Production of Particleboards from *Hevea brasiliensis* Clones and Castor Oil-based Polyurethane Resin

Maristela Gava,[a,b,]* Sarah D. Müzel,[a,c] Larissa R. de Lima,[c] Juliana Cortez-Barbosa,[a,b] José N. Garcia,[d] Bruno S. Ferreira,[a,c] Henrique J. Servolo Filho,[d] Marcos S. Bernardes,[e] and Victor A. De Araujo [a,d]

The economic exploitation of rubber tree (*Hevea brasiliensis*) usage is primarily directed toward latex extraction. After the productive life of the rubber tree forest, the managed area is harvested for planting reformulation. The harvested wood is most often used for energy generation purposes. The aim of this work was to study the feasibility of using rubberwood waste and castor oil-based polyurethane resin in the production of particleboards. Homogeneous and heterogeneous panels were made with nominal dimensions of 500 x 500 mm and thicknesses of 10 mm using particles from GT1 and RRIM600 clones of the rubber tree and 12% castor oil-based polyurethane adhesive. The panels were pressed at 140 °C for 12 min with 40 kgf/cm^2 specific pressure. Density, moisture content, thickness swelling, water absorption for 2 and 24 h, static bending, and internal bonding determinations were performed according to the Brazilian Standard (NBR) 14810-3 (2006) for the physical-mechanical panel characterization. The results show that using *Hevea brasiliensis* in particleboard production is viable. However, multilayer boards exhibited better results.

Keywords: Physical-mechanical properties; Wooden-based material; Rubber tree; Waste use

Contact information: a: Research Group LIGNO, Rua Geraldo Alckmin, 519, Itapeva/SP, Brazil; b: Department of Wood Industrial Engineering, UNESP – São Paulo State University, Rua Geraldo Alckmin, 519, Itapeva/SP, Brazil; c: Post-Graduation Program of Mechanical Engineering, UNESP – São Paulo State University, Avenida Ariberto Pereira da Cunha, 333, Guaratinguetá/SP, Brazil; d: Department of Forest Sciences, USP – University of São Paulo, Avenida Pádua Dias, 11, Piracicaba/SP, Brazil; e: Department of Agriculture, USP – University of São Paulo, Avenida Pádua Dias, 11, Piracicaba/SP;
** Corresponding author: mgava@itapeva.unesp.br*

INTRODUCTION

Alternative uses for waste materials are commonly studied, especially to solve the problems caused by wood shortages in Europe and, more recently, to reduce the waste generated by the timber industry and achieve more sustainable production (FAO-UN 1997; Ros-Tonen 2007). One solution to this problem is the production of wooden panels.

Wooden composites include a range of products obtained from the disintegration of wood logs into laminas, particles, or fibers, subsequent aggregation with synthetic resins, and consolidation at high temperatures and pressures (FPL 2010; Irle and Barbu 2010). Compared to solid wood, the main advantage of these wooden composites is their more homogeneous structure, which provides more uniform physical-mechanical properties (Irle and Barbu 2010).

The production of panels also enables the use of timber industry by-products such as slabs, leavings, or small-diameter round wood, increasing their value, reducing the demand for wood, and allowing greater usage per hectare of forest (Irle and Barbu 2010).

Particleboard is suitable for industrial use (packaging, container, furniture and cabinetry, and vehicle parts), structural use in construction (ceiling, partitions, formwork and concrete boxes, internal and external walls, subflooring and carpeting, siding, and others), and even for toy manufacture, shelves, and household utensils (Carll 1986; FPL 2010; Kowaluk *et al.* 2011; Buyuksari 2012; Fiorelli *et al.* 2014; Warmbier *et al.* 2014). Wood chipboard, among other wood-based products, has increased in popularity as a raw material because of its profitability and market growth (Zaia *et al*. 2015).

The Brazilian particleboard industry uses rapidly growing plantation species such as pine and eucalyptus (SBS 2006). Although these two species are the most prevalent in Brazil in terms of planted area, other species such as teak, acacia bark, and rubber tree are also of great economic importance for the Brazilian timber sector. The area of rubber tree plantations has increased considerably in recent years, rising from 85,768 ha in 2007 to 168,848 ha in 2012, an increase of 51% in five years (ABRAF 2008, 2013).

The rubber tree is the popular name for a plant of the *Hevea* genus and Euphorbiaceae family. It grows naturally only within the Brazilian Amazon region but has shown great adaptability to varied environments such as the Brazilian Southeast, Midwest, Bahia (Northern state), and more recently, western Paraná (Southern state). It can also be found in other regions, such as in Latin America, Western Africa, South and Southeast Asia, *etc*.

Hevea brasiliensis (Willd. ex. A. Juss.) Müll. Arg. species is economically exploited by producing good-quality latex with high rubber content. Rubber tree plantations have positive environmental impact because they have tropical forest-like characteristics. In addition, natural rubber production does not require much energy, and the trees contribute to CO_2 fixation, helping to minimize problems with the greenhouse gas effect (EMBRAPA 2007; IAC 2012).

Rubber trees have an erect stem with few branches, reaching 30 m tall under favorable conditions. In São Paulo, a Southern Brazilian state, the rubber trees can reach 30 to 35 cm in diameter at breast height (DBH), *i.e.*, a suitable size for cutting (IAC 2012; Juliana *et al*. 2012).

Latex extraction begins in the sixth year after planting, but the production does not reach its peak until around the tenth year, and the tree remains productive for about 25 years (Srinivasakannan and Abu Bakar 2004). After latex extraction in a forest field is no longer economically viable, characterizing the end of their productive lives, the trees are harvested for a new planting (Kurdthongmee 2008). In Brazil, this timber obtained at the end of the latex production cycle is traditionally used almost exclusively for energy generation purposes (Leonello *et al*. 2012).

Rubber tree wood has good workability and, according to Lim *et al*. (2003), exhibits no difference between its heartwood and sapwood and has straight to interlocked grain. Kurdthongmee (2008) and Lim *et al*. (2003) found that the density of *Hevea brasiliensis* to be around 0.48 to 0.65 g/m^3, varying according to genetic, environmental, and physiological factors. Kurdthongmee (2008) state that rubberwood has characteristics that qualify it as an excellent material for various purposes, such as furniture production and ceiling and stairs construction.

Abdul Halip *et al*. (2014) state that the addition of rubberwood particles greatly improved various properties of the particleboards produced with urea-formaldehyde.

With the global trend toward the use of biodegradable products from renewable, clean inputs, polyurethane resins based on castor oil have been discovered (Fiorelli *et al.* 2014). This type of resin presents as a promising alternative in the particleboard production (Dias 2008).

Castor oil-based polyurethane resin was initially developed for bone grafting in medicine, characterizing it as not aggressive for the environment and for humans (Dias 2008). This adhesive has been used in Brazilian studies and has shown promising results, because it is more ecologically friendly than purely chemical-based adhesives such as urea-formaldehyde, whereas it uses castor beans, a natural material (Zaia *et al*. 2015). Lastly, Dias (2008) emphasizes that the curing of this resin occurs at room temperature, but it could be accelerated with a temperature ranging from 60 to 90 °C.

This work was done to evaluate the potential use of *Hevea brasiliensis* wood with castor oil-based polyurethane resin to produce wooden particleboards from rubber tree material arising from planting reformulation, which is frequently characterized as wood waste.

EXPERIMENTAL

Materials

The main inputs used in this work were the wood of the rubber tree and a castor oil-based polyurethane resin. *Hevea brasiliensis* wood was obtained from GT1 and RRIM600 clones, approximately 25 years old, from an experimental plantation located in Piracicaba, São Paulo state in Brazil. The equipment and materials used were a band saw, circular saw, woodchipper, wood mill, drier, sieves (20- and 32-mesh), forming box (mat) and industrial mixer. The castor oil-based polyurethane resin used was acquired directly from a local producer.

The particles used in this study were obtained from a mixture of waste generated during the initial sawing of the rubber tree logs (slabs) and also from the tested samples (from another academic study), with the latter used in static bending testing.

Methods

The particles used were initially characterized in terms of their physical and chemical properties.

The moisture content test was carried out by means of a gravimetric analysis for wood particles. In this analysis the initial sample was measured in a Becker (tare weight) and after it was led to a drier during 24 h. After this period, it was measured over again, obtaining the final weight of the sample.

The total extractives content of particles test was realized according to the international standard TAPPI T204 cm-97 (1997). The pH test was realized according to TAPPI T252 om-98 (1998), in the situations of hot and cold materials, using a pH-meter.

Two kinds of panels were produced. The first model was a panel with homogeneous layer and the last one with multilayer (heterogeneous).

Initially, the mixture of samples (tested and sawn) with variable dimensions and forms of rubber wood were cut into smaller pieces using the circular saw and band saw. Then, the smaller pieces were machined in a woodchipper to reduce their sizes into chips/flakes, and finally, they were machined in a wood mill to obtain the particles of rubberwood.

The homogeneous boards contained particles retained in a 20-mesh sieve, and the heterogeneous boards contained various different particle sizes, with particles retained in a 20-mesh sieve for the inner layer and particles retained in a 32-mesh sieve for the outer layers.

Bonding was done with castor oil-based polyurethane resin at 12% (dry mass) proportion. This resin was mixed with the particles of rubberwood in an industrial mixer. In the production of each panel, 2 kg of particle material was glued and arranged in a single layer in the forming box to obtain homogeneous panels. For the heterogeneous panels, particles were arranged in three layers at a 1:2:1 (outer:inner:outer layers) ratio. Two panels were produced with nominal dimensions of 500 x 500 mm and thicknesses of 10 mm for each treatment (homogeneous and heterogeneous). This particle amount of 2 kg was the suitable weight for a nominal density of 0.80 g/cm^3.

The panels were pressed at a temperature of 140 °C and 40 kgf/cm^2 of specific pressure for 12 min. After the pressing stage, the boards were placed in a climate-controlled chamber at a temperature of 20 ± 2 °C and 65 ± 3% relative humidity for 72 h to allow curing, according to NBR 14810-2 (2002).

Tests were conducted to determine the moisture content, density, static bending, internal bonding, thickness swelling, and water absorption (for 2 and 24 h) of the panels. The compaction ratio (CR) was realized through the determination of the average values for the board density as well as the wood density, according to the NBR 7190 (1997).

Statistical analysis was performed with the statistics program "R" (2.15.2-1 2012 version). The design was completely randomized, and the results were evaluated by analysis of variance (ANOVA) using Student's t test and the Tukey test at a significance level of 5%.

RESULTS AND DISCUSSION

Physical-Chemical Analysis

The physical-chemical characteristics of rubber wood are shown in Table 1.

Table 1. Chemical Analysis of *Hevea brasiliensis* Wood

Analyzed Property	Value
Moisture Content of Particles (%)	9.21
Total Extractives Content of Particles (%)	14.55
pH (hot)	7.28
pH (cold)	6.43

According to Kollmann *et al*. (1975), the moisture content of the particles after drying and before the application of the adhesive can vary between 3% and 12%. The value obtained in this study was within the allowable range (Table 1). Iwakiri (2005) stated that the percentage of extractives in wood can vary from 5% to 30%. The interaction of wood with adhesive is better when the extractives content is smaller. In general, rubberwood has low extractives content compared to other species because of its high starch content: approximately 8% (Santana and Eiras 1999). The average value for this wood species is close to the range noted by Iwakiri (2005) as acceptable for the manufacture of particleboards.

The difference between the value obtained and the values found in literature could be related to the location, planting time, weather, and other factors that influence the chemical properties of woods.

With respect to pH, the wood samples had near-neutral values, a fact that reveals a positive aspect. Wood species with low pH influence in the resin curing used in the gluing stage (Dias 2005), and this situation accelerates its curing (Irle and Barbu 2010).

Density and Moisture Content

According to the Brazilian standard NBR 14810-3 (2006), all boards produced in this study can be classified as high-density (Table 2).

Table 2. Average Density and Moisture Content of the Panels

Layer Type	Density (kg/m^3)	CV (%)	Moisture Content	CV (%)
Homogeneous	842.50 a	6.79	5.74 a	4.17
Heterogeneous	879.84 a	5.61	6.08 a	4.24

Averages with the same letter do not significantly differ from one another (Tukey p > 5%); CV: Coefficient of Variation.

The values obtained for the moisture content in both treatments were within the permitted range of variation both for standards NBR 14810-3 (2006) and EN 312 (2003). These standards state that the moisture content in particleboard can vary from 5% to 8% and 5% to 13%, respectively. The statistical analysis revealed no difference between the two treatments. The CR values were 1.76 for Homogeneous boards and 1.80 for Heterogeneous boards.

Thickness Swelling (TS)

The panels made with multiple layers exhibited TS values higher than those with homogeneous layers. The difference was statistically significant after 24 h (Table 3).

Brazilian standard NBR 14810-3 (2006) only specifies a guideline value for the TS after 2 h of immersion, at 8%. Both types of panels met this requirement.

Table 3. Average Values of Thickness Swelling

Layer Type	TS after 2 h (%)	CV (%)	TS after 24 h (%)	CV (%)
Homogeneous	3.72 a	13.02	17.09 a	6.18
Heterogeneous	3.58 a	7.92	14.88 b	9.65

Averages with the same letter do not significantly differ from one another (Tukey p > 5%); CV: Coefficient of Variation

According to the European standard EN 312 (2003), the panels were fit for general purpose and furniture use. They can also be classified as structural use panels and special structural use panels for use in dry conditions, which require TS values after 24 h of immersion below 16% and 15%, respectively.

Water Absorption (WA)

Table 4 shows the WA values after 2 and 24 h of immersion. The Brazilian and European standards do not present reference values for the water absorption parameter because this kind of panel is not suitable for prolonged, direct contact with water. It was observed that the type of layer did not interfere with water absorption.

Table 4. Average Values of Water Absorption

Layer Type	WA after 2h (%)	CV (%)	WA after 24h (%)	CV (%)
Homogeneous	10.16 a	14.81	38.80 a	6.18
Heterogeneous	10.63 a	19.43	37.80 a	10.00

Averages with the same letter do not significantly differ from one another (Tukey p > 5%);
CV: Coefficient of Variation

The average water absorption values in this study were lower than those presented by Iwakiri *et al*. (2010) for panels produced with three different species of pine and urea-formaldehyde resin (UF), which ranged from 83.74% to 90.67% after 24 h of immersion. They were also lower than the average values reported by Okino *et al.* (2000), who produced panels using *Hevea brasiliensis* wood with urea-formaldehyde resin and found average 2- and 24-h WA values ranging from 39.8% to 61.1% and 61.3% to 74.3%, respectively. Lower WA values were expected because castor oil-based polyurethane resin is known to have lower affinity for water than the traditional UF adhesive commonly used in particleboard manufacturing.

Internal Bonding (IB)

In the IB tests, all the types of panels exceeded 0.4 MPa, the minimum requirements of standard NBR 14810-3 (2006) for panels 8 to 13 mm in thickness. Table 5 shows that the highest values were achieved with the multilayer panels and that statistically, there was a difference between the IB of the treatments.

Table 5. Average Values of Internal Bonding

Layer Type	IB (MPa)	CV (%)
Homogeneous	2.68 b	11.61
Heterogeneous	3.26 a	13.72

Averages with the same letter do not significantly differ from one another (Tukey p > 5%);
CV: Coefficient of Variation

According to European standard EN 312 (2003), for panels with thicknesses from 6 to 13 mm, the internal bonding values found in this study qualify the boards as suitable for use in different areas. This includes general uses, furniture use, and special structural use, all in wet or dry conditions.

Static Bending (SB)

In static bending tests, the Brazilian standard recommends a minimum modulus of rupture (MOR) of 18 MPa, achieved in the multilayer panels (Table 6). It was noted that the average MOR was significantly lower for the homogeneous panels. The multilayer boards had increased resistance to static bending because they contained smaller particles in their outer layers. This situation provides better interaction between the adhesive and the particles, resulting in better bonding. From an economic point of view, the boards whose MOR was below the minimum prescribed by standard NBR 18410-3 (2006) should not be considered unsuitable for use insofar as the companies have already produced medium-density particleboards (MDP) with SB values below the standards specifications. For example, Berneck and Tafibra produced MDP with MOR values of 13 and 10 MPa, respectively (Berneck 2013; Tafibra 2013).

Regarding the modulus of elasticity (MOE), the Brazilian standard did not have reference values. However, it is possible to verify that the layer type can affect this property. As with the MOR, the average MOE of the homogeneous boards was significantly lower than that of the heterogeneous boards.

Table 6. Average Values of Modulus of Rupture and Modulus of Elasticity

Layer Type	MOR (MPa)	CV (%)	MOE (MPa)	CV (%)
Homogeneous	13.21 b	20.88	1893.55 b	18.79
Heterogeneous	18.79 a	10.09	2594.98 a	9.77

Averages with the same letter do not significantly differ from one another (Tukey p > 5%);
CV: Coefficient of Variation

According to the European standard EN 312 (2003) for panels with thicknesses from 6 to 13 mm, the MOE and MOR values found in this study qualify the homogeneous boards as suitable for general and furniture use.

Nevertheless, the heterogeneous boards are suitable for general, furniture, and structural use. Both types of boards produced should be restricted to use in dry locations. Table 7 shows values obtained by Paes *et al*. (2011), Iwakiri *et al*. (2010), and Okino *et al*. (2000) for the same properties as those evaluated in the present research.

Paes *et al*. (2011) produced *Pinus elliottii* Engelm wood panels with bi-component polyurethane resin (PU). Iwakiri *et al*. (2010) manufactured *Pinus caribaea* var. *caribaea* and *Pinus caribaea* var. *bahamensis* particleboards with urea-formaldehyde resin (UF). Okino *et al*. (2000) used *Hevea brasiliensis* wood from clones IAN 717, IAN 873, GT 711, and AVRO 130, all with urea-formaldehyde adhesive. The highlighted column refers to the values found in this study.

It was verified that, in general, the particleboards produced in this study exhibited good physical-mechanical performance in that the results obtained were consistent with those given in the literature (Table 7). Thus, the panels produced were superior to the commercial boards of Pine and urea-formaldehyde, popular in South America.

Table 7. Physical and Mechanical Properties of Particleboards

Properties	Paes *et al*. (2011)	Iwakiri *et al*. (2010)	Okino *et al*. (2000)	*Current study	
				Hom	Het
Wood Species	*Pinus elliottii*	*Pinus caribaea*	*H. brasiliensis*	*H. brasiliensis*	
Resins	PU	UF	UF	PU	
Density (kg/m^3)	720 to 890	676 to 694	700	842.50	879.84
TS 2 h (%)	7.43 to 9.71	–	20.30 to 25.30	3.72	3.58
TS 24 h (%)	15.51 to 16.91	25.35 to 31.34	28.50 to 31.80	17.09	14.88
WA 2 h (%)	3.91 to 20.73	–	39.80 to 61.10	10.16	10.63
WA 24 h (%)	43.70 to 16.54	83.74 to 90.67	61.30 to 74.30	38.80	37.80
IB (MPa)	0.85 to 1.72	0.58 to 1.14	0.60 to 0.65	2.68	3.26
MOR (MPa)	5.73 to 14.42	12.03 to 18.08	17.30 to 20.90	13.21	18.79
MOE (MPa)	675 to 636	1866 to 2515	2600 to 3000	1894	2595

Hom: Homogeneous; Het: Heterogeneous

CONCLUSIONS

1. Rubberwood has great potential for use in the production of particleboards because the panels produced in this study complied with the minimum requirements prescribed by Brazilian and European particleboard standards.
2. The production of multilayer particleboards improves the physical and mechanical characteristics of these panels.

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