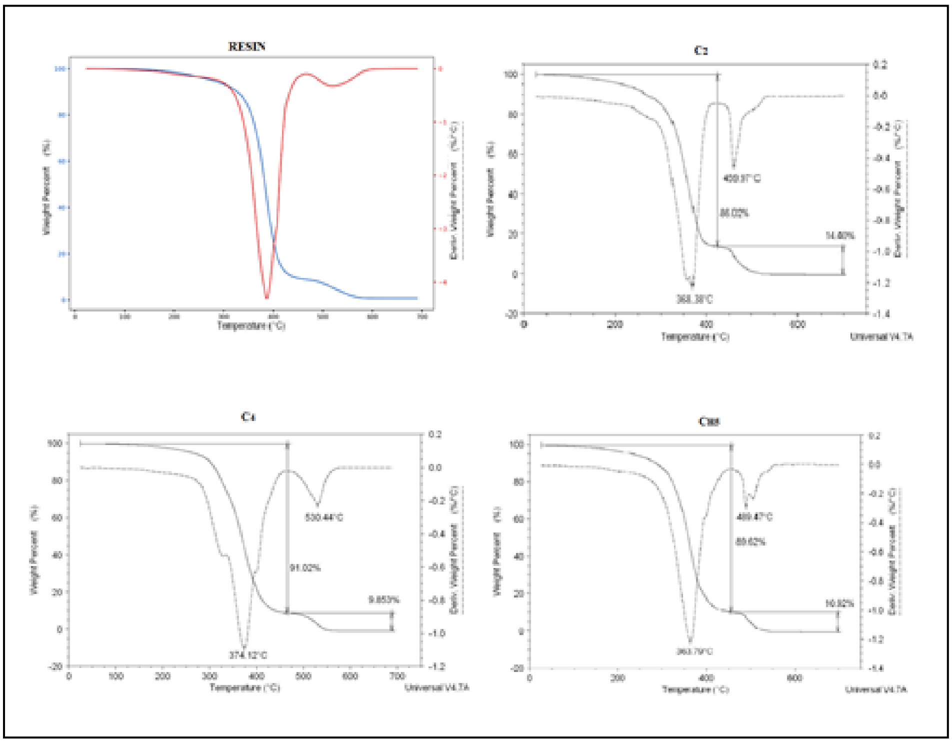
Figure 4. TGA curves for polyester resin and composites.



Source: Authors.

Figure 4 shows the curves of the thermogravimetric test of composites and resin to assess the loss of mass due to the increase in temperature. This loss is very important with regard to the process of obtaining the composites at higher temperatures.

Mass losses are generally caused by chemical substances, such as thermal degradation, water loss, crystallization and combustion, and by physical transformations, such as vaporization, evaporation, sublimation, drying and desorption (Souza, 2019). The ASTM E2550-17 standard requires the determination of the variation in mass and the initial temperature (temperature at which the loss of mass begins) of each reaction observed during the test. The values required by the standard are shown in Table 7.

Table 7. T_{onset}, T_{peak} and mass loss values for the composites and the polyester resin.

Matrix/Composites	**Onset temperature (°C)**	**Peak temperature (°C)**	**Mass variation (%)**
Resin	344.07	386.88	99.28
C_2	308.60	368.40	100.00
C_4	310.20	374.20	100.00
C_4	312.50	363.80	100.00

Source: Authors.

Figure 4 shows parameters of the thermogravimetric test of composites and resin to assess the final mass after the test. It should be noted that the analysis is comparative between resin and composites.

In general, the composites showed similar behavior, with low resistance for temperatures above 300°C, demonstrating that the loads used did not produce greater resistance to mass loss due to the increase in temperature in relation to the resin. The resin is more thermally stable and the hybrid composite the less thermally unstable

The composites showed the same behavior as the resin, with low mass loss up to 225°C. Between 300°C and 400°C, there was a great loss of mass, leaving the composites to be competitive with resin.

It was found that the resin and composites showed temperatures of onset of thermal degradation, just above 300°C, showing, therefore, the same levels of thermal stability. The composites showed worse results than the resin, being less resistant to thermal degradation as the temperature increased.

It is important to emphasize that the processability of the composites occurs in cold conditions, with temperatures below 100°C, and the structures produced with the composite materials obtained will not be in environments subject to high temperatures, a condition in which the studied composites will not undergo thermal degradation. If it is desired to use them in a temperature range that causes such degradation, thermal stabilizers must be included in the material composition.

Table 8 shows a summary of the results of the characterization tests of composites C1, C2, C3, C4 and CH5 and matrix resin.

Table 8. Summary of properties of composites and polyester resin.

PROPRIERTIES	RESIN	C_1	C_2	C_3	C_4	C_{H5}
DENSITY (g/cm³)	1.240	1.185	1.173	1.195	1.221	1.180
DISTILLED WATER ABSORPTION (%)	1.06	3.15	3.81	1.50	2.28	3.25
SEAWATER ABSORPTION (%)	1.04	3.08	3.64	1.44	2.15	3.19
OIL ABSORPTION (%)	1.00	1.69	2.44	1.11	1.72	1.99
THERMAL COND. (W/m.K)	0.218	0.202	0.172	0.194	0.157	0.190
THERMAL CAP. VOL.(MJ/m³.K)	2.12	1.80	1.53	1.91	1.57	1.92
THERMAL DIFUSIVITY (mm²/s)	0.103	0.112	0.112	0.102	0.100	0.100
THERMAL RESISTANCE (°C.cm/W)	459.07	495.57	582.23	516.03	636.03	527.03
TS(MPa)	30.7	16.7	13.3	15.8	11.2	16.6
FS(MPa)	60.0	31.3	32.2	35.8	28.2	36.3
IS (J/cm²)	0.282	0.323	0.333	0.367	0.55	0.457
MASS LOSS – AGING (%)	0.25	0.54	0.49	0.30	0.28	0.34
ONSET TEMPERATURE (°C)	351.07		308.6		310.2	312.5
PEAK TEMPERATURE (°C)	386.88		368.4		374.2	363.8
MASS LOSS TGA (%)	99.28		100		100	100

Source: Authors.

Table 8 presents a compilation of all the properties analyzed in this work, showing the comparative behavior between resin and composites, for diagnosing the viability of such produced composites and their competitiveness in relation to polyester resin.

3.8. Composite application

Among the applications that can be implemented using the composites obtained is the manufacture of furniture, panels, countertops and handicrafts, which can replace marble/granite, glass, even wood. Some characteristics of the composites are important for these applications: Low weight, low water absorption capacity, high resistance to natural aging, low cost and good aesthetics.

We opted for the manufacture of furniture, a coffee table and a bench, also using PVC tubes and connections in the table structure, another low-cost material, good aesthetics and adequate strength for the intended applicability.

Figure 5 shows the table and bench manufacturing and assembly processes. The composite used for the manufacture of the table top was the C4 and for the seat of the bench the composite C2, both with higher percentages of OLWP and PB, respectively.

Figure 5. Table and bench manufactured with C2 and C4 composite material.

Source: Authors.

Figure 5 shows the two factory structures using the studied composites, table and bench, for use on terraces and balconies.

4. Conclusions and Suggestions

The feasibility of obtaining and manufacturing the proposed composites was demonstrated using loads of BP and OLWP and polyester resin, however the manual manufacturing process used needs to be optimized. The composites presented a behavior inferior to matrix resin, presenting mechanical viability in the traction and flexion only for low loads, however for the intended applicability they presented technical and mainly economic viability. In terms of impact, composites showed excellent results, with powders acting as reinforcement loads, increasing the impact resistance capacity by 40% in relation to resin. They presented lower masses than the resin with greater lightness, an important characteristic for a composite material. They had little thermal resistance to temperature rise, but were competitive with resin. They presented worse results in terms of absorption for the three levels tested, but with low levels for composite materials. They did not show viability to be used as thermal insulators. They were very competitive with resin in their ability to resist degradation due to exposure to bad weather; presented high aesthetic quality, a fundamental characteristic for the intended applications. Despite the good results of CH5, the most technically and economically feasible combined was C4. Another type of resin could be used to obtain the composites, characterize them and compare their results with those obtained with the polyester resin. Test

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the composites for acoustic insulation, characterize the composites after exposure to the weather for one year, diagnosing levels of losses in the studied properties. Manufacture other structures to expand the field of applicability of the composites produced.

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