Forests **2013**, *4*, 270-278; doi:10.3390/f4020270

OPEN ACCESS

forests

ISSN 1999-4907

www.mdpi.com/journal/forests

Article

Effect of Nondestructive Evaluation of Veneers on the Properties of Laminated Veneer Lumber (LVL) from a Tropical Species

Cláudio Del Menezzi [1,*], Luana Mendes [1], Mário de Souza [2] and Geraldo Bortoletto Jr. [3]

[1] Department of Forest Engineering, Faculty of Technology, University of Brasília, P.O. Box 04357, 70904-970, Brasília, DF, Brazil; E-Mail: luana.fagundes.m@gmail.com

[2] Forest Products Laboratory, Brazilian Forest Service, Ministry of Environment, 70818-900, Brasília, DF, Brazil; E-Mail: mario.souza@florestal.gov.br

[3] Department of Forest Science, Luiz de Queiroz College of Agriculture, University of São Paulo, 13418-900, Piracicaba, SP, Brazil; E-Mail: gbjunior@usp.br

* Author to whom correspondence should be addressed; E-Mail: cmenezzi@unb.br;
Tel.: +55-61-3107-5634; Fax: +55-61-3107-5642.

Received: 28 January 2013; in revised form: 21 April 2013 / Accepted: 24 April 2013 / Published: 29 April 2013

Abstract: This study aimed at evaluating the potential of *Schizolobium parahyba* to produce laminated veneer lumber (LVL) and the feasibility of a nondestructive method for grading the veneers. Initially, 64 *S. parahyba* veneers were nondestructively tested using the stress wave method, and stress wave velocity (wv) and veneer dynamic modulus of elasticity (E_{dV}) were determined. Afterwards, the veneers were graded according to E_{dV} descending values and used to manufacture 8-ply LVL boards. After the manufacturing, the boards were also nondestructively tested, and the board dynamic modulus of elasticity (E_{dB}) was determined. Simple linear regression analysis was run to evaluate the relationship between the nondestructive and mechanical properties of veneers/boards. A positive effect of veneer stress wave properties on the LVL properties was found. Therefore, the higher the E_{dV} values, the higher the LVL properties. The relationships between E_{dV} and E_{dB} properties were highly significant with all mechanical properties. It was clearly observed that when this grading procedure was used, the veneers were indirectly graded by their density. Finally, it could be concluded that *S. parahyba* showed good potential to produce LVL.

Keywords: stress wave evaluation; tropical wood veneer; veneer grading

---

1. Introduction

Nondestructive evaluation (NDE) is the science that aims to obtain properties of the material without altering its end-use, and to use this information to make decisions regarding appropriate applications [1]. With respect to isotropic materials, NDE is used to detect voids, nonhomogeneous spots and other irregularities. However, these irregularities are common in wood products, so NDE is also used to evaluate their effect on physical and mechanical properties. In spite of these irregularities, nondestructive methods have been used to evaluate the quality of several types of already consolidated wood-based composites such as oriented strandboard [2,3], wood-plastic composites [4], cement/gypsum bonded particleboard [5], bamboo particleboard [6], plywood [7], laminated veneer lumber [8] and oriented/laminated strand lumber [9]. However, the literature on NDE of wood-based materials remains relatively scarce, especially as regards engineered wood products made from tropical hardwoods.

Nevertheless, the usual approach is to employ the nondestructive method before composite manufacturing, thus assessing the quality of the raw material being processed. Visual and acoustic nondestructive methods have been used previously to sort logs, lumber and veneers employed in the manufacturing of ply-based wood composites, as seen in several works [10–15]. Wang *et al.* [15], while studying ultrasonically (US) rated veneer from red maple, found a positive relationship between veneer US variables and LVL billet stiffness and strength. Bortoletto [13] on the other hand did not find any effect on the properties when plywood was manufactured using randomly or ultrasonically rated veneers from *Pinus merkusii*. Teles *et al.* [12] found that lumber nondestructively tested by means of transverse vibration yielded stronger and stiffer glulam beams made from a tropical hardwood (*Sextonia rubra*).

The tropical hardwood species *Schizolobium parahyba* is a Brazilian native tree which has been studied for use as a plantation tree, and encouraging results have been obtained. It is a fast growing tree species, presents straight trunk without branches and produces low density wood, which makes this species suitable for plywood production [16]. Nowadays, the Brazilian wood industry does not employ any kind of NDE method to grade raw material based on strength or stiffness. This means that the quality control of the products is carried out only at the end of the processing. Therefore, it is very important to propose and study the application of new technologies for processing wood-based products in order to improve their quality, reliability, safety and serviceability. For instance, the Brazilian wood design code is currently under review to include three NDE methods to qualify wood for structural purposes. In this context, this study aimed at evaluating the potential of *Schizolobium parahyba* to produce laminated veneer lumber and the feasibility of a nondestructive method to grade the veneers, and its effect on the board's properties.

2. Materials and Methods

2.1. Wood Material and Nondestructive Evaluation

Logs from 16-year-old *Schizolobium parahayba* plantation trees were rotary peeled, and veneers were made measuring 980 × 1000 × 2 mm^3 (length × width × thickness). Further information about tree origin, plantation and veneer production can be obtained from our previously published work [16]. The veneers were air-dried for 10 days and then cut to reduce dimensions to 490 × 250 × 2 mm^3 (length × width × thickness). A total of 64 veneers were produced. A small sample was collected and macroscopically identified through comparison with the standard samples deposited at the Wood Anatomy Section of the Forest Products Laboratory (*Index Xilarium* FPBw), Brazilian Forest Service.

The veneers were nondestructively tested lengthwise using stress wave method (Metriguard Stress Wave Timer model 239A) (Figure 1). The material was hit three times by an impact pendulum (Figure 1A), and two accelerometers (Figure 1B,C) connected to the veneers measured the stress wave transit time (t, μs), *i.e.*, the time required for the wave to travel between them (span, L). The average value of t was used to determine the veneer stress wave velocity (wv, m/s) and then the stress wave dynamic modulus of elasticity (E_d, MPa), according to equations 1 and 2. Thereafter, the 64 veneers were graded according to E_d values in descending order:

$$wv\,(m/s) = V_{LL}\,(m/s) = L/(t \times 10^{-6}) \tag{1}$$

$$E_d\,(MPa) = wv^2 \times \rho \tag{2}$$

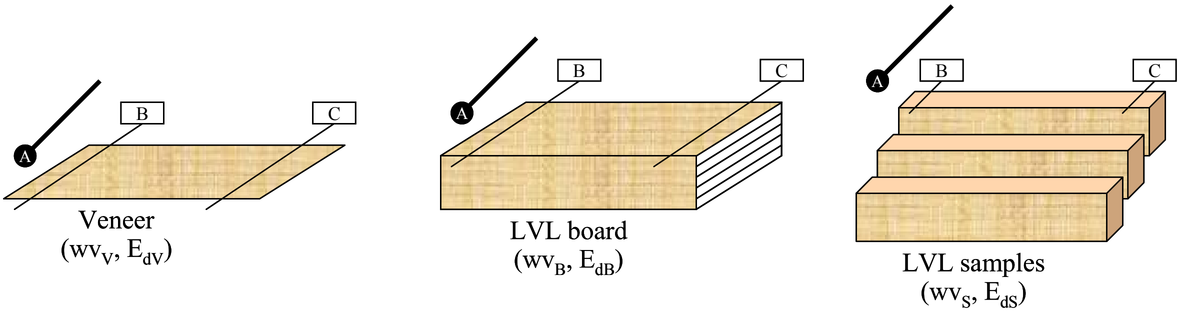
where, wv is the stress wave velocity (m/s); L is the span (m); t is the transit time (μs); and ρ is the density (kg/m^3).

2.2. Manufacturing and Testing of LVL

Eight LVL boards (8-ply) were manufactured according to E_d values. Thereunto, the first board was composed of eight stiffest veneers, and successively up to the eighth board, which was composed of eight less stiff veneers. The boards were manufactured using resorcinol formaldehyde (RF) adhesive (61.5% of solid content; 2130 cP) at a spread rate of 220 g/m^2, prepared by mixing five parts of resorcinol and one part of formaldehyde by weight (5:1). The boards were pressed at room temperature (25 °C) for 24 h at pressure of 2.94 MPa. Finally, the boards were trimmed to reach the final dimension of nearly 450 × 200 × 16 mm (length × width × thickness). The boards were kept at conditioning room (20 °C; 65% RH) until they reached constant weight (≈ 30 days).

Afterwards, the consolidated boards were nondestructively tested in the same way as previously described for the veneers (Figure 1), and stress wave velocity (wv_B, m/s) and stress wave dynamic modulus of elasticity of the boards (E_{dB}, MPa) were calculated. The samples were then cut from the boards to determine physical and mechanical properties according to ASTM D5456 [17] standard. The samples were also nondestructively tested and the stress wave variables were determined (wv_S; E_{dS}) in the same way as for veneers and boards (Figure 1). Moduli of rupture (f_m, MPa) and elasticity (E_M, MPa) were assessed at flatwise (glue-line perpendicular to load direction) as well as edgewise (glue-line parallel to load direction) positions using a span, about 18 times the specimen depth. The samples for assessing the parallel compression strength ($f_{c,0}$, MPa) presented slenderness ratio about 16. Five samples per board were cut for each type of mechanical testing. The average moisture content of the samples was close to 10.7%.

Figure 1. Scheme of nondestructive evaluation to determine stress wave velocity (wv) and dynamic modulus of elasticity (E_d) of veneer, laminated veneer lumber (LVL) boards and samples (A: impact pendulum; B, C: accelerometers).



2.3. Statistical Analysis

The relationship between stress wave variables (wv_V, E_{dV}, wv_B E_{dB}, wv_S and E_{dS}) and mechanical properties (f_M, E_M and $f_{c,0}$) was analyzed by means of simple linear regression analysis ($y = a + bx$), where stress wave variables were considered as independent variables, and mechanical properties as dependent variables. The following analyses were performed: veneer stress wave properties *vs.* LVL mechanical properties ($N = 8$); board stress wave properties *vs.* LVL mechanical properties ($N = 8$); samples stress wave properties *vs.* LVL mechanical properties ($N = 24$). These analyses aimed to fit mathematical models for explaining the variation in the mechanical properties of LVL boards.

3. Results and Discussion

Table 1 shows the results of nondestructive evaluation of veneers and boards. It was observed that the stress wave velocity in veneers was quite similar to that in boards. On the other hand, the values of dynamic modulus of elasticity observed for boards were higher compared to veneers.

Table 1. Nondestructive variables and density of veneers and boards.

Board #	wv_V ^{1} [m/s]	Ed_V [MPa]	wv_B [m/s]	Ed_B [MPa]	Density ^{2} [kg/m^3]	Density ^{3} [kg/m^3]
1	4479	9098	4520	10,561	445	512
2	4523	8393	4505	9,748	403	478
3	4498	8022	4454	9,227	392	469
4	4488	7848	4484	9,468	391	462
5	4418	7713	4346	8,861	389	461
6	4360	7528	4409	9,236	386	475
7	4407	7285	4469	8,835	368	435
8	4280	6810	4376	8,517	365	442
Mean	4432	7837	4445	9,307	392	467

Note: ^{1} mean value of all veneers comprising the board; ^{2} veneers; ^{3} boards.

It should be emphasized that nondestructive grading of veneers based on E_{dV} values implied density segregation; thus, denser veneers presented higher E_{dV} values, which significantly affected the properties of manufactured LVL. As seen on Table 1, board #1 had the highest density (512 kg/m^3), whereas board #8 had the lowest density (442 kg/m^3). Similar behavior was found by Teles *et al.* [12], who employed the transverse vibration nondestructive method to grade lumber to produce glulam beams. The mechanical properties of the LVL boards are presented on Table 2. The mean values can be considered suitable compared to others found in the literature [18].

The effect of testing position (edge *vs.* flat) on modulus of rupture (p = 0.46679) and modulus of elasticity (p = 0.9519) was not identified. Data on Table 2 clearly show that the mechanical property values are descending from board #1 up to board #8. An exception can be observed for board #3, which was considered an outlier. Further details about this particular observation are given in the next section. The results obtained herein are in agreement with those found in the literature. Recently, Palma *et al.* [10] studied the effect of veneer nondestructive grading on properties of *Hevea brasiliensis* plywood. They found that veneer presenting high values of stress wave dynamic modulus of elasticity had a great positive impact on flexural properties, while plywood made from low-value veneer had worse performance even when combined with those first. Similar results were found by Wang *et al.* [15] manufacturing LVL with ultrasonically rated red maple veneers.

Table 2. Mechanical properties of LVL from *Schizolobium parahayba*.

Board #	**E_M—*edge* [MPa]**	**f_m—*edge* [MPa]**	**E_M—*flat* [MPa]**	**f_m—*flat* [MPa]**	**$f_{c,0}$ [MPa]**
1	9978	72.8	10,462	77.0	35.1
2	9429	69.3	9,337	70.4	31.4
3	7679	52.7	7,024	51.1	28.1
4	8862	61.8	8,815	60.9	28.1
5	8916	61.0	8,170	61.6	29.3
6	9479	66.5	9,206	67.0	32.8
7	8249	53.9	8,020	51.5	26.6
8	8092	54.7	8,002	52.3	25.4
Mean	8836	61.6	8,629	61.5	29.6

Pio *et al.* [11] employed the same nondestructive method for grading *Eucalyptus grandis* veneers peeled from 15- and 20-year-old trees. The results pointed out that the stiffness of the veneers had a direct and positive effect on flexural properties of LVL made from this graded material. Therefore, LVL made based on the stiffness grade presented better mechanical properties. Nevertheless, Bortoletto Jr. [13] found different results, and plywood assembled with randomly or pre-graded *Pinus merkusii* veneers presented similar bending and shear properties.

Table 3 presents the mathematical models fitted to predict flexural properties of the boards using stress wave variables of veneers and boards. For each property there are two models: the first one involves computing all 8 replications (N = 8), while the second one includes 7 replications (N = 7), with board #3 excluded from the statistical analysis. As previously mentioned, it was observed that LVL board #3 presented discrepant values for the mechanical properties (Table 2) although the values of its nondestructive properties did not show any unusual pattern (Table 1).

Table 3. Models to predict LVL mechanical properties using nondestructive variables of veneers (E_{dV}) and boards (E_{dB}).

Material	LVL Property	Model ^{A}	R^2	F
Veneer	E_M—*edge*	$3227.1 + 0.715E_{dV}$	0.404	4.07 ^{NS}
		$2780.1 + 0.7964E_{dV}$	0.766	21.3 **
	E_M—*flat*	$1104.8 + 0.961E_{dV}$	0.403	4.05 ^{NS}
		$481.3 + 1.0725E_{dV}$	0.800	26.7 **
	f_m—*edge*	$0.234 + 0.007E_{dV}$	0.528	6.72 *
		$-3.35 + 0.00854E_{dV}$	0.793	25.1 **
	f_m—*flat*	$-21.02 + 0.011E_{dV}$	0.585	8.48 *
		$-11.7 + 0.0097E_{dV}$	0.848	30.7 **
	$f_{c,0}$	$0.595 + 0.003E_{dV}$	0.629	10.21 *
		$-0.9048 + 0.0039E_{dV}$	0.700	13.8 **
Board	E_M—*edge*	$429.2 + 0.903E_{dB}$	0.539	7.02 *
		$909.6 + 0.8683E_{dB}$	0.769	21.4 **
	E_M—*flat*	$-3506.7 + 1.304E_{dB}$	0.622	9.91 *
		$2843.5 + 1.2558E_{dB}$	0.927	45.9 **
	f_m—*edge*	$-27.15 + 0.009E_{dB}$	0.656	11.45 *
		$-23.54 + 0.0093E_{dB}$	0.802	24.6 **
	f_m—*flat*	$-55.02 + 0.012E_{dB}$	0.693	13.58 *
		$-33.60 + 0.0105E_{dB}$	0.835	28.3 **
	$f_{c,0}$	$-10.03 + 0.004E_{dB}$	0.698	13.89 **
		$-10.58 + 0.0043E_{dB}$	0.719	14.9 *

Note: ^{A} for each property in the first model $N = 8$, while $N = 7$ in the second; **,* statistically significant at $\alpha = 0.01$ and 0.05, respectively; ^{NS} not significant.

Visually there was not any apparent defect such as bonding failure, delamination, warps, blow-up and cracks in board#3. However, it was observed that some samples taken from this board had been moderately attacked by boring insects during the acclimatization phase. Recently, Campos *et al.* [19] have observed unusual failure of wood I-beams whose flange was damaged by boring insects.

In terms of locations (veneers or board) and positions evaluated (flatwise and edgewise), the models were statistically significant at high level ($p < 0.001$), and the coefficients of determination (R^2) were higher than 0.76. The models fitted to the mechanical properties presented better predictability when stress wave board variables were used as independent variables. The mean R^2 value, considering all models, was about 0.81, while models fitted by means of veneer variables presented a mean near 0.78. It can be inferred that the adhesive application somehow affected these results, probably because it is more homogeneous than wood, which certainly helps to improve the predictability of the models.

Additionally, the resorcinol adhesive, a polymeric material, is stiffer than wood, leading to better results when nondestructive testing is performed. Nevertheless, the adhesive affected only the dynamic modulus of elasticity. The stress wave velocity was similar for veneers and boards (4432 m/s *vs.* 4445 m/s), as presented in Table 1. This phenomenon might be strictly related to density improvement observed on boards as a function of adhesive application. Taking the testing position into account, it was observed that the models presented higher R^2 values at flatwise (0.85) position than at edgewise (0.78) position.

This result might be related to the LVL pressing stage, since the pressure is applied exactly on flatwise position. It may lead to a certain level of surface densification reducing wood voids, gaps and eventually improving the quality of the prediction. Nonetheless, it should be pointed out that stress wave velocity was almost the same for both positions: 4115 m/s (edge) and 4119 m/s (flat). In a recent study, DeVallance *et al.* [20] employed ultrasonic and optical systems to grade *Pseudotsuga menziesii* veneer for LVL production. They found that the integration of both methods considerably improved the prediction of LVL properties (R^2 = 0.58), because the optical model takes into account average defect, density and growth ring as well.

According to the results shown in Table 3, E_M could be predicted more accurately than f_m and $f_{c,0}$. Undoubtedly, it is a very usual result, which is widely found in the literature concerning nondestructive testing. The theory behind the wood nondestructive testing is based on its elastic behavior. Therefore, in this case the stiffness of the material usually presents better relationship than those related to maximum strength, whose determination is beyond the elastic limit of the material. It explains why f_m and $f_{c,0}$ (maximum strength properties) could be modeled at a level lower than E_M. Nevertheless, the results found herein are important for the prediction of compression strength, as it is also a key property when LVL is used as structural member.

Table 4 shows the mathematical models for predicting samples' flexural properties individually. In this analysis, every sample was nondestructively tested and further tested up to rupture. The models presented R^2 values ranging from 0.68 to 0.81, which can be considered suitable in this kind of analysis. Meanwhile, in general all models together presented R^2 values (0.74) lower than those obtained when veneer (0.78) or board (0.81) variables were used. It can be considered a discrepancy. As the evaluation was done directly on the samples, it should have reflected a more accurate evaluation and better predictability.

Table 4. Models to predict LVL mechanical properties using nondestructive variable of samples (E_{dS}).

LVL Property	Model	R^2	F
E_M—*edge*	$657.4 + 0.9628E_{dS}$	0.693	49.7**
E_M—*flat*	$-635.4 + 1.087E_{dS}$	0.682	47.1**
f_m—*edge*	$-18.0 + 0.0094E_{dS}$	0.799	87.9**
f_m—*flat*	$-32.3 + 0.011E_{dS}$	0.807	91.8**

Note: ** statistically significant at $\alpha = 0.01$.

Regardless of this finding, the results presented herein are within the range usually found by studies on nondestructive testing of laminated wood composites. Achim *et al.* [21], when studying the properties of LVL made from *Populus tremuloides* veneer found a strong relation (R^2 = 0.83) between dynamic (ultrasound) and static bending modulus of elasticity. Souza *et al.* [8] employed this same nondestructive method to predict flexural properties of LVL from *Pinus oocarpa* and *P. kesiya*. Only the modulus of elasticity of *P. kesiya* LVL could be suitably modeled at a reasonable level (R^2 = 0.586), while no other species/properties could. Ferraz *et al.* [9] manufactured oriented strand lumber (OSL) and laminated strand lumber (LSL) with *Chrysophyllum sp* wood, whose flexural properties were modeled at a level similar to that observed in the present work using stress wave variables: f_m ($R^2 = 0.74 - 0.70$) and E_M ($R^2 = 0.80 - 0.60$).

4. Conclusions

Laminated veneer lumber boards from the tropical plantation tree *S. parahyba* were produced. Veneer grading based on stress wave nondestructive variables showed a positive impact on LVL mechanical properties. A close relationship was found between veneer properties and LVL properties. This improvement could be significantly modeled using both veneer and board nondestructive properties. Nondestructive evaluation was found to lead to veneer density segregation, which directly reflected on the improvement of the mechanical properties. It could be concluded that *S. parahyba* showed good potential to produce LVL, whose properties could be enhanced using the stress wave nondestructive testing as a grading method. Nevertheless, the research effort should continue in order to improve the quality of the boards produced.

Conflict of Interest

This paper was presented at 11th Pacific Rim Bio-Based Composites Symposium held in Shizuoka, Japan (27–30 November 2012) and was fully revised and upgraded to meet the journal requirements.

References

1. Pellerin, R.F.; Ross, R. J. *Nondestructive Evaluation of Wood*; Forest Products Society: Madison, WI, USA, 2002; pp. 1–210.
2. Ross, R.J.; Yang, V.W.; Illman, B.L.; Nelson, W.J. Relationship between stress wave transmission time and bending strength of deteriorated oriented strandboard. *For. Prod. J.* **2003**, *53*, 33–35.
3. Del Menezzi, C.H.S.; Tomaselli, I.; Souza, M.R. Avaliação não-destrutiva de painéis OSB modificados termicamente. Parte 1: Efeito do tratamento térmico sobre a velocidade de propagação de ondas de tensão. *Scientia Forestalis* **2007**, *76*, 67–75.
4. Nzokou, P.; Freed, J.; Kamdem, D.P. Relationship between non destructive and static modulus of elasticity of commercial wood plastic composites. *Holz als Roh und Werkstoff* **2006**, *64*, 90–93.
5. Araújo, P.C.; Arruda, L.M.; Del Menezzi, C.H.S.; Teixeira, D.E. Lignocellulosic composites from Brazilian giant bamboo (*Guadua magna*). Part 2. Properties of cement and gypsum bonded particleboards. *Maderas. Ciencia y Tecnologia* **2011**, *13*, 295–306.
6. Arruda, L.M.; Del Menezzi, C.H.S.; Teixeira, D.E.; Araújo, P.C. Lignocellulosic composites from Brazilian giant bamboo (*Guadua magna*). Part 1. Properties of resin bonded particleboards. *Maderas. Ciencia y Tecnologia* **2011**, *13*, 49–58.
7. Han, G.; Wu, Q.; Wang, X. Stress-wave velocity of wood-based panels: Effect of moisture, product type, and material direction. *For. Prod. J.* **2006**, *56*, 28–33.

8. Souza, F.; Del Menezzi, C.H.S.; Bortoletto, G., Jr. Material properties and nondestructive evaluation of laminated veneer lumber (LVL) made from *Pinus oocarpa* and *P. kesiya*. *Eur. J. Wood Wood Prod.* **2011**, *69*, 183–192.
9. Ferraz, J.M.; Del Menezzi, C.H.S.; Teixeira, D.E.; Okino, E.Y.A.; Souza, F.; Bravim, A.G. Propriedades de painéis de partículas laminadas paralelas utilizados com alternativa à madeira maciça. *Cerne* **2009**, *15*, 67–74.
10. Palma, H.A.L.; Escobar, J.F.; Ballarin, A.W.; Leonello, E.C. Influência da qualidade das lâminas no desempenho mecânico à flexão de painéis compensados de *Hevea brasiliensis*. *Floresta e Ambiente* **2012**, *19*, 133–140.
11. Pio, N.S.; Keinert, S., Jr.; Iwakiri, S.; Cunha, U.S.; Rocha, M.P.; Lucas Filho, F.C. Análise da resistência e elasticidade em flexão de painéis LVL de *Eucalyptus grandis* com lâminas pré-classificadas. *Floresta* **2012**, *42*, 11–20.
12. Teles, R.F.; Del Menezzi, C.H.S.; Souza, M.R.; Souza, F. Effect of nondestructive testing of laminations on the bending properties of glulam made from louro-vermelho (*Sextonia rubra*). *Cerne* **2010**, *16*, 77–85.
13. Bortoletto, G., Jr. Effects of ply grading and assembly on the properties of plywood panels from *Pinus merkusii*. *Cerne* **2010**, *16*, 145–153.
14. Ross, R.J.; Erickson, J.R.; Brashaw, B.K.; Wang, X; Verhey, S.A.; Forsman, J.W.; Pilon, C.L. Yield and ultrasonic modulus of elasticity of red maple veneer. *For. Prod. J.* **2004**, *54*, 220–225.
15. Wang, X.; Ross, R.J.; Brashaw, B.K.; Verhey, S.A.; Forsman, J.W.; Erickson, J.R. *Flexural Properties of Laminated Veneer Lumber Manufactured from Ultrasonically Rated Red Maple Veneer*; USDA/FS/FPL Research Note FPL-RN-0288; USDA: Washington, DC, USA, 2004; pp. 1–5.
16. Bortoletto, G., Jr.; Belini, U.L. Produção de lâminas e manufatura de compensados a partir da madeira de guapuruvu (*Schizolobium parayba* Blake) proveniente de um plantio misto de espécies nativas. *Cerne* **2003**, *9*, 16–28.
17. *Standard Specification for Evaluation of Structural Composites Lumber*; ASTM D5456; American Society for Testing and Materials: West Conshohocken, PA, USA, 2006.
18. Palma, H.A.L.; Ballarin, A.W. Propriedades físicas e mecânicas de painéis LVL de *Eucalyptus grandis*. *Ciênc. Florest.* **2011**, *21*, 559–566.
19. Campos, M.B.S.; Del Menezzi, C.H.S.; Souza, M.R. Flexural properties of wood I-beams flanged with tropical hardwoods. *J. Trop. For. Sci.* **2012**, *24*, 369–378.
20. DeVallance, D.B.; Funck, J.W.; Reeb, J.E. Evaluation of laminated veneer lumber tensile strength using optical scanning and combined optical-ultrasonic techniques. *Wood Fiber Sci.* **2011**, *43*, 169–179.
21. Achim, A.; Paradis, N.; Carter, P.; Hernández, R.E. Using acoustic sensors to improve the efficiency of the forest value chain in Canada: A case study with laminated veneer lumber. *Sensors* **2011**, *11*, 5716–5728.