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COMPARATIVE STUDY OF PARTICLEBOARDS WITH *HEVEA BRASILIENSIS* WASTE FROM DIFFERENT PRODUCTION AND MOISTURE CONFIGURATIONS

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ABSTRACT

After the production cycle of latex, *Hevea brasiliensis* trees become residual living plants for this activity, although their woody trunks are still potentially subject to industrial utilization. Bio-composites derived from rubberwood particles were manufactured using two different configurations as a strategy to examine the potential of this species with respect to mechanical behavior. Homogeneous panels were developed from particles at the saturation condition, and heterogeneous panels were obtained from dry particles conditioned at 12% moisture content. Both examples were heat-pressed and glued with castor oil-based polyurethane resin. Density, short-term water absorption and thickness swelling, modulus of rupture and modulus of elasticity in the static bending and perpendicular tensile were evaluated. Panels derived from rubberwood particles proved to be viable according to the technical standards.

KEYWORDS: Rubberwood, timber, castor oil-based polyurethane, sawmilling waste.

INTRODUCTION

Brazil has the largest tropical forest as well as the second largest forest cover after only Russia, since about 70% of this covered area has some productive potential. Lumber, plywood and sub-products sectors contribute to about US$ 3 billion for the Brazilian economy, justifying its domestic relevance (SNIF 2020, http://snif.florestal.gov.br/pt-br/cadeia-produtiva), that is why this scenario is eager for training aimed at the transformation of renewable bioresources into bioproducts (De Araujo et al. 2021a). Without a formal stimulus from the Brazilian government for the intensification of forest plantation, the domestic silviculture has an increasing potential due to the broad possibility of wood-based products (De Araujo et al. 2017). The commercial production of planted forests is limited to the predominance of dozens of eucalypt and pine varieties as verified by IBÁ (Annual report 2020), as there are other species with reasonable presences such as teak, black wattle and rubber trees.

From Amazon region, trees of *Hevea* genus have at least 11 species of tropical rainforest climate, being more proliferated in regions of floodplains and riverbanks (EMBRAPA 2021, embrapa.br/agrossilvipastoril/sitio-tecnologico/trilha-ecologica/especies/seringueira). Known as rubber tree or 'seringueira' in the Brazilian language, *Hevea brasiliensis* species produces an important source for the production of natural rubber, that is, latex (Eufrade Junior et al. 2015). Native to Brazil, rubber trees have been cultivated in China since the early 20th Century (Jiang et al. 2020). Currently, rubber trees are significantly utilized in Southeast Asia because of their bioresources (Zhu et al. 2021) as well as they are extremely important sources for the Brazilian production of natural rubber (Souza 2018). The of latex extraction cycle extends between 25 and 30 years, and rubber trees become a low cost source of lignocellulosic material for energy purposes (Eufrade Junior et al. 2015). As a strategy to generate an optional source of income for latex producers after this cycle, recent studies raise proposals to utilize rubberwood for other alternatives such as furniture, lumber and panel (Müzel et al. 2015). Due to attractive color, this wood has been tested for household items, flooring, furniture, and ladder components (Juliana et al. 2012), as it is colored in white or light cream, darkening with age to light brown, being featured by a light hardwood with coarse or moderate coarse textures, and basic density ranging from 0.480 to 0.650 $g \cdot cm^{-3}$ (Lim et al. 2003). A problem related to the use of rubber tree is due to its absence of heartwood, which makes this species more sensitive to attack by fungi and insects in search of its high levels of starch and sugars (Gonçalves 2002).

Recent scientific studies still propose the utilization of rubberwood in the production of activated carbon (Li et al. 2019), and thermally-modified lumber for solid flooring, wallboard, and furniture (Zhao et al. 2019, Jiang et al. 2020, Zhu et al. 2021). But, *Hevea brasiliensis* has not yet been considered as a recommendable species for structural purposes in Brazil, because studies do not include it among those commercial options for timber-based construction and structural parts such as De Araujo et al. (2021b) and Lahr et al. (2021a,b).

Regarding wood processing, general losses in sawing and resawing can range from 20 to 40% of the total volume of processed logs (Finotti 2006). Wooden residues have been used as biomass for the heat and electricity generations, agricultural lining for corrals and stalls as well as for the production of fiberboards and particleboards (Cassilha 2004). Simultaneously, there is the possibility of using particulate residues in the production of wood-based panels.

Particleboards are differentiated based on particle distributions, insofar as a homogeneous panel is featured by a random distribution of particles and a heterogeneous panel, also named as multi-layered panel, has distinct layers organized from granulometry of particles (Iwakiri 2005). Still according to this author, resins represent the highest costs in the panel production. Maloney and Pizzi (1994) stated that about 90% of adhesives applied for panel manufactures through dry processes, i.e. water-free, have required urea-formaldehyde and phenol-formaldehyde resins. A convenient alternative for the panel production includes castor oil-based polyurethane, whose resin is biodegradable and non-polluting according to Araujo (1992) and Wechsler et al. (2013).

Some studies already considered rubberwood for the production of particleboards, for example, Gava et al. (2015), Iwakiri et al. (2018), Faria et al. (2021), Gilio et al. (2021), either as pure raw material composite, waste material, or with mixed species, whose potential utilization of this species may emerge as a viable alternative, above all, after the conclusion of latex cycle.

Therefore, this study aims to evaluate the potential, based on meeting the performance requirements prescribed by technical standards, of panels manufactured from homogeneous and heterogeneous compositions with residual particles of *Hevea brasiliensis* wood species at two different moisture contents, and glued with castor oil-based polyurethane resin.

MATERIAL AND METHODS

This study utilizes particle-shaped residues from sawmilling activities of rubberwood. This waste comes from wooden trunks of 20-year trees of *Hevea brasiliensis* species, formed by Rubber Research Institute of Malaysia (RRIM – 600) clones, planted in the experimental farm at Campus of Ilha Solteira of the São Paulo State University (UNESP), in Ilha Solteira, Brazil. Using a planer machine, trunks of this silvicultural species were processed into wood particles. But, residual particles were also utilized in the development of bio-composites as a strategy to value the perceptible wood losses – which may overcome 40%.

Particle agglutination was supported by castor oil-based polyurethane – a resin with less pollution liabilities compared to traditional options. Formed by two main components, the resin was manufactured by *Imperveg*® company, located at Aguai, Brazil. In addition, the proportion was 1 : 1 ratio of polyol and prepolymer.

Homogeneous panels were manufactured through residual particles directly collected after wood processing – that is, at the saturation moisture.

In contrast, heterogeneous panels were produced through dry particles at 12% moisture content. These particulate materials were conditioned in a laboratory stove at 70°C ± 2°C to obtain a 2 to 3% moisture content – this consideration followed the methods in use by Klímek et al. (2016) and Borysiuk et al. (2020).

Wooden particles were processed in a knife mill equipped with sieves (#10 mm with round holes) to obtain more regularized particles for heterogeneous panels, which were classified by granulometry in accordance with the Brazilian standard document ABNT NBR 9939: 2011 (Coarse aggregate – determination of total moisture content. Test method.).

The evaluation of moisture content of particulate material was carried out using a stove at 103°C ± 2°C during 24 hours, where dry mass was collected every 2 hours, and weight was measured in a point less than 0.1% of dry mass variation.

Two Brazilian standard documents ABNT NBR 6458: 2017 (Gravel grains retained on the 4.8 mm mesh sieve. Determination of the bulk specific gravity, of the apparent specific gravity and of water absorption.) and ABNT NBR 6457: 2016 (Soil samples. Preparation for compactation and characterization tests.) were adopted to determine particle densities.

Test adaptation regarded a pycnometer (#2) calibrated to 500 mm of anhydrous ethyl alcohol (99.3° INPM) with the addition of 10 g of rubberwood material, and a thermometer with 0.1°C graduation at -10°C to 100°C interval.

Homogeneous panels were produced without the uniformity of particle size, which were directly collected in the sawmilling activity. Formed by a single layer, they were defined as "S1 panels". Heterogeneous panels, as described by Gava et al. (2015), were formed by three-layer particleboards named as "S2 panels", where inner layer contained particles from 4.75 to 19.1 mm and outer layers included particles from 1.19 to 4.75 mm using a mass distribution of 30% for each outer layer and 40% for inner layer, following Iwakiri et al. (2003).

All panels were manufactured respecting the following conditions: dimensions of 350 × 350 × 12 mm, nominal density of 0.550 $g \cdot cm^{-3}$, and mass of 810 g. Particles were glued in a percentage of castor oil-based polyurethane adhesive calculated on the dry weight of particles. Homogeneous panels (S1) utilized 10% w/w of this resin, and heterogeneous panels (S2) used 12% w/w in a composition of 4% w/w per layer – this increase was necessary for the greater surface area of finer particles, which require a greater amount of adhesive.

All panel mats were heat-pressed at 5 MPa and 100°C for 10 min. After initial 5 min, each pressing stage was interrupted and opened to release internal gases of panels as followed by Sugahara et al. (2020) and Buzo et al. (2020). After these pressing stages, all panels were conditioned at room temperature for 7 days in order to finish the curing of two-component resin and, therefore, obtain more stable composites.

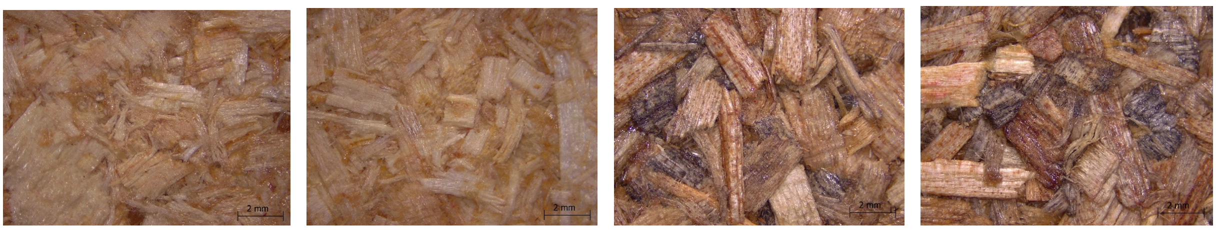
Density (D), short-term water absorption (WA) and thickness swelling behavior after 24 h (TS), moisture content (MC), and modulus of rupture (MOR) and modulus of elasticity (MOE) in the static bending and perpendicular tensile (PT) were the properties under study. Ten specimens per particleboard configuration and each physical and mechanical property were considered in accordance with premises and methods in the Brazilian standard document NBR 14810-1 and 14810-2 (ABNT 2013, ABNT 2018). The Tukey's range test at 5% significance level headed the statistical analysis, where the influence of two panel configurations (homogeneous and heterogeneous types) was studied for each physical and mechanical property.

RESULTS AND DISCUSSION

Initially, biomaterial amounts retained per sieve were measured. Thereby, Tab. 1 describes compositions of rubberwood particles in percentage for both types of panel under analysis. About rubberwood particles at saturation moisture towards homogeneous panels, there was a greater concentration of biomaterial volumes from 12.50 to 1.19 mm sieves with about 87% of total mass of sample as well as 12% of thinner particles in the bottom vessel. Yet, there was a perceptible dispersion of granulometry in the particle sizes (Tab. 1), insofar as 64% of the retained particles corresponded to three sieves (4.75, 2.36 and 1.19 mm). This condition confers a good superficial packing of panel as verified in the Figs. 1a,b.

Tab. 1: Fractional composition of the particles used for two particleboard configurations.

Sieve		Homogeneous panel (S1)	Heterogeneous panel (S2)	
Number	Hole diameter (mm)	Single layer % retained	Inner layer % retained	Outer layers % retained
3/4"	19.10	0.00	3.14	–
1/2"	12.50	5.71	10.86	–
3/8"	9.52	6.86	15.43	–
1/4"	6.30	10.86	19.14	0.00
#4	4.75	11.14	16.29	0.00
#8	2.36	34.00	30.29	23.43
#16	1.19	18.86	4.57	63.14
#20	0.084	–	–	12.57
Bottom	–	12.00	0.00	0.29



(a) (b) (c) (d)

Fig. 1: Particleboard surfaces (8x enlarged photos): (a) superior and (b) inferior surfaces of homogeneous panels, and (c) superior and (d) inferior surfaces of heterogeneous panels.

About rubberwood particles at 12% moisture contents towards heterogeneous panels, there was a greater distribution in the particle sizes for inner layer, varying from 19.10 to 1.19 mm sieves, insofar as they included 99.71% of total mass with loss consideration. Outer layers showed particles from 2.36 to 0.084 mm sieves. Thus, good packing and less void space after resin curing was confirmed and identified by Figs. 1c,d.

Based on Fig. 1, it is possible to observe the modification in the color of rubberwood particles due to water losses and change in the geometry of particles. Particles at the saturation moisture evinced a panel with a more fibrous surface. But, 12%-moisture particles showed a geometric feature, that is, without punctual concentration of resin in the particleboard surfaces, which demonstrated an efficient homogenization of resin among wooden particles.

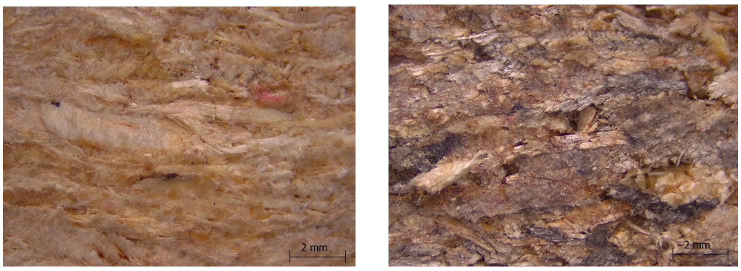
About tests, Tab. 2 exhibits results of particle densities and effective compression ratio for homogeneous (S1) and heterogeneous (S2) particleboards. An increase of compression ratio was observed in the comparison of these examples. There was a lower ratio in the homogeneous panels due to a greater granulometry dispersion showed in the Tab. 1. The greater ratio was caused by the readjustment of the particles in the heterogeneous panels, as evinced by Figs. 2a,b. But, effective compression ratios did not reach the recommended values for both panels – which may vary from 1.3 to 1.6 according to Iwakiri (2005) and Araujo et al. (2019).

From effective density of panels, it is possible to classify particleboards in accordance with the standardized parameter from the NBR 14810-1. Both evaluated panels in Tab. 2 (S1 and S2) were classified as medium density particleboards from this standard document (ABNT 2013), whereas they are in the 0.550 to 0.750 $g \cdot cm^{-3}$ interval.

Tab. 2: Density results for particleboards produced from Hevea brasiliensis species waste.

Panel	Particle density ($g \cdot cm^{-3}$)	Panel density ($g \cdot cm^{-3}$)	Coefficient of variation	Effective compression ratio
S1	0.630	0.693^B	2.53	1.10
S2	0.630	0.745^A	2.92	1.18

** Equal letters represent statistically equivalent means, and A is bigger than B otherwise.*



(a) (b)

Fig. 2: Cross section of particleboards: (a) homogeneous and (b) heterogeneous profiles.

Other properties are obtained (Tab. 3), which included thickness swelling (TS), water absorption (WA), moisture content (MC), modulus of rupture (MOR), modulus of elasticity (MOE), and perpendicular tensile (PT). In this table, coefficients of variation (CV) and values prescribed by the ANSI (2009) and ABNT (2018) were also described.

Tab. 3: Property results for particleboards produced from Hevea brasiliensis species waste.

Property	Homogeneous panel (S1)		Heterogeneous panel (S2)		NBR14810 – 2 (ABNT 2018)	A 208.1 (ANSI 2009)
	Means*	CV (%)	Means*	CV (%)	Values prescribed by standards	
TS – after 24h (%)	15.85^{B}	14.55	22.99^{A}	11.24	22	–
WA – after 24h (%)	78.03^{A}	14.12	76.56^{A}	3.50	–	–
MC (%)	4.72^{B}	10.70	6.45^{A}	4.06	5 – 13	–
MOR (MPa)	12.46^{A}	9.94	8.53^{B}	15.13	11	11
MOE (MPa)	2232^{A}	8.10	1589^{B}	7.40	1800	1725
PT (MPa)	0.92^{A}	10.10	0.84^{A}	14.64	0.40	0.4

** In the mean values, equal letters represent statistically equivalent means, and A is bigger than B otherwise.*

All properties were visibly affected at significance level of 5%, not only by the composition of particles (homogeneous and heterogeneous) but also by the particle moisture contents. For similar configurations with rubberwood particles glued with 12% castor oil-based polyurethane at same moisture contents, Gava et al. (2015) verified that heterogeneous panels were better than homogeneous ones. Due to the use of particles at different moisture contents (saturated and 12%), our study shows otherwise – that is, properties decreased in this comparison (Tab. 3).

Still, the reconfiguration of the single-layer panels to three-layer panels demonstrated an improvement in the water absorption after 24 hours (WA) and moisture content (MC), because a reduction of almost 2% and an increase of about 37% were verified, respectively. In addition, there was a significant increase of 45% in the thickness swelling after 24 hours (TS). But, this result opposes the analysis of Gava et al. (2015), as they described a reduction of 13% in this property for panels produced with raw materials at the same moisture content.

Mechanical properties showed a similar decreasing behavior in the comparative of heterogeneous with homogeneous particleboards (Tab. 3), since modulus of elasticity (MOE), modulus of rupture (MOR) and perpendicular tensile (PT) also decreased about 32%, 29% and 9%, respectively. According to Brito et al. (2020), gradual increases in the compression ratio of panels increase their modulus of rupture in static bending and screw pull-out properties as well as decrease their thickness swelling and water absorption behaviors. Modulus of rupture decreased as well as there was no statistically significant change in the water absorption after 24 hours (Tab. 3).

Heterogeneous particleboards still require specific technical standards to be followed. According to NBR 14810-2 (ABNT 2018) and A 208.1 (ANSI 2009), the homogeneous model was classified as a non-structural panel for internal uses at dry conditions.

CONCLUSIONS

With the effective support of the North-American and Brazilian technical standards, the better feasibility was verified for homogenized configuration for particleboards based on *Hevea brasiliensis* wood species. Homogeneous particleboards were classified for internal uses at dry conditions such as furniture, decoration, and objects. Geometry of particles was changed due to different moisture contents of the biomaterial utilized in the processing, causing the weakening of heterogeneous panels. The greater addition of resin and reconfiguration of layers were not sufficient to meet the performance mechanical requirements for heterogeneous panels.

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