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Influence of finger joint length on the elastic modulus of reconstituted wood from *Pinus taeda* L.

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ABSTRACT: The aim of this study was to evaluate the influence of three finger joint splice lengths on the dynamic modulus of elasticity of pieces of reconstituted wood from *Pinus taeda* L. Wooden specimens had finger joint splices of 5, 7 and 15 mm in length and were evaluated using the Stress Wave Time equipment, to analyze the wave propagation speed and dynamic modulus of elasticity, as well as the density of the pieces. As a result, increasing the finger joint's length did not reduce the wave propagation speed through the wooden specimen. On the other hand, there was a reduction in the strength of the spliced wood as the much as the length of the finger joint increased. The density of the material may have influenced the reduction in the modulus of elasticity, even if it did not interfere with the wave propagation speed through the specimen.
Keywords: wood properties, wood strength, Stress Wave Time, notched joint.

Influência do comprimento de emenda *finger joint* no módulo de elasticidade da madeira reconstituída de *Pinus taeda* L.

RESUMO: O objetivo deste trabalho foi avaliar a influência de três comprimentos de emendas *finger joint* no módulo de elasticidade dinâmico de peças de madeira reconstituída de *Pinus taeda* L. Foram utilizados corpos de prova que apresentavam emendas *finger joint* de 5, 7 e 15 mm de comprimento, avaliados utilizando o equipamento *Stress Wave Timer.* Analisou-se a velocidade de propagação das ondas e módulo de elasticidade dinâmico, assim como a densidade aparente das peças. Como resultado, o aumento do tamanho das emendas não reduziu a velocidade de propagação da onda através do corpo de prova de madeira. Por outro lado, houve redução na resistência da madeira emendada à medida que a emenda aumentou de tamanho. A densidade do material pode ter influenciado na redução do módulo de elasticidade, mesmo que não tenha interferido na velocidade de propagação da onda pelo corpo de prova.
Palavras-chave: propriedades da madeira, resistência da madeira, Stress Wave Timer, emenda dentada.

INTRODUÇÃO

Jointing smaller pieces has become a viable alternative for reducing waste in the wood industrialization production chain. The process consists of removing defective parts of the wood, such as knots and resin pockets, keeping an integral part of the wood, in order to perform the notched joint. The finger joint technique is used for this purpose, highlighting its application in the construction of glued laminated wood panels, such as edge glued panel (EGP).

In general terms, the physical and mechanical properties of the jointed piece depend on the clean wood parts used, the glue used in the joint and the wood machining process to make the finger joints (MUTHUMALA et al., 2021; GONZÁLEZ-PRIETO et al., 2022). In this sense, the analysis of the modulus of elasticity (MoE) is a good parameter to be evaluated when studying the resistance of wood, as it indicates the stiffness of the material and provides information to calculate the modulus of rupture (CUNHA; MATOS, 2010).

These properties can be evaluated using destructive or non-destructive methods, the latter being an alternative to keeping the wooden piece undamaged. An example is the acoustic wave emission technique to evaluate the MoE, using the Stress Wave Timer equipment, creating an impact on the surface of the test piece to propagate stress waves in the material (NASIR et al., 2019). This result is used to determine the dynamic MoE of wood, being a tool for quality control of the analyzed material. The finger joint can vary in shape, length and depth, characteristics that can alter the technological properties of the wooden piece, as they can have the effect of propagating the emitted wave in a non-destructive evaluation. In addition, studies have shown a relationship between the type and size of the finger joint and the effectiveness of gluing,

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mechanical resistance and structural performance (ÖZÇIFÇI; YAPICI, 2008; RAO et al., 2012; DANAWADE et al., 2013-2014; HABIPI; AJDINAJ, 2015; TSALAGKAS et al., 2021).

In practical terms, for the industry, it is interesting that non-destructive methods are analyzed regarding their effectiveness. These are techniques considered simpler to apply, with a reduction in analysis time and cost, which provides values that can be compared regarding their structure, allowing a mechanical classification of the material produced. In this scenario, this study aimed to evaluate the influence of the length of the finger joint on the dynamic modulus of elasticity of pieces of reconstituted wood from *Pinus taeda* L. originating from an industrial process.

MATERIAL AND METHODS

Preparation of test specimens

The material used was collected from a homogeneous commercial plantation of *P. taeda*, 9 years old, located in the southwest region of Paraná (Brazil). The raw material is intended for industrial use in the production line of a wooden frame factory. From the wood leftovers from the frame production process, the wood was processed and glued slats were made with three finger joint lengths (5 mm, 7 mm and 15 mm, Figure 1).

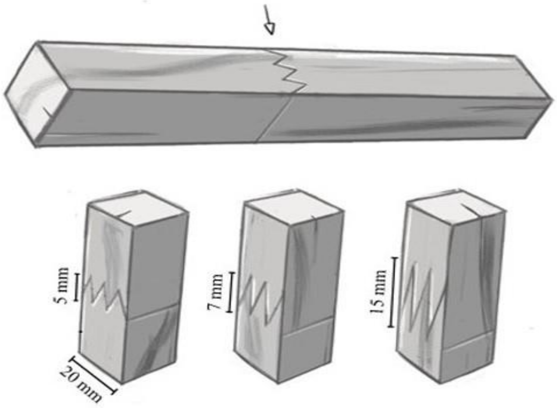

Figure 1 – Representation of the specimens (20 mm x 20 mm x 300 mm), with the three finger joint lengths used in this study (5 mm, 7 mm and 15 mm).

From these materials, specimens measuring 20 mm x 20 mm x 300 mm were obtained, in accordance with the Pan-American standard for the evaluation of static bending of wood (COPANT, 1973). The joints were kept in the center of the specimen. Each treatment evaluated consisted of 10 specimens. This material remained in a climate chamber (20ºC and 65% relative humidity) until it reached a constant mass, with the wood's moisture content stabilized at ~12%.

Determination of dynamic modulus of elasticity (DMoE)

After reaching the equilibrium humidity, the specimens were used to determine the apparent density at 12% humidity, in kg.m^{-3} (ABNT, 1997).

The dynamic modulus of elasticity (MPa) and wave propagation speed (WPS, in cm.s^{-1}) were determined using the acoustic wave emission method using the equipment Metriguard Stress Wave Timer 239A (CUNHA e MATOS, 2011; NASIR et al., 2019), as illustrated in Figure 2.

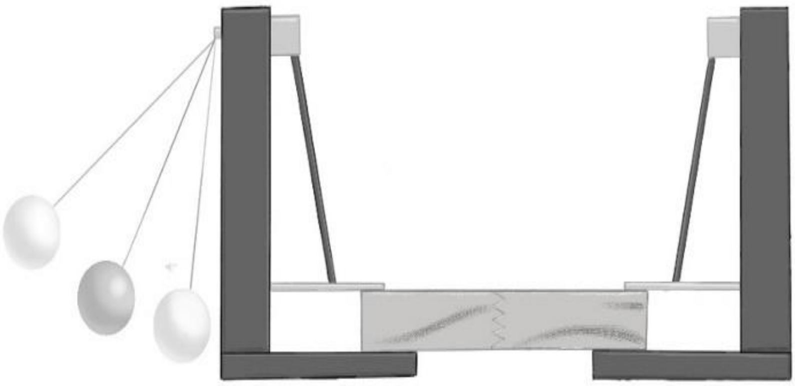

Figure 2 – Representation of the Metriguard Stress Wave Timer 239A equipment, applied to emit acoustic waves.

The wave propagation speed was calculated according to equation 1 and the DMoE was calculated according to equation 2.

$$\text{WPS} = \frac{\text{d}}{\text{t}} \qquad \text{(Equation 1)}$$

where: WPS: wave propagation speed in the longitudinal direction ($cm.s^{-1}$); d: distance between the Stress Wave Timer transducers (cm); and t: time it takes for the wave to travel through the wood.

$$\text{DMoE} = \delta * \text{WPS} - 2 * \frac{1}{g} \qquad \text{(Equation 2)}$$

where: DMoE: dynamic modulus of elasticity (MPa); δ: apparent density of wood at 12% humidity ($kg.m^{-3}$); g: acceleration of specific mass (density) (9.80665 $m.s^{-2}$).

Statistical analyzes

Data were analyzed in a completely randomized design. The means were compared using the Tukey test at a probability level of 95%, submitted to the Pearson correlation test to evaluate the interaction between the dynamic modulus of elasticity, the apparent density at 12% humidity and the wave propagation speed in the parts. All statistics were performed using RStudio version 1.1.463.

RESULTS AND DISCUSSION

Increasing the size of the finger joint did not reduce the wave propagation speed through the specimen. A tendency to reduce speed is observed, but there is no statistical difference related to the size of the finger joint. Waves propagate at different speeds, depending on the material evaluated (Nassar et al., 2020). Although the speed variable does not present differences, it is noted that there was a reduction in the strength of the jointed wood as the length of the finger joint used increased (Table 1).

Table 1. Dynamic modulus of elasticity (DMoE), wave propagation speed (WPS) and apparent density of solid and reconstituted *Pinus taeda* wood with different finger joint sizes.

Finger joint length	DMoE (MPa)	WPS (cm.s-1)	Apparent density ($kg.m^{-3}$)*
0 mm	11, 291.07 a	423.843 a	653.09 a
5 mm	10,880.74 a	423.149 a	597.96 a
7 mm	8,040.27 b	396.670 a	505.45 b
15 mm	6,816.72 b	388.113 a	449.80 b
CV (%)**	29.80	7.81	11.62

Means followed by the same letter do not differ statistically from each other, according to the Tukey test at a 95% probability level. *Apparent density of wood at 12% humidity. **Coefficient of variation.

Statistically, the speed of wave propagation in wood with finger joints of the three lengths did not differ from the results obtained in seamless solid wood. Despite this, the DMoE of solid wood and wood jointed with a 5 mm finger joint did not differ but presented higher resistances than wood with 7 and 15 mm fingers.

The same trend was observed for variable density. The density of the test specimens, which is associated with the anatomical constitution of the wood, impairs the modulus of elasticity, even if it has not interfered with the speed of wave propagation. Corroborating the above, Pereira et al. (2016) state that when pieces joined by finger joints are denser, they can perform better in this variable than solid wood that is less dense or that has some type of defect. These characteristics were confirmed by correlation analysis (Table 2).

Table 2. Pearson correlation between dynamic modulus of elasticity (DMoE), wave propagation speed (WPS) and apparent density of solid and reconstituted *Pinus taeda* wood with different finger joint lengths.

	DMoE	WPS	Apparent density
DMoE	1.00	0.84	0.90
	WPS	1.00	0.54
	Apparent density		1.00

Where: DMoE is the dynamic modulus of elasticity and WPS is the wave propagation speed.

We observed that the dynamic modulus of elasticity reduced by 40%, when analyzing the seamless material (0 mm) with the material with the longest seam length (15 mm), while the density reduced by around 31%. As noted by Danawade et al. (2013-2014), finger joints can reduce around 36% of the strength of glued wood compared to solid wood, with a reduction in strength between 26% and 37% when compared to the values obtained by the 5 mm finger joint and 7 mm and 15 mm, respectively. This reduction may be related to the discontinuity of the wood anatomy when it is cut and glued, however, density has a direct influence on the DMoE variable.

Some studies correlate the type of joint with the loss of mechanical resistance, mainly in static bending tests (ÖZÇIFÇI e YAPICI, 2008). Factors such as species, specific gravity and humidity of the wood, type of glue, geometry, and orientation of the finger joints during the test can also affect the mechanical resistance of the reconstituted wood

(RAO et al., 2014; SRIVARO et al., 2019; MUTHUMALA et al., 2021).

One way to overcome this reduction in resistance compared to solid seamless and defect-free parts is to form more robust panels. This new composite is generally used to manufacture glued laminated wood parts, which can be reinforced with different splice lengths and the use of higher density woods. (SEGUNDINHO; DIAS, 2023). Other applications ensure the use of jointed pine wood for a variety of uses, including furniture and structural wood (TIENNE et al., 2011; LUENGO et al., 2023). Thus, there is less influence of the finger in reducing the resistance of pine wood.

CONCLUSION

The length of the finger joint interfered with the strength of the glued *Pinus taeda* wood. The lengths of 7 and 15 mm presented the lowest values of the dynamic modulus of elasticity. The three lengths evaluated in this study did not significantly influence the propagation speed of the wave emitted by the Stress Wave Timer method. The speed of propagation is not a variable that can be used to classify the modulus of elasticity of wood. Therefore, it is suggested to evaluate the influence of finger length using materials with similar density, aiming to characterize the influence of density combined with this length on wave propagation by Stress Wave Timer.

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