Article

Comparative study between paraju wood and wood-plastic for application in civil construction

Estudo comparativo entre paraju e madeira plástica para aplicação na construção civil

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Abstract

In the search for products which meet to human needs and collaborate with the environment, comes up the wood-plastic composite as a good alternative. It is a material which comes from wood and plastic residues, has considerable environmental appeal and had higher resistance to moisture than wood. This work aimed to evaluate a wood-plastic composite in comparison to natural paraju wood (*Manilkara* sp.) in using these materials for civil construction. Physical, mechanical and biodeterioration properties were tested. Despite not presenting mechanical strengths similar or superior to paraju wood, the composite had satisfactory and better values for density, shrinkage and swelling, as well as resistance to the termite *Nasutitermes corniger*. Elements produced from plastic require greater care in relation to the propagation of flames. The wood-plastic composite cannot be used as a structural element. However, it can be used in civil construction as cladding on facades, floors, and room dividers.

Keywords: Biodeterioration. Mechanical characterization. Physical characterization. Plastic. Waste. Wood waste.

Resumo

A busca por produtos que atendam às necessidades humanas e colaborem com o meio ambiente, surge o compósito madeira-plástico, como uma boa alternativa. O material é proveniente de resíduos de madeira e plástico, tendo considerável apelo ambiental e maior resistência à umidade que a madeira. O objetivo deste trabalho foi avaliar um compósito madeira-plástico em comparação à madeira natural de paraju (Manilkara sp.) na utilização desses materiais na construção civil. Foram testadas propriedades físicas, mecânicas e a resistência à biodeterioração. Apesar de não apresentar resistências mecânicas semelhantes ou superiores à madeira de paraju, o compósito exibiu valores satisfatórios e melhores densidade, retração e inchamento, além de resistência ao cupim Nasutitermes corniger. Elementos produzidos a partir de plástico requerem maiores cuidados em relação à propagação de chamas. O compósito madeira plástico não pode ser aplicado como elemento estrutural. Entretanto, pode ser empregado na construção civil como revestimento de fachadas, pisos e divisórias.

Palavras-chave: *Biodeterioração. Caracterização mecânica. Caracterização física. Resíduos plásticos. Resíduos de madeira.*

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Introduction

Brazil generates the fourth largest amount of waste in the world, trailing behind only the United States, China, and India. According to the Brazilian Association of Public Cleaning and Special Waste Companies (ABRELPE, 2019), approximately 211 thousand tons of waste are generated daily, which corresponds to annually a total of 81.8 million tons. The resources applied by municipalities in public urban cleaning and urban solid waste management services, which include collection, transportation, final disposal and general urban cleaning services, reached R$29,2 billion in 2022, which represents R$ 11.96 per inhabitant by month (ABRELPE, 2019).

In 2022, the country recorded 77.1 million tons of urban solid waste, which corresponds to 94.25% of the total generated. The portion that corresponds to 7% of the waste generated that receives environmentally inappropriate disposal indicates the need for investments in infrastructure to universalize appropriate disposal (ABRELPE, 2019).

According to the Brazilian Association of the Polyethyl Ethyl Terephthalate Industry (ABIPET, 2020), the recycling industry is established throughout the country, with an average annual growth of 12%. One of the most common types of plastics found in solid waste in Brazil is high-density polyethylene (HDPE), widely used in manufacturing products that require greater resistance to impacts, such as medicine bottles, cosmetics, toilet flush boxes and packaging for lubricating oil (Mello, 2011). According to Teixeira, Moreira and Costa (2002), the rise in the concentration of people and the adoption of a series of facilities offered by industry to society causes an increase in these types of waste in urban centers.

According to Yamaji and Bonduelle (2004) and Vale and Gentil (2008), the large amount of waste generated in the timber sector comes from slabs, chips, sawdust, sawdust and shavings, and deserves special attention, since this waste is generally low-density materials and natural fuels, requiring proper disposal or storage. In this sense, many companies do not consistently use their waste, claiming that the cost:benefit ratio is not justifiable (Gonçalves; Lelis; Carvalho, 2017).

According to Abrelpe (2019), industries use 6.7 million tons year^{-1} of plastic. The exposure of this waste and the costs involved in its storage have caused society to seek alternatives to reduce the volume stored, since plastic is one of the materials that require the most time to decompose (Evode *et al.*, 2021; Chamas *et al.*, 2020).

Thus, a search for new technologies which aim to reuse these materials originated the product known as wood-plastic composite; however, Yamaji and Bonduelle (2004) mentioned that the difficulty of transporting wood waste to the manufacturing sites contributes to it being discredited.

However, the advantage of wood-plastic composite over wood is mainly associated with the low propensity to present defects such as cracking, warping, requiring little or no maintenance and its ease to be molded into complex shapes (Brandt; Fridley, 2003). The use of these composites is presenting growth in Brazil of about 30% to 40% per year, as cited by Brazilian Support Service for Micro and Small Businesses (SEBRAE, 2015).

There are still few factories in Brazil which use wood-plastic composite as raw material, however factories have noticed an increase in consumption over the years, and its use is employed in producing furniture, benches, fences, railroad ties, manhole covers, garbage cans, and artifacts used in civil construction (SEBRAE, 2015).

According to Guamá *et al.* (2008), a wood-plastic composite is only produced with recycled plastic, in which equal or even superior material properties to those of wood can be added when chemicals are added to its composition, as is the case of increased resistance to moisture, for example. The authors also inform that as the composite has plastic in its composition, its durability time would be equivalent to that of the plastic *in natura*.

In a study by Molina, Carreira and Calil Junior (2009) with wood-plastic composite profiles, deformability was observed in the flexural strength test. When the strength class was analyzed, the wood-plastic composite was classified as C25 in the case of conifers, and C20 in the hardwood class from the results obtained in the compression test. When analyzing the shear test, the authors found three times higher strength values for the wood-plastic composite than the C20 class of conifers and hardwoods. Thus, this work aimed to evaluate a wood-plastic composite in comparison to natural paraju wood (*Manilkara* sp.) wood in using these materials for civil construction.

Material and methods

Material

In this research wood-plastic composite samples were used, whose material was obtained in the market, consisting of 70% wood waste (pine and eucalypts) and 30% plastic waste (High Density Polyethylene - HDPE).

The wood pieces of *Manilkara* sp., known in Brazil as paraju or maçaranduba and in international trade as paraju wood, were obtained through donation to the Department of Forest and Wood Sciences of the Federal University of Espírito Santo. This wood was chosen for this work because it has great natural durability, low moisture absorption and high mechanical strength, and these characteristics are suitable for use in civil construction.

Sampling the plastic wood composite and the paraju wood

The pieces were initially resized into smaller pieces to perform the physical and mechanical tests, from which the specimens were obtained as defined by the Brazilian Regulatory Standard (ABNT, 2022b) of the Brazilian Association for Technical Standards (ABNT, 2022b), using 10 repetitions for each test.

Characterization of the wood-plastic composite and the paraju wood

Physical Properties

The characterization of the physical properties of paraju wood and wood-plastic composite was performed according to the test methods defined in NBR 7190-3 (ABNT, 2022b). The specimens were weighed and subsequently measured with size 3 cm × 2 cm × 5 cm (radial × tangential × longitudinal) directions.

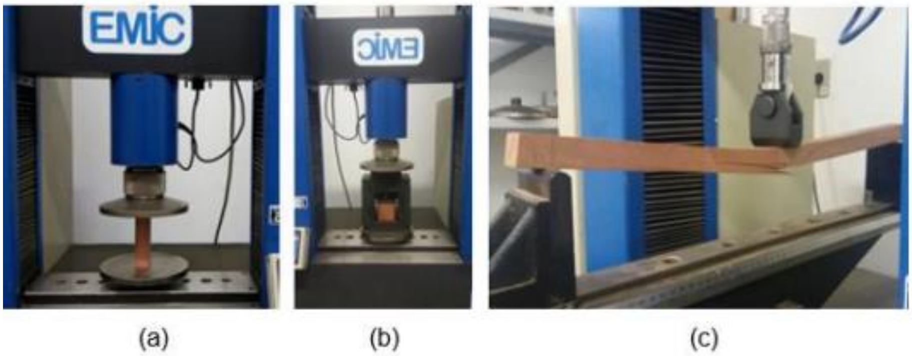
Mechanical properties

For characterization of the mechanical properties of paraju wood, the standard test methods for small clear specimens of timber, described by American Society for Testing and Materials - D 143 (ASTM, 2022) was used to determine the compressive, shear and static bending strengths. The study was conducted utilizing a universal test machine (EMIC, DL 10000 - 100 kN), as shown in Figure 1.

The measurements described by the standard for the test specimens are parallel compression with 2.5 cm × 2.5 cm × 10 cm (width × height × length), shear with 5 cm × 5 cm (width × height) and static bending with 2.5 cm × 2.5 cm × 57.5 cm (width × height × length).

For the compressive strength test, the load was applied continuously at a rate of 0.003 mm min^{-1}. The load for the shear strength test must be applied continuously at a rate of 0.6 mm min^{-1}. For the static flexural strength test, the load is applied to the central span at a rate of 2.5 mm min^{-1}. After carrying out the tests, the results for the evaluated strengths are provided by the software coupled to the machine.

Figure 1 – **Methodology adopted for testing with paraju wood – (a) compression test. (b) shear test and (c) bending test**



For the tests with wood-plastic composite was used the NBR 7190-3 (ABNT, 2022b), because there is no specific regulatory standard for this material. The tests were also conducted using the universal machine (EMIC - 100 kN). However, some adaptations were made regarding the measures of the specimens in a proportional way to those established by NBR 7190-3 (ABNT, 2022b), where the ratio between width and length was 1:3. As the strengths are calculated considering the area of the material, these adaptations did not interfere in the result. It is noteworthy that the wood-plastic composite has no fiber orientation, and therefore, only parallel compression was adopted.

For the parallel compression test, the specimen size was 6 cm in height and 2 cm in width. In the shear test, the size was 2 cm in width and 5 cm in length. And for the static flexion one, 6 cm width, 2 cm thickness and 60 cm length. In the test to determine conventional bending strength, the loading must be monotonically increase at a rate of around 10 MPa min^{-1}.

No-choice feeding test against termites

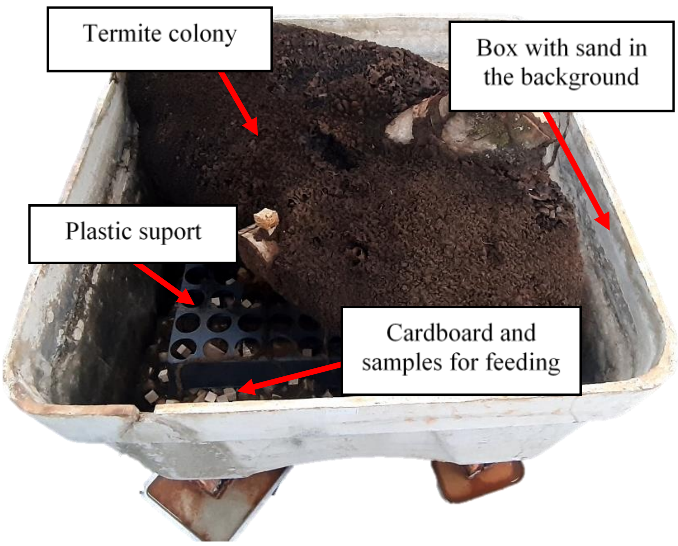
For this work, the no-choice feeding test, as described by American Wood Protection Association - AWPA E1-16 (AWPA, 2016) was performed, with modifications suggested by Brocco *et al.* (2020). Therefore, the colony of the *Nasutitermes corniger* (Motsch.) species was collected in the rural area of Jerônimo Monteiro, south of the state of Espírito Santo, and transported to the Laboratory of Wood Biodeterioration of the Department of Forestry and Wood Sciences. The colony was kept in a 500 L capacity fiber cement box. This box was prepared with a 15 cm layer of sand, and a layer of cardboard on the surface, both moistened. For the colony not to be in direct contact with the cardboard and sand, a plastic grid was placed, supported by two tiles (Figure 2).

The termites remained in the box for 48 hours to allow them to rest. After that they were carefully collected directly on the cardboard and weighed on a precision scale.

The test was set up in 600 mL bottles containing 200 g of sand washed and sterilized in the oven at 103 ± 2 °C for 24 hours. To moisten the sand, 36 mL of distilled water was added in each vial aiming to correct the humidity to 75%, calculated according to E1-16 (AWPA, 2016), modified by Brocco *et al.* (2020).

Three treatments (*Pinus elliottii*, paraju wood and wood-plastic composite) were made, with ten repetitions each, with the use of *Pinus elliotti* wood, as described by E1-16 (AWPA, 2016) to serve as a witness between the treatments. Each specimen had dimensions of 2.5 cm × 2.5 cm × 0.5 cm (width x length x thickness).

Figure 2 – ***Nasutitermes corniger* termite colony arranged inside the fiber cement box for termite collection**



With the bottles prepared, the specimens were weighed and placed inside, taking care to insert only half of the specimen into the sand. Then, approximately 1 g ± 0.05 g of termite was placed in each bottle (average of 329 termites: 7% soldiers and 93% workers). The bottles were kept in an air-conditioned room at 27 °C ± 2 °C for 28 days.

At the end of the test, the specimens were removed from the bottles and carefully cleaned with a soft bristle brush to remove dirt from them. Then they were dried in an oven at 103 ± 2 ºC and weighed again so that the mass loss could be measured. The number of days for termite mortality in each treatment was counted and, finally, the specimens were analyzed for wood damage by five different evaluators (Table 1) (AWPA, 2016).

Flammability test

For the test of reaction to fire, the analysis of the flammability of the specimens was carried out based on an adaptation of the method of the International Organization for Standardization - ISO 11925-2 (ISO, 2002) and literature (Lopez *et al*., 2022). The samples were prepared in dimensions of 250 mm × 50 mm × 12 mm (length × width × thickness) and fixed on a double U-shaped frame made of stainless steel, so that the underside of the samples is directly exposed to the single flame from a Bunsen burner, vertically (Figure 3). For this case, two types of wood-plastic composites were compared (produced by extrusion and by injection). For the measurements, the free software Image J was used (Rasband, 2023).

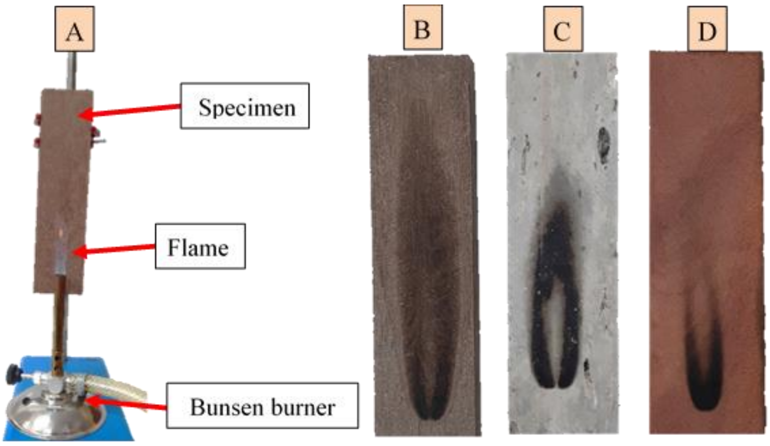
The flame is set at a height of 16 to 20 mm in height, and 5 mm away from the specimen surface. The flame exposure is carried out for a duration of 30s.

Table 1 – **Visual rating score assigned to wood damage after termite attack**

Wood damage	Visual rating (score)
Sound, surface nibbles permitted	10
Light attack	9
Moderate attack, penetration	7
Heavy attack	4
Failure, with rupture of the samples	0

Source: modified from E1-16 (AWPA, 2016).

Figure 3 – **Apparatus for the flammability test (A) of Extrusion wood-plastic composite (WPCe) (B), Injection wood-plastic composite (WPCi) (C) and paraju wood (D)**



Comparation and statistical analyses

The experiment was conducted under entirely randomized design (DIC), with ten repetitions (specimens) and two treatments (wood-plastic composite and paraju wood) in the evaluation of physical and mechanical properties and three treatments (wood-plastic composite, paraju wood and pine) in the evaluation of biodeterioration. The termite test was carried out in randomized blocks. Analysis of variance was performed, and when the treatments were significant ($F < 0.05$) the means of the treatments were compared by Tukey's test ($p < 0.05$).

In the evaluation of the termite test, the mass loss percentage (ppm) was transformed according to Equation 1, the visual damage (score) and the time (days) for termite death according to Equation 2. These transformations, suggested by Steel, Torrie and Dicky (1997), were employed due to the need to normalize the data distribution (Lilliefors test) and homogenize variances (Cochran and Bartlett's test).

$$arcsin\sqrt{\frac{ppm}{100}} \qquad \text{Eq. 1}$$

$$\sqrt{(score)+0,5} \qquad \text{Eq. 2}$$

Results and discussion

Physical properties

Table 2 shows the average values found for shrinkage and swelling for the wood-plastic composite and paraju wood in the Longitudinal (L_1), Tangential (T_1) and Radial (R_1) directions. The volumetric shrinkage (R_v) and volumetric swelling (I_v) are also presented.

The wood-plastic composite presented lower values than the paraju wood in the shrinkage and swelling tests, except for the longitudinal plane. The wood-plastic composite also presented lower values in volumetric shrinkage and volumetric swelling. With this analysis, it is possible to say that the wood-plastic composite is more stable in its dimensions than paraju wood. This great stability may be related to the fact that there is 30% plastic in its composition, which contributes to the composite not undergoing dimensional changes from moisture, since plastic is not hygroscopic.

The longitudinal plane presents irrelevant values when wood is analyzed, close to zero, which is related to fiber orientation. The longitudinal plane of the paraju wood presented lower values than the wood-plastic composite, which can be explained by the fact that the composite does not have fiber orientation. It should be noted that the variation proportions among the directions (longitudinal, tangential and radial) are smaller for the composite than for the wood. This reduces the development of defects (presence of cracks and warping), especially when used for material in places that are usually exposed to temperature variations due to sunlight and humidity.

Mechanical properties

Table 3 shows the modulus of elasticity (MOE) value from the static bending test. In addition, the moisture content (MC), the modulus of rupture (MOR) from the bending test, and the stress from the parallel compression and shear test are also displayed.

Table 4 show the comparison of the hardwood strength classes, along with the characteristic values of parallel compression ($f_{c0,k}$), shear ($f_{v,k}$) and the modulus of elasticity ($E_{c0,m}$). The basic density (ρ_{bas}) and apparent density (ρ_{ap}) values of the wood-plastic composite and the paraju wood are also shown.

Table 2 – **Shrinkage and swelling of the materials studied**

Material	Shrinkage (%)				Swelling (%)			
	L_1^*	T_1	R_1	R_v	L_2	T_2	R_2	I_v
Paraju wood	0.14b	8.25a	5.27a	13.21a	0.14b	9.00a	5.56a	15.23a
Wood-plastic composite	1.34a	2.38b	1.07b	4.72b	1.36a	2.44b	1.08b	4.97b

Note: *averages followed by the same letter in the column do not differ statistically (Tukey's test, $p > 0.05$). $L_{1,2}$: Longitudinal; $T_{1,2}$: Tangential; and $R_{1,2}$: Radial directions; and R_v: Volumetric Shrinkage; I_v: Volumetric swelling.

Table 3 – **Mean static bending (modulus of elasticity – MOE and rupture – MOR) and shear values of wood-plastic composite and paraju wood**

Mechanical properties	Wood-plastic composite (MPa)	Moisture (%)	Paraju wood (MPa)	Moisture (%)
Shear (Stress)	4.70 b*	1.27	16.39 a	13.68
Static bending (MOE)	2251.48 b	1.27	19579.09 a	12.93
Static bending (MOR)	9.97 b	1.84	157.82 a	14.13
Parallel compression (Stress)	11.55 b	1.84	69.20 a	14.13

Note: *means followed by the same letter in the row do not differ (Tukey's test, $p > 0.05$).

Table 4 – **Comparison of the strength classes between the wood-plastic composite and paraju wood**

Class	$f_{c0,k}$ (MPa)	$f_{v,k}$ (MPa)	$E_{c0,m}$ (MPa)	ρ_{bas} (g cm^{-3})	ρ_{ap} (g cm^{-3})
Wood-plastic composite	11.77	4.37	22512.48	1.06 a**	1.13 a
Paraju wood	71.81	15.59	19579.09	0.82 b	0.98 b
D20*	20	4.0	10000	-	0.50
D30*	30	5.0	12000	-	0.63
D40*	40	6.0	14500	-	0.75
D50*	50	7.0	16500	-	0.85
D60*	60	8.0	19500	-	1.00

Note: *strength classes in accordance with NBR 7190-1 (ABNT, 2022a). ** Means followed by the same letter in the column do not differ (Tukey's test, $p > 0.05$). Where: $f_{c0,k}$: parallel compression; $f_{v,k}$: shear; $E_{c0,m}$: modulus of elasticity; ρ_{bas}: basic density; ρ_{ap}: and apparent density.

The shear stress of the paraju wood in the compression test was six times higher than that of the wood-plastic composite and the modulus of rupture in the static bending test of the paraju wood showed a value almost 16 times higher than that of the composite. In addition, the shear stress and the modulus of elasticity in static bending were lower for the wood-plastic composite when compared to the paraju wood.

There were very low moisture content values due to the high density coming from the plastic existing in its composition, but this factor did not influence the mechanical properties of the wood-plastic composite, since the paraju wood presented superior results in all tests.

Both the bending and compression specimens presented residual deformation at the end of the test. However, the composite did not rupture in the bending test, even when exceeding the limit of use L/200, unlike the paraju wood. This indicates that if any problem occurs in the structure made by the wood-plastic composite, it will not break immediately, and in turn there will be time to solve the problem without the structure breaking.

A study by Molina, Carreira and Calil Junior (2009) presented an elasticity modulus for wood-plastic composite of 1.314 MPa. This is equivalent to that found in this study for the bending test. The value found by the authors in the shear test was higher (17.32 MPa) than what was found in this work (4.70 MPa).

One of the explanations for these discrepancies may be the fact that the wood-plastic composite used by the cited authors is composed of different materials, such as rice husk instead of wood. In this study, only wood and plastic were used.

The physical and mechanical properties of wood-plastic composite made from particleboard and polypropylene were evaluated by Gozdecki *et al.* (2015). In this study, virgin wood particles, recycled wood particles, and wood flour were used as fillers for the manufacturing. The properties of composite made from recycled wood particles did not significantly differ from those of wood-plastic compound - WPC made from virgin wood particles, and were comparable with composite made from wood floor.

Delviawan *et al.* (2019) suggests that the strength between plastic and wood flour can be improved by using a coupling agent that provides a chemical interaction between the two. Martins *et al.* (2017) reported the optimization of wood-plastic composites made of industrial residues of pine sawdust, high density polyethylene and maleic anhydride-grafted-polyethylene as coupling agent. The results showed that the combination of materials improved mechanical strength and physical properties. The authors recommend the application of the material on building facades as shading shutters.

The wood-plastic composite analyzed herein did not fit into any strength class, according to strength classes determined in NBR 7190-1 (ABNT, 2022a), being below the C20 strength class. On the other hand, the paraju wood obtained a value higher than the C50 strength class, which is considered of high mechanical strength.

The wood-plastic composite presented higher values than the paraju wood in the comparison between the composite and the paraju wood for both the basic density and the bulk density. Thus, we can state that the composite is classified as being of higher quality in terms of density for materials which should be denser and have high strength to moisture.

Although the composite is not recommended for structural use, it can be applied in civil construction in environments with humidity. Furthermore, Ribeiro *et al.* (2023) reports that composites manufactured from plastic waste have low thermal degradation, allowing them to withstand high temperatures in environments of use, making them suitable for applications in the construction industry. Such composites can be used as facade coverings, floors, panels, as well as interior decoration materials, contributing to the construction of more efficient and sustainable buildings, with better energy performance (Ribeiro *et al.*, 2023; Wang *et al.*, 2023; Mohan; Jayanarayanan; Mini, 2021).

Durability of the wood-plastic composite compared to paraju wood

Table 5 show the summary of the analysis of variance for mass loss percentage, damage (score), and number of days for termites death.

The paraju wood obtained the highest visual score for damage, with less termite attack. The wood-plastic composite obtained the same score as the *Pinus elliottii* wood by the Duncan test ($p > 0.05$).

The mortality rate (time to death of termites) in paraju wood was higher than in the other two woods analyzed, demonstrating the wood's excellent resistance to attack by termites *Nasutitermes corniger*. This is possibly due to the presence of chemical compounds, such as polyphenols, which can present toxicity to these insects, as observed by Gonçalves *et al.* (2013), in a study with other native species where similar behavior occurred.

The resistance of wood-plastic composite was evaluated for the xylophagous termites *Nasutitermes corniger* and *Cryptotermes brevis* (Lopez *et al.*, 2020). This study showed resistance to attack by termites indicating enhanced biological properties of the composite.

A study used the spruce sawdust with different amounts (from 0 to 30% by weight) blended with bioplast to determine the biological resistance of the composites (Candelier; Atli; Alteyrac, 2019). Rot and termite resistance tests were carried out and the results showed an increase in fungal and termite degradation levels with increasing amounts of wood.

Flammability test

Table 6 and Figure 4 show the results obtained from the flammability test for the treatments analyzed, treatments with plastic showed greater damage caused by fire.

Table 5 – **Mean values for mass loss, damage and time to death of termites**

Evaluated material	Mass loss (%)	Damage (Visual score)	Number of days
Pinus elliottii	3.21 a	7.28 b	14.10 a
Manilkara sp.	0.77 b	8.84 a	7.80 b
Wood-plastic composite	0.65 b	7.50 b	14.90 a

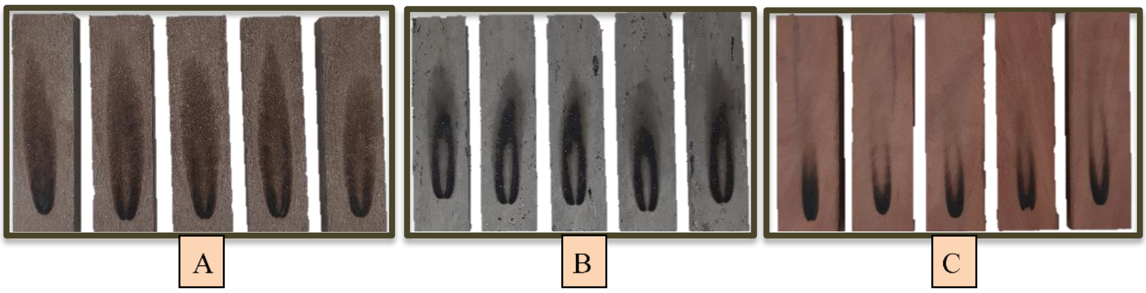
Note: *means followed by the same letter in the column do not differ (Duncan's test, $p > 0.05$).

Table 6 – **Results from the flammability test in the materials**

Treatment	Ignition	Height of flame area (cm)	Width of flame area (cm)	Flame area (cm²)
Paraju wood	No	5.95 a (0.89)	1.49 a (0.09)	4.34 a (0.92)
WPCe	No	14.50 c (1.23)	2.92 c (0.16)	28.23 b (3.14)
WPCi	No	12.10 b (0.54)	2.13 b (0.11)	24.97 b (3.88)

Note: *means followed by the same letter, in the same column, do not differ statistically (Tukey's test, $p > 0.05$). Value in parentheses corresponds to the standard deviation. Where: WPCe: extrusion wood-plastic composite; WPCi: Injection wood-plastic composite.

Figure 4 – **Fire behavior in the tested specimens. (A) Extrusion wood-plastic composite (WPCe), (B) Injection wood-plastic composite (WPCi), and (C) paraju wood**



Pinus elliottii wood presented the highest mass loss percentage when compared to the paraju wood and the wood-plastic composite. The paraju wood and the wood-plastic composite do not differ from each other statistically, and therefore present the same mass loss percentage.

The paraju wood showed less damage by fire (Table 6) in comparison to the other tested materials. The samples did not remain in combustion after removing the flame, unlike the test carried out by Lopez *et al*. (2022), in similar samples, possibly due to smaller available polymer carbon chains (Lee; Salit, Hassan, 2014), as well as the density of the material (Cosnita; Balas; Cazan, 2022; Friedrich, 2022; Lopez, Paes, Rodriguez, 2018; Pham, 2022).

Flame propagation was more intense in the WPCe-type sample (Figure 2B), even if superficial, compared to the WPCi-type sample, which can be explained due to the low exothermic energy released in the presence of the flame (Lopez *et al*., 2022), thus preventing the melting of the plastic during the process, indicating self-extinguishing property.

Conclusions

The wood-plastic composite presented lower values in all mechanical tests, indicating that it does not meet the requirements for structural use. Despite this, the material shows potential for application in civil construction, particularly as cladding on facades, floors, and room dividers.

The composite exhibits considerably satisfactory values for structural elements concerning shrinkage, swelling, density and resistance to the termite *Nasutitermes corniger*, as assessed in this study. The composite is recommended for use in external environments and in direct contact with humidity.

However, wood-plastic composites contain petroleum-based elements, so they have a certain potential for ignition and are not recommended for use in areas with a high risk of fire.

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