STUDY OF BRAZILIAN COMMERCIAL ORIENTED STRAND BOARD PANELS USING STRESS WAVE

Elen Aparecida Martines Morales São Paulo State University Júlio de Mesquitafilho, Campus Itapeva Properties of Materials Laboratory Itapeva, Brazil

Marília Da Silva Bertolini, Maria Fátima do Nascimento Francisco Antonio Rocco Lahr University of São Paulo, São Carlos Engineering School Wood and Timber Structures Laboratory of The Structural Engineering Department São Carlos, Brazil

Adriano Wagner Ballarin São Paulo State University Júlio De Mesquita Filho, College of Agronomic Sciences of Botucatu, Rural Engineering Department Botucatu, Brazil

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ABSTRACT

Today lumber industry has shown a clearly evident trend towards wood based panels' production; and, among them, Oriented Strand Board (OSB) has become more and more prominent. Nondestructive Testing (NDT) such as stress wave is one of the possible ways to make their mechanical characterization. This study aimed to investigate the efficiency of NDT stress wave to estimate mechanical parameters of Brazilian commercial OSB panels. National commercial OSB panels (15 and 25 mm in thickness) were tested by standard methods, EN codes, and non-destructive tests employing Stress Wave Timer, METRIGUARD, model 239 A. Data obtained in tests were analyzed using mean comparison by analysis of variance (ANOVA) and Tukey method. R² values greater than those established by EN 326-2 2002 to determine correlation between mechanical properties in bending (f_m and E_m), obtained by the standard and non-destructive testing, suggest the possibility of using stress wave for quality control in OSB industry.

KEYWORDS: Oriented strand board, nondestructive testing, stress wave, static mechanical properties.

INTRODUCTION

In the group of wood based products, OSB has been increasingly applied worldwide, with greater employment in construction, considering advantages in comparison to plywood, especially in terms of logs utilization, increased productivity and lower cost. With production and marketing since 2002 in Brazil, it is estimated that domestic production of OSB reach 350.000 m³/year (LP BRASIL 2012).

OSB is made up by several layers of long wood particles with a well-defined length-width relationship, glued with adhesive resin. Long wood particles of external layers are paralleled to the length of the board, while particles of internal (central) layers may be either in a random or oriented disposition, often perpendicularly aligned with the direction of the external layers, according to EN 300 2006.

Technology for NDT applied to wood gradually developed in the 1960s, used primarily in studies on growth, anatomical structure and internal defects, as well as physical and mechanical characterization. Using this information turned possible to perform classification and tracking from trees, logs and sawn timber even in products such as panels (Xiao et al. 2009). They can be used in the process of wood veneer grading for Laminated Veneer Lumber (LVL) panels and also serve to detect flaws (such as bubbles or voids) in particleboards, MDF (Medium Density Fiberboard), OSB or plywood (Ross et al. 1998). These methods have many advantages, one of the most important being the possibility of the wood to be characterized efficiently without specimen extraction, once its evaluation is made in the part or structure itself (Oliveira 2001; Xiao-Dong et al. 2010). They also allow quickness when analyzing a great population and improved versatility when conforming to a standardized routine in a production line (Oliveira and Sales 2000).

Stress wave is one of the most common NDT for wood and wood based composites (Bodig 2001). As proposed by Jayne (1959), the storing energy and dissipation properties of wood, which can be measured by nondestructive testing, are controlled by the same mechanisms that determine the static behavior of this material. Thus, there is the possibility of mathematical relationship between stress wave and the static mechanical properties of the wood by techniques of linear regression analysis.

In accordance with EN 326-2 2002, if the calculated value of correlation coefficient is higher than or equal to 0.70, which is the same as $R^2 = 0.49$, the regression equation may be used to adjust the test results obtained through alternative procedure to the ones obtained in standard procedure.

Stress wave uses vibration generated waves caused by direct impact on the part to be studied. Sound velocity value is then measured and used for dynamic modulus of elasticity (E_{md}) determination (Bodig 2001). Acoustic wave application and consecutive propagation time measurement are performed by positioning two transducers (accelerometers) on the material to be evaluated. Registered times are used to calculate wave propagation longitudinal velocity (V) and once longitudinal velocity is given, dynamic constant (C) can be calculated.

Some studies have been made using nondestructive methods such as stress wave, among others, for physical and mechanical characterization of wood based products, including OSB. Ross and Pellerin (1988) have pointed to the usefulness of NDT stress wave when evaluating tensile strength, static bending and internal adhesion properties of wood based composites. Results of preliminary tests have shown that wave velocity and attenuation are properties of the material that have much to do with its mechanical properties. Mendes et al. (2002) have used NDT stress wave to study mechanical properties of 39 OSB panels made of six distinct species of *Pinus* and/or from a mixture of them (with or without paraffin). Low correlation coefficients

between found MOE values in both test types have been observed, although being further research of this nature on OSB still recommendable.

In this context, this research aimed to investigate the efficiency of NDT stress wave to estimate mechanical parameters of Brazilian commercial OSB panels employing OSB panels of 15 and 25 mm in thickness tested by standard methods, EN codes, and non-destructive tests employing stress wave.

MATERIAL AND METHODS

Three Brazilian commercial OSB/3 panels (panels for structural end use, in wet environment) have been used, being the first two 15 (15/1 and 15/2) and the last one 25 mm in thickness, classified as OSB Home, from manufacturer MASISA do Brasil, currently LP Brasil. Their dimensions of width and length are 1.20 m x 2.40 m, respectively. Each of them made up of three layers, having its external layers made up of wood oriented strands extended parallel to the length of the board and its internal layer made up of strands perpendicularly aligned with the external layers. Their face-core-face ratio is 1:2:1.

For stress wave testing, firstly one of the 15 mm panels (15/2) had their width and length along the panel demarcated at each 50 by 50 mm. Measurements with stress wave apparatus were carried out in each one of these demarcations. Then, static bending specimens taken out of the 15 (15/1 and 15/2) and 25 mm boards were previously tested by stress wave. In either case, measurements along longitudinal and transversal directions were carried out.

They have been conducted in the Materials Testing Laboratory (LEM) of the Agricultural Engineering Department of the College of Agronomic Sciences (FCA) of São Paulo State University (UNESP) – Campus Botucatu. Data were obtained using a Stress Wave Timer, METRIGUARD, model 239A and its accessories: accelerometer, impact hammer and panel clamp set (Fig. 1). Wave propagation time along static bending specimens in longitudinal and transversal directions has been measured (Fig. 2) so that velocity values could be found out, as well as their following correlations with modulus of elasticity (E_m) and strength (f_m) values in static bending test. These same correlations have been applied to C (dynamic constant) values.





Fig.1: Stress Wave Timer, METRIGUARD, model 239A a) and its accessories: accelerometer b), impact hammer c) and panel clamp set d). Source: Metriguard Inc (2008).

Fig. 2: Positioning of stress wave transducers for time measurement in board and specimen.

For correlations with nondestructive test, f_m (strength) and E_m (modulus of elasticity) in static bending were determined, according to EN 310 2000. In addition, tests have been made to find swelling in thickness (G_t), water absorption (A_t), moisture content (H), specific gravity (σ)

and IB (internal bond), respectively, according to EN 317 1993, EN 322 2000, EN 323 2000, and EN 319 1993, for physical-mechanical characterization of the panels. The number of specimens used and their dimensions were in accordance with EN 326-1 2000 specifications.

Both of the herein described mechanical and physical tests have been made in the Wood and Timber Structures Laboratory (LaMEM) of the Structural Engineering Department (SET) of São Carlos Engineering School (EESC) of University of São Paulo (USP) – Campus São Carlos, having been DARTEC Testing Universal Machine (100 kN capacity) used for them.

Results were statistically analyzed through graphs, values of means, standard deviations, variation and correlation coefficients, by Kolmogorov-Smirnov, Barttlet and analysis of variance methods, using MINITAB – 13 version and EXCEL – 2003 computer programs.

RESULTS AND DISCUSSION

Physical and mechanical properties observed in the initial stage are shown in Tabs. 1 and 2. *Tab. 1: Physical properties of OSB panels.*

	t	Н	σ	Gt	At
	(mm)	(%)	(kg.m ⁻³)	(%)*	(%)
Mean		9	595	15	71
Stdv	15/1	0.1	44	3	9
VC (%)		1	7	21	13
Mean		9	589	14	75
Stdv	15/2	0.1	38	4	10
VC (%)		1	6	28	13
Mean		9	595	19	87
Stdv	25	0.2	21	1	6
VC (%)		2	4	7	7

• Gt values must be lower than 15 % (EN 300, 2006). t= thickness; H= moisture content; σ = specific gravity;

 G_t = swelling in thickness; A_t = water absorption; Stdv = standard deviation; VC = variation coefficient.

	(mm)	E _m //	Em⊥	f _m //	f _{m⊥}	IB
	t (mm)			(MPa)		
Mean		4142	1652	25	14	0.44
Stdv	15/1	590	231	6	2	0.1
VC (%)		14	14	25	18	30
Mean	15/2	4069	1386	25	10	0.36
Stdv		525	206	5	2	0.1
VC (%)		13	15	20	21	37
Mean	25	4553	1817	26	13	0.18
Stdv		680	132	4	2	0.1
VC (%)		15	7	15	13	46
Values according to EN*	15	3500	1400	20	10	0.32
	25	3500	1400	18	9	0.30

Tab. 2: Mechanical properties of OSB panels.

• EN 300, 2006. t = thickness; $f_{m/\ell}$ = strength along longitudinal direction; $f_{m\perp}$ = strength along transversal direction; $E_{m/\ell}$ = modulus of elasticity along longitudinal direction; $E_{m\perp}$ = modulus of elasticity along transversal direction; IB = internal bond; Stdv = standard deviation; VC = variation coefficient.

The obtained values in both physical and mechanical characterization tests have attained (and even exceeded) the ones stipulated by EN 300, 2006 specifications for OSB panels, except for modulus of elasticity in static bending along transversal direction of the 15 mm (2) board, thickness swelling (24 h) and internal bond of the 25 mm board. The most expressive coefficients of variance have been found amidst strength in internal bond values.

Velocity and dynamic constant values obtained in nondestructive tests are shown in Tabs. 3 and 4.

Tab. 3: Velocity and dynamic constant calculation based on stress wave measured times along longitudinal and transversal directions of the 15/2 panel.

	t	V//	V⊥	C//	C⊥	
	(mm)	(m.	s ⁻¹)	(MPa)		
Mean		2889	2040	4915	2450	
Stdv	15/2	33	30	97	72	
VC (%)		1	1	2	3	

t = thickness; $V_{l/l}$ = velocity along longitudinal direction; V_{\perp} = velocity along transversal direction; $C_{l/l}$ = dynamic constant along longitudinal direction; C_{\perp} = dynamic constant along transversal direction; Stdv = standard deviation; VC = variation coefficient.

Tab. 4: Velocity and dynamic constant calculation based on stress wave measured times along static bending specimens.

	t	V//	V⊥	C//	C⊥	
	(mm)	(m.s ⁻¹)		(MPa)		
Mean		3116	2439	5780	3544	
Stdv	15/1 S	54	66	200	191	
VC (%)		2	3	3	5	
Mean		3139	2187	5804	2818	
Stdv	15/2 S	69	45	254	116	
VC (%)		2	2	4	4	
Mean		3216	2496	6150	3703	
Stdv	25 S	90	43	355	125	
VC (%)		3	2	6	3	

t = thickness; $V_{//}$ = velocity along longitudinal direction; V_{\perp} = velocity along transversal direction; $C_{//}$ = dynamic constant along longitudinal direction; C_{\perp} = dynamic constant along transversal direction; Stdv = standard deviation; VC = variation coefficient.

As to the nondestructive tests, found velocity values for longitudinal and transversal directions have diverged from each other, with coefficients of variance ranging from 1 to 3 %, which are considered low values.

Measured longitudinal and transversal velocity values for OSB are compatible with those ones obtained in ultrasound tests made by Bekhta et al. (2000) and Morales et al. (2004), except for transversal direction of both 15 mm board and specimens.

Some wood based panels can present inherent heterogeneity that conduce to lower values of stress wave velocity and, consequently, of dynamic modulus of elasticity elated to solid wood (Arruda et al. 2011).

Souza et al. (2011) point out that high stress wave velocity values are obtained in more homogeneous materials. As example, they determined 4775 and 4946 m.s⁻¹ in perpendicular direction and 4687 and 4860 m.s⁻¹ in edgewise of *Pinus oocarpa* and *Pinus kesiya* LVL, respectively. To bamboo particleboards with formaldehyde resin, Arruda et al. (2011) obtained velocities among 1937 and 1996 m.s⁻¹; Araújo et al. (2011), to cement-bamboo composites obtained an average of 1900 m.s⁻¹.

Han et al. (2006) shows stress wave velocities to different wood based panels and solid wood, in moisture contents 9 and 23 %. For OSB case refered velocity is around 2500 and 3000 m.s⁻¹ (in direction parallel to production) and around 2000 and 2500 m.s⁻¹ (direction perpendicular to production). Values of $V_{//}$ (longitudinal) e V_⊥ (transversal) to samples 15/1, 15/2 and 25 mm are coherent with cited literature.

Values of $V_{//}$ e V_Lobtained in this work are compatible with those presented by Del Menezzi et al. (2007). These authors carried out a non-destructive evaluation of OSB panels, chemically treated in laboratory in two temperature (190 and 220°C) and three times (12, 16 and 20 min.) and confirmed anisotropic performance caused by high discontinuity in direction perpendicular to production that provokes wave dissipation and velocity reduction.

Velocity and dynamic constant mean values have been 7, 8, 13, and 16 % lower, respectively, for the board than for static bending specimens, both in transversal and longitudinal directions, which proves that such values are indeed affected by the dimensions of material involved in tests. It has been occurred probably because wave dispersion through the boards was higher than in the specimens.

As expected, longitudinal and transversal dynamic constant values for the three studied boards have been considerably different from (and higher than) modulus of elasticity values obtained in static bending test.

In a qualitative analysis of correlation between conventional and nondestructive data, a certain lack of homogeneity (especially in transversal direction) in the group of studied OSB panels could be noticed as it is shown in Fig. 3. Higher strength in static bending values has been obtained for 15 (15/1) and 25 mm boards than for 15 mm (15/2) board.



Fig. 3: Difference of velocity populations from all tested boards and strength in static bending and correlation among V_m and f_m values, along transversal direction.

 $V_{m\perp}$ = strength in static bending along transversal direction; $f_{m\perp}$ = strength in static bending along transversal direction.

Statistical equivalence between velocity and dynamic constant of the 15 (15/1 and 15/2) and 25 mm populations have been analyzed in order to detect any statistically significant difference between the velocity values that have attained EN 300 2006 stipulations for the modulus of rupture value in static bending test along transversal direction (15/1 and 25) and those ones that have not (15/2).

After variances in the obtained data were found to be normal and homogeneous, by means of tests Kolmogorov-Smirnov and Barttlet, respectively, variance in velocity and dynamic constant means was also analyzed. Found F values are: 402.7 and 422.34 (higher than $F_{2, 291, 0.05} = 3.37$). Tukey test has also been applied, with $\lambda = 0.05$ and 291 freedom degrees (k = 3 and n = 98).

Difference in velocity and dynamic constant between 15 (1) and 15 (2), 15 (1) and 25, and 15 (2) and 25 mm boards has been, respectively: 252.0, 57.0 and 309.0 m.s⁻¹; 726.0, 159.0 and 885.0 MPa, all of them higher than the minimum significant differences (d.m.s.) found for each one of the following parameters: 16.4 m.s⁻¹ and 46.0 MPa.

So it has been statistically proven the non-equivalence of the three studied populations, as well as the existence of a higher minimum significant difference between the 15 mm (15/2) board and the other ones.

As a next step, mechanical parameters of these boards have been analyzed. Analysis of variance in modulus of rupture in static bending along transversal direction has revealed F equal to 30.08 (higher than $F_{2, 291}$, $_{0.05} = 3.37$). Tukey Test has also been applied, with $\lambda = 0.05$ and 291 freedom degrees (k = 3 and n = 98). Results show that the values of this parameter for the 15/1 and 25 boards are statistically equivalent to each other but not to the 15/2 board.

A study of correlation between V_m and f_m (strength in static bending), and C and E_m (modulus of elasticity) values, found in specimens taken out from all of the three tested boards, has been made in transversal and longitudinal directions, where few discrepant data have been excluded. Data considered discrepant were those not included in mean confidence interval. Correlation equations, R (correlation coefficient) and R² (determination coefficient) values are shown in Tab. 5.

Longitudinal direction			Transversal direction		
Correlation equation R ²		R	Correlation equation R ²		R
$f_m = 0.0055V + 8.5302$	0.02	0.15	$f_m = 0.0076V + 5.5821$	0.51	0.71
$E_{\rm m} = 0.391C + 1982.6$	0.22	0.47	$E_m = 0.3179C + 582.7$	0.49	0.70

Tab. 5: Correlation equations, R (correlation coefficient) and R^2 (determination coefficient) values.

 f_m = strength and E_m = modulus of elasticity, in static bending

A graph illustrating the correlation between V_m and f_m values in transversal direction is shown in Fig. 3.

Although considering only three boards in this preliminary study, R and R² values obtained in transversal direction are in accordance with standard EN 326-2 2002 to determine the correlation between the results obtained in alternative and standard procedure. However, Arruda et al. (2011) cite that when only the wave velocity (V_m) was employed as an independent variable to predict fm and E_m , both linear and nonlinear models gave low R² values. These authors obtained high correlations when used E_{md} (dynamic modulus of elasticity), resulting in R² values up to 0.83. This can be justified because of E_{md} is obtained from wave velocity, density and gravity acceleration.

Similar behavior was observed with regard to higher values of R² in the transverse direction, in studies carried out by Han et al. (2006), performed with commercial OSB panels (Southern Pine flooring), 18 mm thick, in the directions parallel and perpendicular to the panel, in order to correlate MOR and MOE obtained from bending strength (ASTM D 1037-96) and stress wave velocity using linear regression analysis. Authors found in parallel and perpendicular directions, respectively, R² to 0.60 and 0.81 for the MOE and 0.58 e 0.82 for the MOR.

Analogous behavior occurred in relation to stress wave velocity: higher coefficients R^2 in the transverse direction may be associated with greater discontinuity in direction that involves two perpendicular layers, affecting wave propagation. Del Menezzi et al. (2007) observed similar performance in thermally treated OSB, relating mass loss after treatment with wave propagation velocity, which resulted in R^2 of 0.598 and 0.942 in parallel and perpendicular directions. Those values can be related to dynamic modulus of elasticity (E_{md}) sensitivity to changes in mass very effective for predicting properties relating to rigidity and strength of composed products.

Density or specific gravity has great influence on wave propagation. More homogeneous compaction and consequently more uniform density along wood panel result in better propagation of wave emitted by equipment. This makes possible to estimate the modulus of elasticity by density. Arruda et al. (2011) obtained correlations (\mathbb{R}^2) for linear and nonlinear models up to 0.92.

Moisture content is another influential factor in obtaining properties by stress wave. Brashaw et al. (2004) observed lower wave velocity with moisture content increasing, for measurements carried out in southern pine veneers. Han et al. (2006) observed the same behavior for OSB manufactured with mixture of species, reporting the importance of considering the moisture, enabling the development of correction factors to estimate mechanical properties, such as MOR and MOE.

The influence of moisture content (MC) may be associated with presence of water between cell walls (water hygroscopic) causing alterations in the volume and cell walls separation. According to Han et al. (2006), stress-wave velocity is affected by about 1 percent per percent of MC change in the hygroscopic range.

CONCLUSIONS

The following conclusions can be considered:

- a) Divergent velocity and elastic constant values in longitudinal and transversal directions show that it is possible to detect the variance in mechanical characteristics of OSB boards by using stress wave nondestructive testing.
- b) Found velocity values in longitudinal and transversal directions of the studied boards are in accordance with the ones already found by the previously mentioned authors.
- c) Board dimensions affect time measurements. The respective velocities and dynamic constants values are higher in specimens.
- d) Stress wave is perceptive to detect differences in f_m and E_m values in static bending when tests are carried out to effective different board groups.
- e) Obtained results suggest the possibility of using NDT stress wave in quality control of mechanical parameters of Brazilian commercial OSB panels and, hence, the continuity of the study.

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REFERENCES

- Araújo, P.C., Arruda, L.M., Del Menezzi, C.H.S., Teixeira, D.E., Souza, M.R., 2011: Lignocellulosic composites from Brazilian giant bamboo (*Guadua magna.*) Part 2: Properties of cement and gypsum bonded particleboards. Maderas, Ciencia y tecnología 13(3): 297-306.
- Arruda, L.M., Del Menezzi, C.H.S., Teixeira, D.E., Araújo, P.C., 2011: Lignocellulosic composites from Brazilian Giant Bamboo (*Guadua magna*) Part 1: Properties of resin bonded particleboards. Maderas, Ciencia y tecnología 13(1): 49-58.
- Bekhta, P.A., Niemz, P., Kucera, L., 2000: The study of sound propagation in the woodbased composite materials. In: Proceedings of the 12th International Symposium on Nondestructive Testing of Wood University of Western Hungary, Sopron, 13-15 September 2000.
- 4. Bodig, J., 2001: The process of NDE research for wood and wood composites. The e -Journal of Nondestructive Testing 6(3):
- 5. Brashaw, B.K., Wang, X., Ross, R.J., Pellerin, R.F., 2004: Relationship between stress wave velocities of green and dry veneer. Forest Products Journal 54(6): 85–89.
- Del Menezzi, C.H.S., Tomaselli, I., Souza, M.R., 2007: Non-destructive evaluation of thermally modified OSB. Part 1: Effect of the thermal treatment on the stress wave velocity. (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 76: 67-75 (in Portuguese).
- 7. EN 317, 1993: Particleboards and fiberboards. Determination of swelling in thickness after immersion in water.
- 8. EN 319, 1993: Particleboards and fiberboards. Determination of internal adhesion.
- 9. EN 322, 2000: Wood-based panels. Determination of moisture content.
- 10. EN 323, 2000: Wood-based panels. Determination of density.
- 11. EN 310, 2000: Wood-based panels. Determination of modulus of elasticity in bending and of bending strength.
- 12. EN 326-1, 2000: Wood-based panels. Sampling, cutting and inspection. Part 1: Sampling and cutting of test pieces and expression of test results.
- 13. EN 326-2, 2002: Wood-based panels. Sampling, cutting and inspection. Part 2: Initial type testing and factory production control..
- 14. EN 300, 2006: Oriented strand boards (OSB). Definitions, classifications and specifications.
- 15. Han, G., Wu, Q., Wang, X., 2006: Stress-wave velocity of wood-based panels: Effect of moisture, product type, and material direction. Forest Products Journal 56(1): 28-33.
- Jayne, B.A., 1959: Vibrational properties of wood as indices of quality. Forest Products Journal 9(11): 413–416.
- 17. LP Brasil. LP Building Products, 2012: Available at: < http://www.lpbrasil.com.br>. Accessed 15.02.12.

- 18. Mendes, L.M., Matos, J.L.M., Iwakiri, S., Mori, F.A., Truguilho, P.F., 2002: Use of acoustic emission methods for determination of non-destructive properties of OSB panels (Oriented Strand Board). (Uso de métodos de emissão acústica para determinação não-destrutiva de propriedades de painéis OSB (Oriented Strand Board)). In: Anais do II Congresso Ibero-Americano de Pesquisa e Desenvolvimento de Produtos Florestais I Seminário em Tecnologia da Madeira e Produtos Florestais Não-Madeiráveis, Curitiba, PR, 10 pp (in Portuguese).
- 19. Metriguard Inc., 2008: Available at: < http://www.metriguard.com/239A.htm>. Accessed 27.02.12.
- 20. Morales, E.A.M., Rocco Lahr, F.A., Nascimento, M.F., Gonçalves, R., 2004: Estimation of mechanical properties of OSB (Oriented Strand Board) by ultrasound. (Estimativa de propriedades mecânicas de painéis OSB (Oriented Strand Board) através de ultra-som). In: Anais do IX Encontro Brasileiro em Madeiras e Estruturas de Madeiras, Jul 27-29, 2004, Cuiabá, M. UFMT, 1: 1-13, CD ROM (in Portuguese).
- Oliveira, F.G.R., Sales, A., 2000: Acoustic wave propagation in wood. (Propagação de ondas acústicas na madeira). In: Anais do VII Encontro Brasileiro em Madeiras e Estruturas de Madeiras, Jul 12-14 2000, São Carlos, SP.USP, 10 pp, CD ROM (in Portuguese).
- 22. Oliveira, F.G.R., 2001: Study of mechanical properties of dicotyledons by non- destructive testing using ultrasound equipments. (Estudo de propriedades mecânicas de dicotiledôneas por meio de ensaio não-destrutivo utilizando equipamentos de ultra-som). Master's Degree. Dissertation. Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, SP, 55 pp (in Portuguese).
- 23. Ross, R.J., Brashaw, B.K., Pellerin, R.F., 1998: Nondestructive evaluation of wood. Forest Products Journal 48(1): 14-19.
- 24. Ross, R.J., Pellerin, R.F., 1988: NDE of wood-based composites with longitudinal stress waves. Forest Products Journal 38(5): 39-45.
- 25. Souza, F., Del Menezzi, C.H.S., Bortoletto, Jr.G., 2011: Material properties and nondestructive evaluation of laminated veneer lumber (LVL) made from *Pinus oocarpa* and *Pinus kesiya*. European Journal of Wood and Wood Products 69(2): 183-192.
- 26. Xiao, J., Sa, C., Han, Y., 2009: Nondestructive testing of dynamic elastic modulus of woodbased panel by the method of stress wave. In: 9th International Conference on Eletronic Measurement & Instruments – ICEMI, 16-19 Aug. 2009, Beijing. Pp –2-357 -2-361. (DOI: 10.1109/ICEMI.2009.5274565).
- Xiao-dong, Z., Jun, C., Feng-hu, W., Yu, L., 2010: Non-destructive testing of wood composites based on virtual instruments. In: 3rd International Congress on Image and Signal Processing – CISP, Yantai. Pp 3368–3371 (DOI: 10.1109/CISP.2010.5647629).

Elen Aparecida Martines Morales São Paulo State University Júlio de Mesquitafilho Campus Itapeva Properties of Materials Laboratory Rua Geraldo Alckmin 519 Vila Nossa Senhora de Fátima 18409-010 Itapeva Brazil Corresponding author: profaelen@yahoo.com.br Marília da Silva Bertolini, Maria Fátima do Nascimento Francisco Antonio Rocco Lahr University of São Paulo São Carlos Engineering School Wood And Timber Structures Laboratory of The Structural Engineering Department Avenida Trabalhador São-Carlense 400 13560-970, São Carlos Brazil

> Adriano Wagner Ballarin São Paulo State University Júlio de Mesquita Filho College of Agronomic Sciences of Botucatu Rural Engineering Department Rua José Barbosa de Barros 1780 Fazenda Experimental Lageado 18610-307 Botucatu Brazil