# Physical-mechanical characterization of Amazonian woods by non-destructive methodology for the manufacture of EGP (Edge Glued Panel) panels

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## Abstract

*Studies of the technological properties of little-known native species are essential for an indication of sustainable management of the Amazon. The study aimed to evaluate the physical-mechanical performance of five Amazonian species obtained from an area managed in the Amazon by a non-destructive methodology, and to indicate their use to manufacture EGP panels. The samples were obtained from non-flooded secondary forest in the Amazon/Brazil (EEST/INPA). Fifteen trees were selected to determine the physical-mechanical properties, using the microwave system to determine the moisture, the apparent density test and the dynamic modulus of elasticity (MOEd). The microwave system presents better drying performance when compared to the conventional method (artificial drying), considering that the dry woods in this system present greater stability in the equilibrium moisture, and the woods from Murici, Breu vermelho and Angelim pedra presented content close to 12%, ideal moisture for EGP manufactures. The apparent density of the woods varied from 0.76 to 1.18 g.cm$^{-3}$, classified as high density, following the standards of tropical woods. The studied woods presented MOEd of 11,175 to 14,109 MPa, thus demonstrating good resistance, and lower risk of deformation for the different uses, including for EGP panels, whether structural or not, being necessary to consider the type of adhesive. The quality of the studied woods presents a promising result for industrial indication, since they are mostly unknown or non-commercial woods, where technological characterization is a key tool to assist in decision making in the forest management plans that may indicate the use of new species in the forestry sector.*


**Keywords:** Amazon species; density apparent; dynamic modulus of elasticity; drying microwave; EGP panels.

## 1. Introduction

Woods effectively exploited for commercial purposes are restricted to just over a dozen species, however, the forest produces a great variety, with a high population density. In the initial stage of forest management, studies of the floristic composition describe the number, and varieties of individuals (Gonçalves and Santos 2008). In the following phases, there is the planning, and establishment of sustainable production systems. However, species of great abundance, and little known are relegated to the background since their potential for use, and indication for the market is not yet known.

The evaluation of the technological properties of native species are essential for indication in the processing of wood panels. Regarding the technological profile of woods, properties such as moisture, shrinkage, density, modulus of elasticity (MOE) and rupture (MOR) are generally determined. Density can influence the quality of wood, and manufactured or reconstituted products, and their different uses, while moisture content is an important factor in gluing engineered products. In general, species with high densities tend to have higher mechanical strength, and wood with high moisture content, low mechanical strength (Araújo et al. 2019; Nascimento et al. 2021). The physical-mechanical properties of wood are critical traits regarding the applications they will be destined for, in this sense the woods can be classified and grouped according to the use for which they are most suitable, for example, use in internal or external environments, in structures such as bridges, housing, furniture, panels, packaging, among others (Araújo and Silva 2000; FPL 2021).

The characterization of wood in general is carried out by conventional procedures (ABNT, ASTM, COPANT, EN among others). The methods used to determine the properties of wood are in a constant evolution driven by the search for faster, more accurate and lower cost techniques. In the non-destructive evaluation of wood, it is possible to estimate important technological properties without changing its structure, as an example to this type of test, wave propagation technique (stress wave) or impulse (tomography) has proven to be a satisfactory tool for tropical hardwoods (Medeiros et al. 2017; Nascimento et al. 2019).

In the timber sector, it is necessary to indicate new forest species, given the replacement of sawn wood by panels, which does not require large diameter tree, and the rate of waste is much lower, in addition to the accelerated technological development to produce panels, which present products with greater competitiveness, in the addition to the growing environmental pressure exerted by various sectors of society. The main wood panels manufactured are plywood, agglomerated sheets, and laterally glued wood slats (EGP), among others (Ostapiv 2011; Vieira et al. 2012). The EGP panel fabrication is intimately associated with residential construction, and decoration activities. In general, EGP is used in the manufacture of furniture, in civil construction, both in the structural part and in the decorative part. This panel is a structure formed by a set of wooden pieces (slats) glued on the side. The battens can be whole, or present butt union, finger joint type. This type of joint enhances bond strength longitudinal (Amoah et al. 2014; Cortez-Barbosa et al. 2014).

In this context, the technological research of tropical wood species is of great value for the economic and social development of the region, therefore, the objective of this study was to estimate the properties of moisture, apparent density and dynamic modulus of elasticity (MOEd) of Amazonian woods by methodology non-destructive, to indicate new species for the manufacture of EGP panels.

## 2. Material and Methods

The material used in the study was collected at the Experimental Station for Tropical Silviculture of the National Institute for Research in the Amazon (EEST/INPA), core ZF-2 (2° 37' to 2° 38' of South latitude, 60° 09' to 60 ° 11' of West longitude) which occupies an area of 21,000 hectares and is located at km 23 of the side road ZF-2, which starts to the left of km 934 of the BR-174 highway (Manaus - Mato Grosso), 60 km from Manaus. The climate of the region follows the Afi type of Koppen, with an average temperature of 26 °C (maximum 39 °C and minimum 19 °C). The average annual rainfall is 2,000 mm/year, with the rainy season from December to May and the dry season from June to November. In the station area, the plain is tertiary sedimentary, being extensively dissected by a drainage network, resulting in flattened parts (plateaus), wide valleys surrounded by steep, straight and convex slopes at tens of meters (Medeiros et al. 2017). The samples were obtained from an inventoried plot (sub-plots of 100 x 4, 25 m) and defined within the proposal of the INCT Madeiras da Amazônia – MCTI/CNPq/FAPEAM. Five species with the highest occurrence in the plot were selected (Table 1). Fifteen trees were randomly selected for logging (three individuals per species), based on proximity characteristics between individuals of the same species, such as diameter at breast height (DBH) and commercial height (H).

**Table 1**. Species selected for the study.

| Popular name | Scientific name/ Family | DBH* (cm) | H* (m) | Wood overview (Cross section; 10X macroscopy) |
|---|---|---|---|---|
| Angelim pedra | *Hymenolobium pulcherrimum* Ducke, Fabaceae | 60.00 | 12.10 |  |
| Angelim vermelho | *Dinizia excelsa* Ducke, Fabaceae | 55.70 | 10.50 |  |
| Breu vermelho | *Protium puncticulatum* J. F. Macbr, Burseraceae | 34.65 | 11.75 |  |
| Murici | *Byrsonima crispa* Juss, Malphigiaceae | 31.64 | 10.40 |  |
| Piãozinho | *Micrandropsis scleroxylon* W. Roch, Euphorbiaceae | 36.14 | 18.00 |  |

* DBH = diameter at breast height, H = commercial height.

The logs were processed, and planks were obtained and stored at Portela Woods Industrial and Commercial of woods Ltda. (Manaus-AM/Brazil). Subsequently, the samples were transported to the Laboratory of Engineering and Wood Artefacts (COTEI/INPA) where the specimens (2.54 x 5.15 x 60 cm) were processed for physical-mechanical analyses. Samples from each individual were extracted and sent to the Laboratory of Anatomy and Wood Identification (COTEI/INPA) for confirmation of identification in the field by anatomist J.A. Freitas.

### *2.1 Moisture content (CEN, EN-322/2000)*

The moisture content of the samples (n = 250, 5 species x 50 repetitions) were determined using an electric meter with an accuracy of 90% (Digisystem DUC 2050). The samples were taken to a conventional oven and microwave system (100 ± 5 °C) for a period of 2 h, later the reading was performed on the radial face and the samples were returned to the oven until constant humidity was obtained.

### *2.2 Apparent density (NBR 7190/1997)*

The apparent density was determined by the stoichiometric method, with fixed wood moisture at 12%. A 0.01 g precision digital scale and a digital calliper (Starrett, Series 799) were used in an acclimatized room (20 ± 2 °C, humidity 65 ± 5%). The variable is estimated by the mass x volume ratio from the equation $\rho = m/V$, where m = mass in grams g, and the volume in $cm^3$.

### *2.3 Dynamic modulus of elasticity - MOEd (Barros et al. 2019)*

In this methodology, the variables, voltage wave, are obtained from the Stress Wave Timer 239A (Metriguard) equipment, as shown in the Figure 1, and calculated by the equation $MOEd = (L/t)^2 \times D/g \times 10^{-5}$, where L = specimen length (m), t = wave propagation time (s), D = specimen density ($kg.m^{-3}$) and g = gravity acceleration ($m.s^{-2}$).


**Figure 1**. Overview of stress wave determination: A – Sample subjected to impact; B – Detail of the equipment with the result of the time travelled by the waves.

### *2.4 Data analysis*

Raw data of the physical-mechanical properties were statistically analysed to meet the assumptions of normality, homogeneity and independence of the residues. Analysis of variance (ANOVA) and Tukey's test at 5% were used to compare treatments to assess the influence between species and their resistance. Finally, the principal component analysis (PCA) was performed from property/species data scoring using the Minitab program ® 21.1.

## 3. Results and Discussion

Moisture content is a very important technological trait in studies for the application of raw material wood, given its influence ranging from biological, physical and mechanical resistance. Table 2 presents the results of moisture in the microwave system, and traditional method (artificial drying). In comparing the methods, the microwave system presents better drying performance, and the dry woods in this system have a value of 25.48% lower than the conventional methods. In the manufacturing process of EGP panels, it is recommended that the wood has an average moisture content of 12% to obtain high quality products. The woods submitted to microwave drying provide greater stability in the equilibrium moisture, however, only the Murici, Breu vermelho and Angelim pedra woods presented similar content for this type of panel.

**Table 2**. Result of the moisture determination of the studied woods.

| Woods | Moisture | | | | | |
|---|---|---|---|---|---|---|
| | Artificial drying (%) | F | *p* | Microwave (%) | F | *p* |
| Angelim pedra | 17,68abc | | | 13,10ab | | |
| Angelim vermelho | 18,48a | | | 14,08a | | |
| Breu vermelho | 17,63bc | 5,74 | 0,0052* | 12,98b | 6,72 | 0,0013* |
| Murici | 17,58c | | | 12,72b | | |
| Piãozinho | 18,40ab | | | 14,02a | | |
| Average | 17,96 | | | 13,38 | | |

Measures followed by the same letter do not differ statistically from each other. Tukey test applied at 5% probability level.*Significant at 1% probability level ($p < 1$).

Vinden and Torgovnikov (2000) using microwave drying, obtained time reduction (2x - 10x less) compared to conventional drying. Cavalcante et al. (2016) states that this type of drying is different from the conventional process, depending on the type of heating used, as the difficulty lies in moving the moisture above the saturation point of the fibers. Moisture is an important factor for gluing wood panels, given its reaction with various types of adhesives used by the industry, such as PVAc, and polyurethane (Lopes 2008). During the gluing process, the wood must not have a high moisture content, especially that with high density, since the reduction of the moisture content, which occurs naturally to reach equilibrium moisture with the environment, causes contractions that can result in defects, and tensions in the glue line (Iwakiri et al. 2015).

Apparent density is calculated based on mass, and apparent volume, with wood moisture set at 12%. The results for the woods are presented in Table 3, where they ranged from 0.76 to 1.18 $g.cm^{-3}$, with the study woods being classified as high density, following the standards of tropical woods. The Tukey test revealed that there were no differences between the values of Angelim Pedra, Angelim vermelho, and Breu vermelho woods.

Jesus et al. (2016), studying the behaviour of three Amazonian woods (*Apulea leiocarpa*, *Buchenavia capitata* and *Clarisia racemosa*), arrived at the results of apparent density of 0.63 to 0.86 $g.cm^{-3}$. Dias and Lahr (2004), characterized 40 Brazilian woods, obtaining average results of 0.85 $g.cm^{-3}$, and for the wood of Angelim pedra (*Hymenolobium* sp.) the density was 1.16 and for the Angelim vermelho (*Dinizia excelsa*) was 1.13 $g.cm^{-3}$. In the study developed, the apparent density (average) was 0.98 $g.cm^{-3}$, a value slightly higher than the study by Dias and Lahr, however, for wood from *Dinizia excelsa*, the values were practically

identical.
The results of the dynamic modulus of elasticity (MOEd), as well as the normal distribution, are presented in Table 3 and Figure 2. The average value of the MOEd for the tested woods was 12,498 MPa, with the Angelim vermelho and Piãozinho woods offering higher resistance (14,109, and 14,070 MPa ,respectively), and the Breu vermelho wood presented the lowest value, which was 11,175 MPa. All statistical analyses were performed through standard error analysis (5% of significance) demonstrating that the readings data are within an acceptable range, and that they were tested and showed normality for Angelim pedra woods (p = 0.838), Piãozinho (p = 0.763) and Angelim vermelho (p = 0.528) (Figure 2).

**Table 3**. Results of the determination of apparent density (ρ 12%) and dynamic modulus of elasticity (MOEd) of the studied woods.

| Woods | ρ 12% (g. $cm^{-3}$) | F | *p* | MOEd (MPa) | F | *p* |
|---|---|---|---|---|---|---|
| Angelim pedra | 0.89ab | | | 11,656b | | |
| Angelim vermelho | 1.14ab | | | 14,109a | | |
| Breu vermelho | 0.98ab | 3,54 | 0,0240 | 11,175b | 15.29 | 0.0002* |
| Murici | 0.76b | | | 11,480b | | |
| Piãozinho | 1.18a | | | 14,070a | | |
| Average | 0,99 | | | 12,498 | | |

Measures followed by the same letter do not differ statistically from each other. Tukey test applied at 5% probability level.*Significant at 1% probability level (p < 1).

Lira et al. (2017) used stress waves to assess the quality of the Amazonian tree species *Goupia glabra* and *Ocotea neesiana and* concluded that the technique was able to detect substrates with hollow, and without hollow in standing trees and allowed the grouping of individuals from the MOEd. Costa (2017), characterizing Amazonian woods for making musical instruments, found high values of MOEd for the woods of *Brosimum rubescens* and *Cariniana decandra*, 23,000 and 19,000 MPa, respectively. Carrasco et al. (2017), evaluating mechanical attributes of wood from 29 Brazilian species by non-destructive methodology (impulse excitation), found elastic modulus values for *Peltogyne confertiflora* wood of 14,900 MPa, where this value is close to those of Piãozinho wood (14,070 MPa), and Angelim vermelho (14,109 MPa) which are species of high apparent density.
The analysis of the principal component (PCA) of the physical-mechanical variables indicated the formation of three groups (Figure 3). The Angelim vermelho and Piãozinho clusters show traces of high strength wood, while the Murici cluster is formed by medium to low strength. This information is predictors for the manufacture of EGP panels, where in the interaction with the types of adhesives the panels can be structural or non-structural. According to Nascimento et al. (2021) and Nowak et al. (2021) the technological characterization of Amazonian woods by non-destructive methodology provides robust and satisfactory results generated in a short time, without the need to destroy the sample, and without generating waste, where this principle could be evidenced in this study.

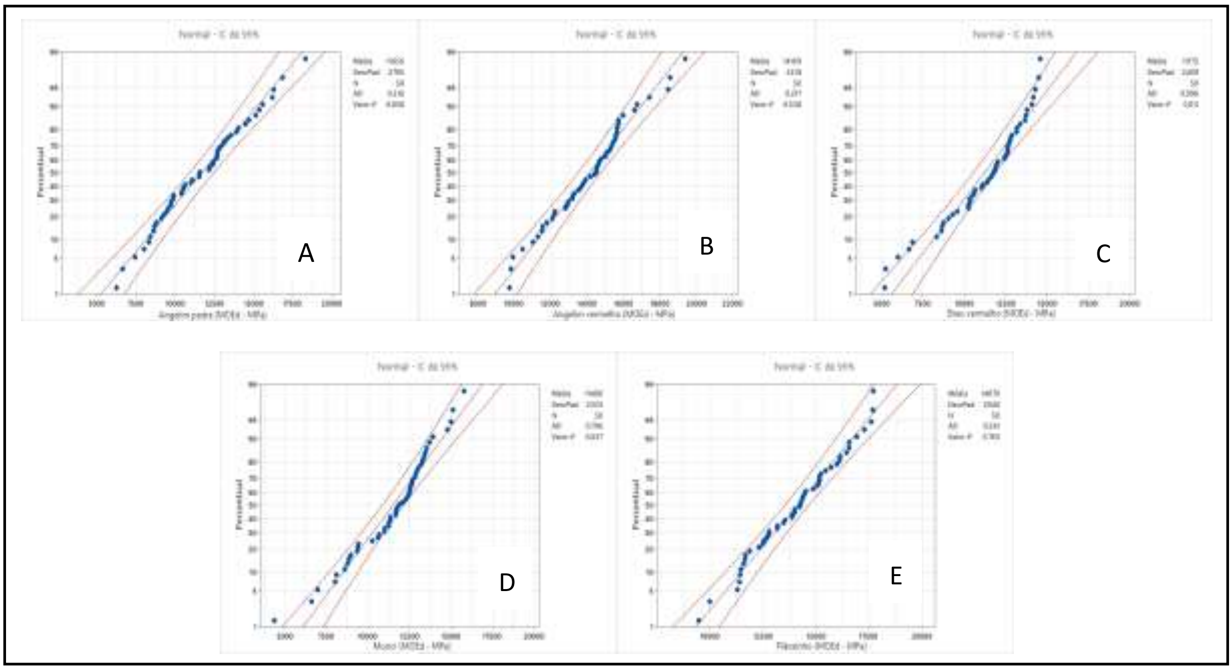


**Figure 2**. Probabilities of estimating the MOEd data for the studied woods: A – Angelim pedra; B – Angelim vermelho, C – Breu vermelho, D – Murici and E – Piãozinho.

P-value > α. P value for the Anderson-Darling (AD) normality test.

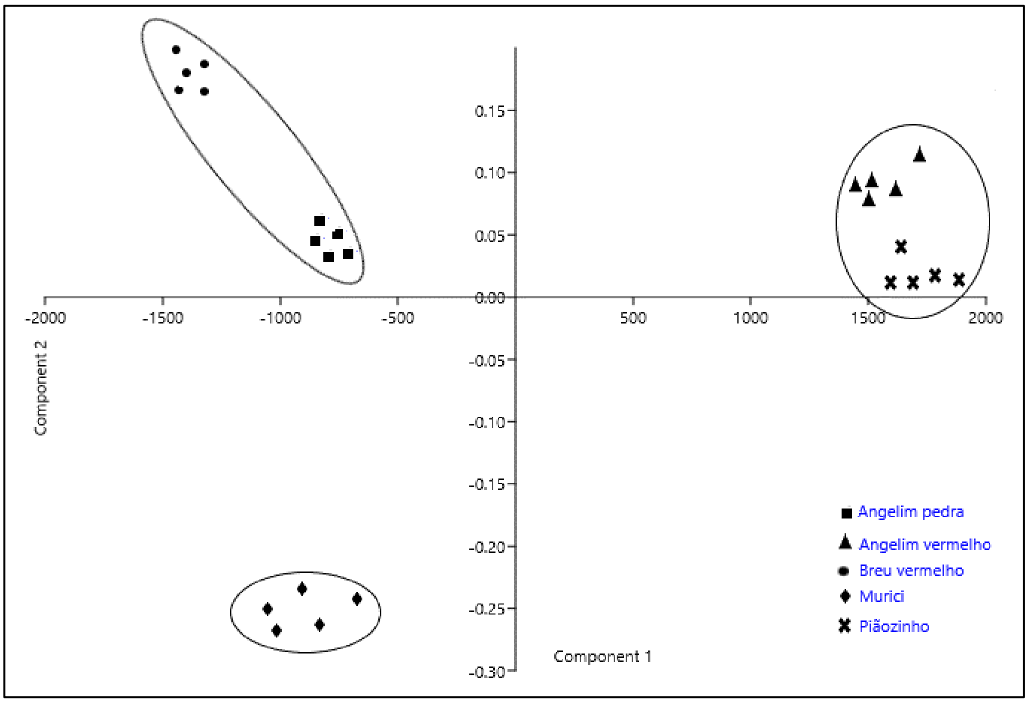


**Figure 3**. Analysis of the principal component of the data of the physical-mechanical properties *x* studied woods.

## 4. Conclusion

The results of the present work allow us to conclude that (i) the microwave system presents satisfactory performance for drying wood as it provides greater stability in equilibrium moisture, where the woods of Murici, Breu Vermelho, and Angelim pedra had a moisture content indicated for the manufacture of EGP panels; (ii) the apparent density of the studied woods was classified as high (> 0.76 g.cm$^{-3}$); (iii) the studied woods presented a dynamic modulus of elasticity between medium and high (11,175 to 14,109 MPa), thus demonstrating good resistance and lower risk of deformation for different uses, including EGP panels, whether structural or not, it being necessary to take into account the type of adhesive; (iv) the quality of the studied woods show promising results for industrial indication since they are little known or non-commercial wood, where technological characterization is a primary tool to assist in decision making in the forest management plans that may indicate the use of new species to the forest sector.

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