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ORIGINAL ARTICLE

Potential of rubberwood (*Hevea brasiliensis*) for structural use after the period of latex extraction: a case study in Brazil

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Abstract In Brazil, after the cycle of latex extraction, rubber plantations are reformulated and the wood of these plantings are traditionally used as a cheap source for energy purposes. Rubberwood has other uses based on the consolidated experience in Asian countries. The aim of this article was to evaluate the technological potential of the wood of two main commercial clones of *Hevea brasiliensis* in Brazil, RRIM600 and GT1, after the period of latex extraction. To accomplish this objective, some physical and mechanical properties of wood were analyzed. The clones had a basic density greater than 0.540 g cm^{-3}, low volumetric shrinkage (<10 %), and medium to high strength in compression parallel to grain (>40 MPa). According to the results obtained, rubberwood has applications in small and secondary structures, lightweight construction, and furniture industry and it can be an alternative in the Brazilian market to reduce the timber demand from native forest species.

Keywords Basic density · *Hevea brasiliensis* · Mechanical properties · Wood technological potential

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Introduction

The rubber tree or *Hevea brasiliensis* is indigenous to the Amazon forest in Brazil [1, 2] and is commercially exploited for the production of latex, which is the raw material used in the manufacture of natural rubber. It arrived in Asia in 1877 by way of the British Colonial Office. Initially, rubber trees were grown experimentally in Sri Lanka, from where they were brought to Singapore and Malaysia [3].

Nowadays, rubber plantations are found in many parts of South and Southeast Asia, Africa, and South America [4]. The global area of rubber plantations is more than 9 million hectares, located mainly in Asia. Indonesia, Thailand, and Malaysia stand out among the major producers of rubberwood in 2010, with, respectively, 86, 48, and 71 % of their plantation forest area with *Hevea brasiliensis* and totaling more than 6 million hectares [5].

The availability of rubberwood has been driving the success of the wood industry in Malaysia and Thailand in recent years [6, 7]. Rubberwood has become established as one of the major timbers for the production of furniture and indoor building components. It can be used as wood-based panels, chipboard, cement-bonded board, medium-density fiberboard, and furniture [3, 8–10]. The wood of the rubber tree is light, has a uniform color that varies from white to cream, and has a homogeneous texture, and the sapwood is not easily distinguishable from the heartwood [8, 10].

In Brazil, the rubber plantation area is about 169,000 ha, which are mostly located in the Sao Paulo State [11]. The clones GT1 (from Gondang Tapen—Indonesia) and RRIM600 (from Rubber Research Institute of Malaysia) dominate the Brazilian market.

After the cycle of latex extraction of *Hevea brasiliensis* (an average of 25–30 years), the rubber plantations in Brazil are reformulated and the wood of these plantings is

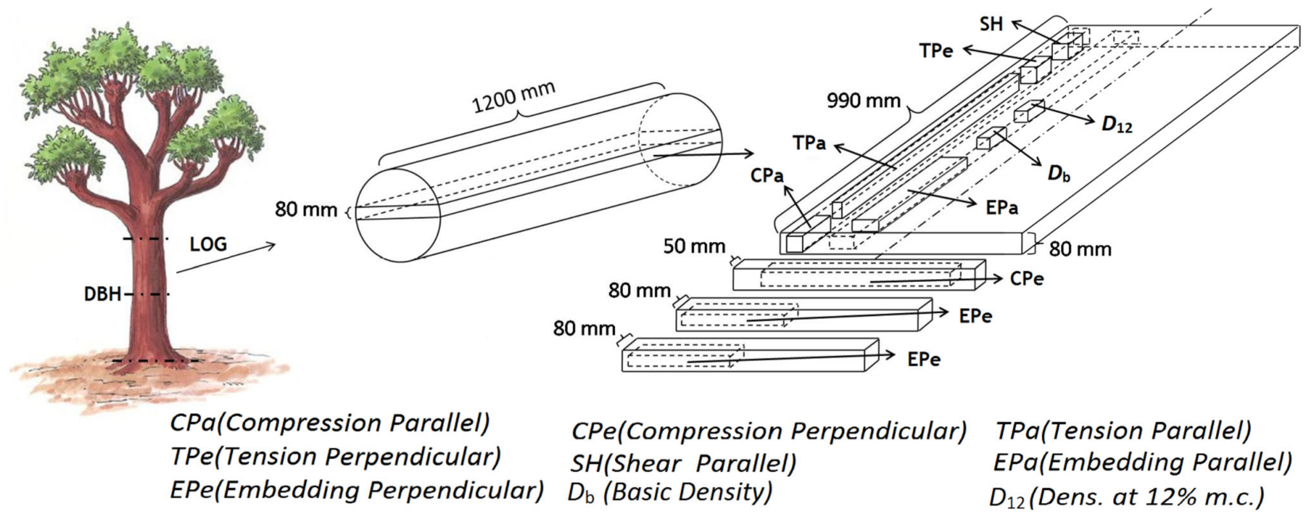

Fig. 1 Sample cutting plane of the half of central plank

traditionally used as a cheap source for energy purposes. However, based on the consolidated experiences in Southeast Asia, rubberwood has potential for other value-added applications.

Rubberwood is an alternative that is used for replacing timber from natural forests [6–8]. Furthermore, it is an option in the wood market to decrease the demand for native species exploited in a predatory manner in Brazil.

In Brazil, studies have been directed toward the use of rubberwood from trees that are more than 30 years old [12]. It was demonstrated that the tapping panel does not influence the properties of rubberwood [13]. However, to use wood to its best advantage and most effectively in engineering applications, specific characteristics or physical properties should be considered [14].

The aim of this article was to evaluate the technological potential of the wood of main commercial clones of *Hevea brasiliensis* in Brazil, RRIM600 and GT1, after the period of latex extraction, through characterization of its physical and mechanical properties.

Materials and methods

Sampling and material preparation

The sample trees were obtained from two clones of *Hevea brasiliensis* (RRIM600 and GT1) plantations, located, respectively, in the cities of Macaubal (20°44′S and 49°56′W) and Itajobi (21°18′S and 49°01′W) situated in the northwest region of Sao Paulo State, Brazil. These plantations were managed to explore latex with a population density of 270 trees per hectare. Both locations have an average altitude of 490 m, a mean annual precipitation of about 1240 mm/year, and an annual average temperature of 23.5 °C.

Six trees of each clone were randomly selected from RRIM600 plantation (30 years old) and GT1 plantation (20 years old). A log (1.20 m length) was cut at the region immediately above the breast height (DBH) from each tree and subsequently, a central board (80 mm thick) was sawed from each log.

From each side of the central board, clear specimens (75 × 75 × 990 mm) from mature wood zone were sawed and conditioned to equilibrium in a climate-controlled room under 65 % relative humidity and 21 °C (approximately 12 % EMC—equilibrium moisture content). After acclimatization, specimens in nominal dimension according to Brazilian standard NBR 7190 [15]—standard based on the Eurocode 5 [16]—were prepared according to physical and mechanical tests (Fig. 1), using 12 samples for each specific test of each clone.

Physical tests

Measurements of maximum shrinkage (β), basic density (D_b), and apparent density at 12 % of moisture content (D_{12}) were conducted in 2 × 3 × 5 cm specimens.

Maximum shrinkage was evaluated by means of the percentual variation of the volume of the specimens (measurements performed in the three main elastic directions—longitudinal, radial, and tangential—accuracy 0.001 mm) after complete saturation and after a complete kiln-dry process.

Basic density (D_b) was determined by the ratio between the dry mass and saturated volume of the specimens. Apparent density was evaluated in acclimatized specimens by the ratio of its mass and volume at that current moisture content (MC). To correct the obtained value to nominal 12 % EMC (D_{12}), the model proposed by Rezende et al. [17] was utilized, which, based on the study of Kollmann and Côté [18], suggested the experimental Eq. 1. This model relates the density at any moisture content ($D_{u\,\%}$) ranging from 0 to 25 % MC with a density at 0 % MC. (D_0). Therefore, the D_{12} was obtained from D_0 using the same simplified equation (Eq. 2).

$$D_{u\%} = D_0(1 + 0.01u\%)\left(1 - \frac{0.0084u\%D_0}{1 + 0.28D_0}\right) \quad (1)$$

$$D_{12\%} = \frac{1.12D_0 + 0.2007D_0^2}{1 + 0.28D_0} \quad (2)$$

Mechanical tests

Mechanical characterization of rubberwood was carried out with the following tests: compression strength parallel ($\sigma_c\|$) and perpendicular to grain ($\sigma_{c\perp}$); modulus of elasticity in compression strength parallel to grain ($E_c\|$); tension strength parallel ($\sigma_t\|$) and perpendicular to grain ($\sigma_{t\perp}$); shear strength parallel to grain (σ_s); and embedding strength parallel ($\sigma_e\|$) and perpendicular to grain ($\sigma_{e\perp}$).

These tests were performed in a computer-controlled 300 kN eletromechanical testing machine in the Material Tests Laboratory at the College of Agricultural Science (FCA) of the Sao Paulo State University (UNESP) in Botucatu-SP, Brazil. Strains were evaluated using a standard mechanical strain gauge extensometer (accuracy 0.001 mm).

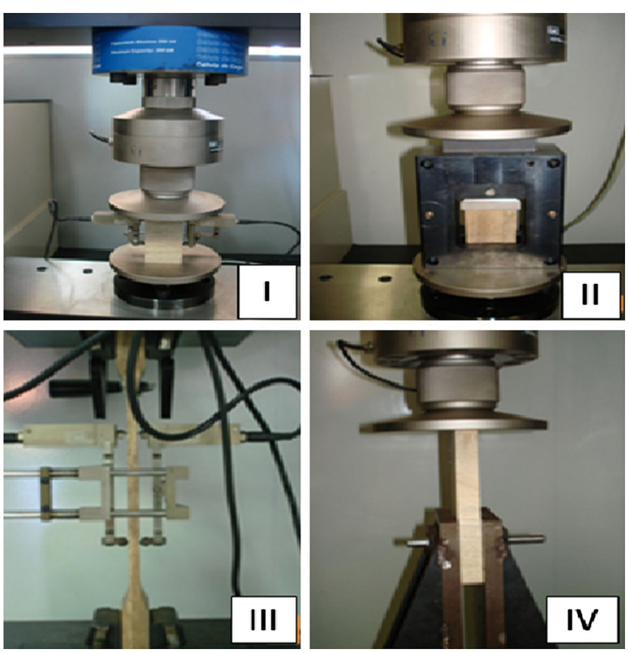

Fig. 2 Test types, *I* compression, *II* shear, *III* tension, and *IV* embedding

All the variables of mechanical tests were adopted according to NBR 7190 [15]. A loading speed of 2.5 MPa/min (for tests perpendicular to grain) or 10 MPa/min (tests in parallel direction) was used in the trials (Fig. 2). Initial results of strength and elastic properties (modulus of elasticity) were corrected to the EMC (12 %) using a conversion coefficient of 3 % (of variation per 1 % of MC variation) for strength properties and 2 % for elastic properties.

According to Brazilian standard, the ultimate strength in compression perpendicular to grain was calculated and reported by the stress at 2 ‰ recoverable nominal compressive strain. For these tests, stresses at proportional limit were also evaluated and reported.

Statistical methods of analysis and results

Basic statistics (central tendencies and dispersion) was used in the report of physical and mechanical properties. In addition, for strength properties, the characteristic value was also reported. The characteristic 5-percentile value is a safety value (lower than the average value) that has only 5 % probability of not been attained in a hypothetical unlimited test series [19], that commonly uses order statistics in its calculation [20, 21]. The characteristic value was determined by means of a simplified expression proposed by the Brazilian standard (Eq. 3).

$$\sigma_k = \left(2\frac{\sigma_1 + \sigma_2 + \cdots + \sigma_{\frac{n}{2}-1}}{\frac{n}{2} - 1} - \sigma_{\frac{n}{2}}\right) \quad 1.1, \quad (3)$$

where σ_k is the characteristic value of strength of the wood to the test considered and "n" is the number of specimens.

To use Eq. 3, some considerations should be attended to: (1) strength results of specimens should be placed in ascending order $\sigma_1 \le \sigma_2 \le \cdots \le \sigma_n$; (2) if the number of specimens is odd, one should exclude the highest value; and (3) the characteristic value (σ_k) should neither be less than σ_1 nor less than 70 % of the average value (σ_m).

In the Brazilian standard, the characteristic value of compression strength parallel to grain ($\sigma_c\|_{,k}$) is used to classify the wood in the system of strength classes (Table 1), guiding the choice of the most suitable species for structural projects.

Results and discussion

Shrinkage values of rubberwood clones are summarized in Table 2. Clones revealed almost the same values of shrinkage. Total shrinkage is an important property in the wood industry, because dimensional changes may cause distortion and collapse of semi-finished products [22]. The

Table 1 Strength classes and characteristic values for hardwoods at 12 % m.c., according to the NBR 7190

HARDWOODS					
Classes	$\sigma_{c\|\|,k}$ (MPa)	$\sigma_{s,k}$ (MPa)	$E_{c\|\|,m}$ (MPa)	D_b (g cm^{-3})	D_{12} (g cm^{-3})
C20	20	4	9500	0.500	0.650
C30	30	5	14,500	0.650	0.800
C40	40	6	19,500	0.750	0.950
C60	60	8	24,500	0.800	1.000

Table 2 Shrinkage (β) for clones RRIM 600 and GT1

Clones	Age (years)	β_t (%)	β_r (%)	β_l (%)	β_v (%)	β_t/β_r
H. brasiliensis–GT1	20	5.8	2.7	0.2	9.3	2.2
H. brasiliensis–RRIM600	30	5.8	2.5	0.6	9.5	2.3

values of volumetric shrinkage were lower than 10 %, and they were classified as low shrinkage according to Zhang and Koubaa [23]. Although the plantations studied were younger, the coefficients of anisotropy of shrinkage (ratio of tangential to radial shrinkage) in clones were similar to those reported by Severo et al. [13] for rubber trees in Brazil that were 53 years old.

Other results obtained for physical and mechanical tests are summarized in Table 3. Average basic densities were 0.541 g cm^{-3} for GT1 and 0.553 g cm^{-3} for RRIM600; results revealed a low variability that can be considered an advantage, when using rubberwood in industrial processes, for example, wood-based panel production. Our results were higher than those cited by Santana et al. [24] for other older clones in Brazil. Other researchers obtained basic densities from 0.560 to 0.650 g cm^{-3} for rubberwood in Asian countries [3, 25–28].

The apparent wood densities (mass and volume at 12 % MC) obtained were 0.662 and 0.678 g cm^{-3} for GT1 and RRIM600, respectively. These results were similar to those from Severo et al. [13], who studied rubberwood after the cycle of latex extraction in Brazil. According to the classification used for timbers in Malaysia by Wong et al. [29], wood of two clones studied can be classified as light hardwood. Rubberwood was also ranked as low wood density according to Chowdhury et al. [30].

The average strength in compression parallel to grain was 49.83 MPa for GT1 and 43.53 MPa for RRIM600. Despite the proximity of the two experimental areas—which suggests similarity in environmental conditions—and the similarity of plantations management, the GT1 clone when compared to RRIM 600 revealed higher strength in compression parallel (statistically different), even though younger and lighter (densities statistically equal). The reverse trend observed in densities and compression strength parallel of the clones might be attributed to other intrinsic characteristics of the wood of the clones, not evaluated in the experimental program, e.g., disposition of fibers. This

Table 3 Physical and mechanical properties of the clones (GT1 and RRIM 600)

Properties	$D_{12}^{(1)}$ (g cm^{-3})	D_b $^{(2)}$ (g cm^{-3})	$E_{c\|\|}^{(3)}$ (MPa)	$\sigma_{c\|\|}^{(4)}$ (MPa)	$\sigma_{t\|\|}^{(5)}$ (MPa)	$\sigma_{e\|\|}^{(6)}$ (MPa)	$\sigma_s^{(7)}$ (MPa)	$\sigma_{c\perp}^{(8)}$ (MPa)	$\sigma_{c,p\perp}^{(9)}$ (MPa)	$\sigma_{t\perp}^{(10)}$ (MPa)	$\sigma_{e\perp}^{(11)}$ (MPa)
Clone GT 1											
Arithmetic mean	0.662	0.541	12.61	49.83	76.45	48.15	9.43	11.24	5.94	4.23	NA
CV (%)	7.5	4.4	11.5	7.5	21.3	8.9	18.7	8.5	15.2	25.9	NA
Median*	0.663a	0.535a	12.75a	48.64a	78.43a	48.03a	8.89a	11.49a	6.14a	3.97a	NA
Clone RRIM 600											
Arithmetic mean	0.678	0.553	9.92	43.53	70.92	44.39	9.60	11.38	6.16	4.04	21.44
CV (%)	4.5	6.3	10.4	8.6	25.6	16.7	17.4	16.9	14.8	15.3	9.5
Median*	0.681a	0.550a	9.47b	42.44b	74.83a	47.70a	9.29a	11.72a	6.05a	4.11a	22.03

CV coefficient of variation (%), *NA* data not available

* Medians followed by the same letter in the same column are not statistically different (Mann–Whitney test, $p > 0.05$). D_{12} density at 12 % of moisture content, D_b basic density, $E_{c\|\|}$ modulus of elasticity in compression parallel, $\sigma_{c\|\|}$ compression strength parallel, $\sigma_{t\|\|}$ tension strength parallel, $\sigma_{e\|\|}$ embedding strength parallel, σ_s shear strength parallel, $\sigma_{c\perp}$ compression strength perpendicular, $\sigma_{c,pl\perp}$ compression stress perpendicular at proportional limit, $\sigma_{t\perp}$ tension strength perpendicular, $\sigma_{e\perp}$ embedding strength perpendicular

Table 4 Comparison of some physical and mechanical characteristics with other timbers at 12 % of moisture content

Common name	D_b (g cm^{-3})	β_r (%)	β_t (%)	β_v (%)	β_t/β_r (%)	$\sigma_{c\|}$ (MPa)	σ_s (MPa)	$\sigma_{t\perp}$ (MPa)	References
Ash black	0.45	5.0	7.8	15.2	1.6	41.20	10.80	4.80	[33, 34]
Cherry, black	0.47	3.7	7.1	11.5	1.9	49.00	11.70	3.90	[33, 34]
Elm (American)	0.46	4.2	9.5	14.6	2.3	38.10	10.40	4.60	[33, 34]
Maple red	0.49	4.0	8.2	12.6	2.1	45.10	12.80	NA	[33, 34]
Oak, red (black)	0.56	4.4	11.1	15.1	2.5	45.00	13.20	NA	[33, 34]
Douglas-fir (north)	0.45	3.8	6.9	10.7	1.8	47.60	9.70	2.70	[33, 34]
Tamarack	0.49	3.7	7.4	13.6	2.0	49.40	8.80	2.80	[33, 34]
Mahogany, true	0.45	3.0	4.1	7.8	1.4	46.70	8.50	NA	[33, 34]
Mahogany, african	0.42	2.5	4.5	8.8	1.8	44.50	10.30	NA	[33, 34]
Meranti,yellow	0.46	3.4	8.0	10.4	2.3	40.70	10.5	NA	[33, 34]
Teak	0.55	2.5	5.8	7.0	2.3	58.80	13.00	NA	[33, 34]
Southern pine	0.40	3.4	6.3	10.5	1,8	40.40	7.40	2.50	[15, 35]
Parana-pine	0.46	4.0	7.8	13.2	2.0	40.90	8.80	1.6	[15, 35]
Jaboty	0.48	3.3	7.7	12.5	2.3	37.80	5.80	2.60	[15, 35]
Spanish cedar	0.44	4.0	6.2	11.6	1.5	31.50	5.60	3.00	[15, 35]
Quaruba	0.49	4.0	8.8	12.1	2.2	47.60	10.0	3.40	[15, 35]
Tornillo	0.44	4.8	7.9	11.8	1.6	46.60	7.20	4.50	[35]
Rubber tree—RRIM 600	0.55	2.5	5.8	9.5	2.3	43.50	9.60	4.00	Present study
Rubber tree—GT1	0.54	2.7	5.8	9.3	2.2	49.80	9.90	4.20	Present study

NA data not available

Table 5 Characteristic strength values of two clones of *Hevea brasiliensis*—RRIM600 and GT1

Clones	Characteristic values σ_k (MPa)						
	Parallel to grain				Perpendicular to grain		
	$\sigma_{c\|\|,k}$	$\sigma_{t\|\|,k}$	$\sigma_{s,k}$	$\sigma_{e\|\|,k}$	$\sigma_{c\perp,k}$	$\sigma_{t\perp,k}$	$\sigma_{e\perp,k}$
GT1	49.63	48.28	7.89	44.37	10.14	2.98	NA
RRIM600	41.90	49.64	7.72	31.49	8.18	3.22	18.74

NA data not available

Table 6 Relations between characteristic strength values for clones RRIM600 and GT1 clones and reference values proposed by Brazilian standard—ABNT

Characteristic relation	Clones		ABNT
	GT1	RRIM600	NBR 7190
$\sigma_{c\|\|,k}/\sigma_{t\|\|,k}$	1.03	0.84	0.77
$\sigma_{c\perp,k}/\sigma_{c\|\|,k}$	0.20	0.20	0.25
$\sigma_{e\|\|,k}/\sigma_{c\|\|,k}$	0.89	0.76	1.00
$\sigma_{e\perp,k}/\sigma_{c\|\|,k}$	NA	0.45	0.25
$\sigma_{s,k}/\sigma_{c\|\|,k}$	0.16	0.18	0.12

NA data not available

fact evidences the importance of continued studies for other rubberwood clones. Strength values of compression parallel to grain were lower than those reported by Gnanaharan and Dhamodaran [26], who obtained 52.70 MPa for rubberwood from a 35-year-old plantation in India.

Most mechanical properties of wood are closely correlated with density, as pointed out by several researchers [18, 31]. It is also well known that the higher the density of the wood, the more it will tend to shrink [32]. As shown in Table 4, the rubberwood clones, in general, had higher strength in compression parallel to grain and lower values of shrinkage when compared with other species ranked in the same level of densities, demonstrating its relatively superior performance. The great similarity in the physical characteristics means that it can substitute several other species, including meranti, teak, oak and pine [3].

Table 5 presents characteristic values of the mechanical properties obtained from the tests. Our results showed that both clones of *Hevea brasiliensis* (GT1 and RRIM600) have medium mechanical strength in compression parallel to grain, ranking it in the class C40 (Table 1), the second higher strength class for wood in Brazil [15]. Despite this, the modulus of elasticity of rubberwood did not reach the expected value for the class C40.

Relationships between mechanical properties were compared with usual reference values proposed by the Brazilian standard (Table 6). It can be noted that some properties such as compression strength perpendicular and shear strength parallel did not maintain the reference relation to compression parallel to grain, due mainly to the high values obtained for compression parallel to grain.

In summary, considering that stiffness of rubberwood did not reach the reference values of class C40 (Table 1) and adopting current patterns of timber structures (in terms of spacing among structural elements), this wood would be better indicated for small and secondary elements rather than for main ones.

Considering the Brazilian market of native woods, the clones have potential to replace some commercial timber, especially *Cedrela* spp. (Spanish cedar), *Cedrelinga cateniformis* (Tornillo), *Vochysia* spp. (Quaruba), and *Erisma uncinatum* (Jaboty). The last specie is among the timbers that are most marketed and exploited from the Amazon rainforest [36].

Brazil has a great rubberwood stock from old plantations that can be used in the scenario evaluated here. In future, more attention should be given to the selection of best clones combining production of latex and wood quality.

The use of rubberwood should be accomplished by a preservative treatment immediately after cutting, to prevent the attack of xylophagous, due to the high carbohydrate content in the wood [10].

Conclusions

According to the results obtained, after the period of latex extraction, the wood of GT1 and RRIM600 clones can be used in small and secondary structures, lightweight construction, indoor building components, general utilities (moldings, e.g.), wood-based panels, and furniture.

Hevea brasiliensis wood can be used as an alternative to replace the wood from native forest species such as *Cedrela* spp. (Spanish cedar), *Cedrelinga cateniformis* (Tornillo), *Vochysia* spp. (Quaruba), and *Erisma uncinatum* (Jaboty). Among the usual timbers of the world, rubberwood has physical performance similar to Teak and mechanical performance similar to Mahogany.

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