Research article

https://revistas.unal.edu.co/index.php/refame

Revista Facultad Nacional de Agronomía

Physical and mechanical properties of cross-laminated timber made from *Pinus tecunumanii* wood

UNIVERSIDAD NACIONAL DE COLOMBIA

Propiedades físicas y mecánica de madera contralaminada fabricada con *Pinus tecunumanii*

https://doi.org/10.15446/rfnam.v78n2.114727

Jhon F. Herrera-Builes[1]*, Juan C. Sierra[1] and Rodolfo Parra[1]

ABSTRACT

Keywords:
Bending static
Density
Finger joint
Wood planks

Timber from forest plantations is of great relevance to be used as a substitute for timber from natural forests; thus, reducing pressure on them and in such a way indiscriminate felling. Alternative building materials, like cross-laminated timber (CLT), are being sought in the world. In Colombia, the CLT production is not well-studied; thus, this investigation characterized the physical and mechanical behavior of cross-laminated timber (CLT) in three layers made with *Pinus tecunumanii* wood manufactured by Finger Joint and wood plank systems. In each of the CLTs, density, modulus of elasticity and modulus of rupture in static bending were evaluated. Both manufacturing systems produced CLTs with an air-dry medium density and low resistance to static bending. The CLT made with finger joints showed low elasticity, while the CLT made with a solid wood planks system showed medium elasticity. The results of this study, with wood match material *Pinus tecunumanii* showed higher values than those reported for other woods. Future studies should focus on determining changes in the physical and mechanical properties of CLT with quality-rated wood.

RESUMEN

Palabras clave:
Flexion estática
Densidad
Finger joint
Tablones de madera

Las maderas procedentes de plantaciones forestales son de gran relevancia para ser utilizadas como reemplazos de las procedentes de bosques naturales; con lo cual se disminuye la presión sobre los mismos y de esta forma la tala indiscriminada. En el mundo se están buscando materiales alternativos para la construcción, como es el caso de la madera contralaminada o CLT. En Colombia se encuentran pocos estudios donde se referencien la producción de CLT; por ello, el presente estudio caracterizó el comportamiento físico y mecánico de CLT en 3 capas fabricados con el sistema de Finger Joint y con tablones de madera maciza de *Pinus tecunumanii*. En cada uno de los CLT fueron evaluadas su densidad, módulo de elasticidad y módulo de rotura a la flexión estática, los CLT fabricados por ambos sistemas de fabricación presentaron una mediana densidad seca al aire; además, ambos presentan baja resistencia a la flexión estática; los CLT fabricados con el sistema de Finger Joint presentaron una baja elasticidad y con el sistema con tablones de madera maciza presentaron una mediana elasticidad. Los resultados arrojados en este estudio con material de partido de la madera *Pinus tecunumanii* son mayores a los resultados reportados para otras maderas. Los estudios futuros deben centrarse en determinar los cambios en las propiedades físicas y mecánicas de CLTs con madera con clasificación de calidad.

[1]Facultad de Ciencias Agrarias, Universidad Nacional de Colombia, Sede Medellín, Colombia. jfherrer@unal.edu.co, jcsierram@unal.edu.co, rhparra@unal.edu.co
*Corresponding author

Received: January 30, 2025; Accepted: April 5, 2025
Rev. Fac. Nac. Agron. Medellín 78(2): 11161-11168. 2025
ISSN 0304-2847 / e-ISSN 2248-7026

The *Pinus tecunumanii* (Schw.) Eguiluz and Perry, is mainly found in Central America and Chiapas, Mexico. It is a remarkable species that frequently can reach 55 meters in height, and the first 30 meters of the trunk are free of lateral branches. It has a very straight stem form (Dvorak and Donahue 1992). Smaller quantities of *P. tecunumanii* are used in plantations, but it is an important plantation species in Colombia and it has acquired importance in Brazil and southern Africa (Dvorak et al. 2000). The mechanical properties of wood make it an efficient option for structural applications in construction (Ramage et al. 2017). Wood constructions are less vulnerable to damage than concrete or brick constructions because they have more flexible material that can better absorb the vibrations of an earthquake (Saxena et al. 2022). The use of wood as a construction material is on the rise in certain countries worldwide, particularly in Europe and Asia. Although wood does not grow as quickly as other materials, it still has other advantages that make it attractive (Heard et al. 2012).

In the early 1990's a new wood product known as Cross-Laminated Timber (CLT) was developed and patented. It is a wood engineering product that consists of an odd number of layers (usually three, five or seven) made of glued sawn timber, where each layer is made up of boards/lamellas placed adjacent to each other, and where the neighboring layers are most often glued at an angle of 90° with each other. As a result, the CLT panels provide high stiffness and strength both in-plane and out of plane (Jele et al. 2018; Fabrizio et al. 2023).

In recent years, the trend for wood materials and building systems has been influenced by the development of CLT. The current trend is to develop new wood products and timber construction systems, which can be optimized for structural use. The use of cross-laminated timber is common in high-demand structural buildings and multi-storey buildings in Europe, Canada, and the USA. In addition, it is a material of low energy consumption and is particularly noted for its exceptional insulation properties, reduced heat transmission and it is an architectural beauty (Ferk 2013; Brandner 2013). The cross laminated timber is competitive and attractive because it is a lighter laminated structure than steel and concrete, allows building elements up to 40 m in length, high chemical resistance to acidic or alkaline environments, a certain tolerance of exposure to fire, greater dimensional stability with respect to solid wood, and optimization of the available resource, among other advantages (Olsson et al. 2025).

Despite important advances in the field of engineering and sustainable building materials, there is no specific information about CLT production in Colombia right now, or on buildings using this material as a structural component. This gap in research and construction practices creates a unique opportunity to explore the potential of this material in the country. CLT, an innovative and increasingly globally applied material, has proven to be an efficient and sustainable alternative to traditional materials such as steel and concrete in architecture and building.

The importance of this study lies in its potential to promote the use of timber from forest plantations as a renewable raw material for the manufacture of non-traditional products in construction, opening new opportunities for the Colombian forestry and construction. This type of research not only contributes to sustainable building practices but can help diversify the use of forest resources and encourage the use of natural materials and their advantages.

Therefore, this work aimed to characterize the physical behavior of density and mechanical static bending of CLT boards made from *Pinus tecunumanii*, to promote its use as an efficient and environmentally friendly alternative in building construction and other structures in Colombia. This study will not only contribute to the development of new non-traditional products, but also strengthen research and technology applied to the country's forestry and construction sectors.

MATERIALS AND METHODS

Materials

Unsawn timber of 22x90x2000 mm (thickness, width, and length, respectively) and wooden lamellas with Finger Joint of 22x60x650 m (thickness, width, and length, respectively) from *Pinus tecunumanii* wood were used. The Company Cipreses de Colombia SA provided the wood, from mature trees (25 years old) collected from plantations located in the municipality of Yolombó (Antioquia, Colombia).

Manufacture of the CLT panels

It was used Polyvinyl alcohol (PVA) adhesive, a water-soluble synthetic polymer used in a variety of applications, with a density around 1.19 g cm^{-3}, pH in the range of 6.0 to 7.0, making it generally neutral or slightly acidic; resin content usually from 40 to 60% weight. The rate of application was 200 g m^{-2} on one side of the piece of wood. Pressing was carried out at 8.0 MPa for 60 min. In total, 12 three-layer CLT panels were manufactured; six boards with a Finger Joint system (Figure 1) and six with solid wood plank system (Figure 2). Each board sizes up to 240 mm wide x 1,800 mm length and a final thickness of 60 mm (EN 16351). The wood board samples were not organized or oriented in a specific radial, or tangential way. Instead, the tables were joined at random, as can be seen in Figures 1 and 2, where the arrangement is observed without a definite pattern. In addition, in Colombia there is no established standards for the visual structural classification of wood, which prevented such activity.

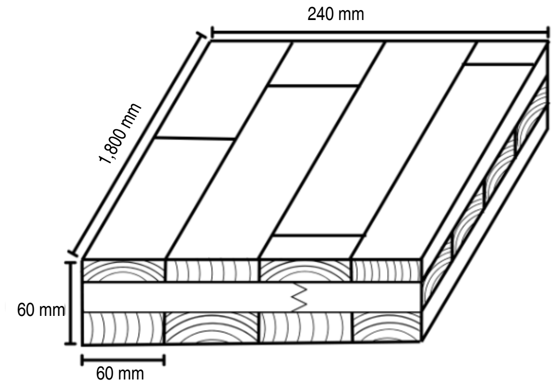

Figure 1. Cross-laminated timber CLT made with Finger Joint.

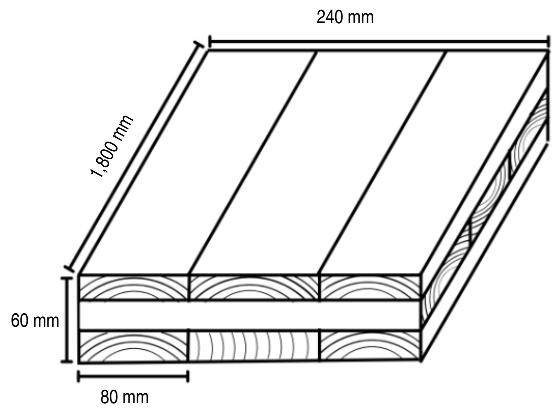

Figure 2. Cross-laminated timber CLT manufactured with solid wood planks.

Evaluation of properties

The properties evaluated in each of the panels were density, modulus of elasticity and modulus of rupture following the method of the UNE-EN 408 standard (UNE 2011). It was performed with a random positional sampling on each CLT panel. Tests were performed using a load frame with a 40,000 kg capacity and a data processor Unitronics (Figure 3).

Figure 3. Loading frame capacity 40,000 kg and data processor Unitronics.

Data analysis

The statistical analysis was performed using a completely randomized design for each test. The information was processed based on the methodology described by Hoshmand (2006).

RESULTS AND DISCUSSION

The results appearing in each box are represented as follows.

$\bar{Y}$	±	q
	CVt	

Where $\bar{Y}$ is the Mean; ± q is the 95% Confidence Interval, and CVt is the total coefficient of variation.

CLT Density

The results of the air-dry densities obtained for (CLT) panels made with *Pinus tecunumanii* wood with the Finger Joint and solid wood planks systems are presented in Table 1.

The results of air-dry densities obtained for CLT panels made from *Pinus tecunumanii* wood using two different manufacturing systems, the solid wood planks, and the Finger Joint systems are presented. These results are crucial to assessing the suitability of this species for the manufacture of CLT panels, a material that is increasingly used in construction due to its mechanical and physical properties. As shown in Table 1, the dry density values obtained for CLT panels manufactured with both systems were 626.05 kg m^{-3} for panels produced with the solid wood planks system and 679.03 kg m^{-3} for those manufactured with the Finger Joint system. Both values are in the middle density range, which according to ASTM classification is between 510 and 750 kg m^{-3}, suggesting that *Pinus tecunumanii* CLT panels may be a viable alternative for structural applications. The average densities obtained for the panels with the solid wood planks system and with the Finger Joint system revealed that there was not significant difference (Table 2), indicating that both manufacturing methods result in materials with similar density characteristics. This is relevant as it suggests

Table 1. Air-dry density of (CLT) panels made with *Pinus tecunumanii* wood and produced with solid wood planks and Finger Joint systems.

Production system	Density (kg m^{-3})
Solid wood planks	626.05±43.95 to 6.69%
Finger Joint	679.03±56.40 to 7.91%

The same letters in the columns indicate no significant difference, according to Tukey's test ($P \leq 0.05$).

that regardless of the manufacturing system used, a material with density characteristics that meets ASTM requirements for the manufacture of medium-density CLTs can be obtained.

Table 2. Analysis of variance for the air-dry density of CLT panels made from *Pinus tecunumanii* wood.

Source	Sum of squares	Df	Mean square	Ratio-F	*P*-value
Between groups	8418.21	1	8418.21	3.63	0.0860
Within groups	23210.5	10	23210.5	-	-
Total (Corrected)	31628.7	11	-	-	-

It is important to note that density is a key parameter in determining the mechanical and physical properties of CLT. The density of a material is directly related to its strength and stiffness, which affects how well cross-laminated timber (CLT) can support structural loads. In this study, the density values obtained for *Pinus tecunumanii* were higher than those reported in other studies conducted with different species of pine, such as *Pinus taeda*, *Pinus elliottii, Pinus radiata, Pinus echinata, Pinus ponderosa*, and *Pinus sylvestris* with density values ranged from 360 to 500 kg m^{-3} for CLT (Godoy et al. 2017; Baño et al. 2018; Glasner et al. 2023; Brandner et al. 2024). This difference could reflect the inherent properties of *Pinus tecunumanii* wood, which has a higher density and therefore could provide a higher quality material for construction.

Mechanical properties

The results of the mechanical characterization for the static bending of CLT panels made of *Pinus tecunumanii* wood, using the Finger Joint and solid wood planks systems, are presented in Table 3. This characterization is essential to evaluate the behavior of CLT panels under bending loads and determine their suitability for structural applications. Both the modulus of rupture (MOR) and the modulus of elasticity (MOE) of panels manufactured with both systems were evaluated. The values obtained for MOR and MOE are indicative of the strength and stiffness of the panels, two key factors for their use in the construction of structural elements.

For panels manufactured with the solid wood planks system, the MOR was significantly higher than that of panels produced with the Finger Joint system, reflecting a greater resistance to static bending in the first system evaluated. This is due to the continuity of wood fiber in solid planks, which contributes to greater structural strength. On the other hand, panels manufactured with the Finger Joint system showed a lower MOE value, which implies a lower stiffness under load.

Table 3. Mechanical resistance to static bending of the CLT panels from *Pinus tecunumanii* wood manufactured with solid wood planks and Finger-Joint methods.

Manufacture method	Modulus of rupture (MOR) MPa	Modulus of elasticity (MOE) MPa
Solid wood planks	41.59±7.08[a] 16.22%	13454.9±2051.89[a] 14.53%
Finger Joint	29.82±11.00[b] 31.15%	9081.86±2914.91[b] 30.58%

Equal letters in the columns indicate no significant difference, according to Tukey's multiple range test ($P \leq 0.05$).

In particular, panels manufactured with the Finger Joint system showed a MOR of 29.82 MPa, which is below the minimum limit recommended by ASTM (39 MPa). This value reflects a very low resistance compared to the requirements for more rigorous structural applications. For the boards manufactured with the Solid wood planks system they showed a higher MOR of 41.59 MPa. In addition, both manufacturing systems presented different values of MOR, with statistically significant differences between them (Table 4), which suggests that the Solid wood planks system offers a higher strength compared to the Finger Joint system. Comparing these results with those reported for other species of the same genus, such as *Pinus radiata*, *Pinus taeda*, *Pinus echinata* and *Pinus silvesrtis*, the values obtained for *Pinus tecunumanii* were higher than those obtained for CLT manufactured with these species, with a reported MOR between 20-30 MPa (Godoy et al. 2017; Baño et al. 2018; Li et al. 2021; Glasner et al. 2023; Olsson et al. 2025).

Table 4. Analysis of variance for the modulus of rupture to static bending of CLT panels made of *Pinus tecunumanii* wood.

Source	Sum of squares	Df	Mean square	F- ratio	*P*-value
Between groups	415.711	1	415.711	5.35	0.0433
Within groups	777.409	10	777.409	-	-
Total (Corrected)	1193.12	11	-	-	-

Tukey test for modulus of rupture to static bending MPa.

	Cases	Mean	Homogeneous groups
Cross-laminated timber Finger Joint	6	29.8216	X
Cross-laminated timber solid wood planks	6	41.5932	X
Contrast	**Sig.**	**Difference**	**+/- Limits**
Cross-laminated timber Finger Joint - Cross-laminated timber solid wood planks	*	-11,3716	11,3425

* Indicate a significant difference.

The results obtained for the MOE in static bending of CLT panels manufactured with *Pinus tecunumanii* show significant differences between the two manufacturing systems evaluated (Table 5); for the Finger Joint system, the MOE was 9081.86 MPa, with a confidence interval between 6,962 and 9,807 MPa; this value is classified as low according to the standards established by ASTM, which consider a minimum MOE of 10,000 MPa for structural woods in more demanding applications. On the other hand, panels manufactured with the solid wood

Table 5. Analysis of variance for the modulus of elasticity to static bending of CLT panels made of *Pinus tecunumanii* wood.

Source	Sum of squares	Df	Mean square	F- ratio	*P*-value
Between groups	$5{,}73705 \times 10^{7}$	1	5,73705	9.94	0.0103
Within groups	$5{,}76897 \times 10^{7}$	10	5,76897	-	-
Total (Corrected)	$1{,}1506 \times 10^{8}$	11	-	-	-

Tukey test for modulus of elasticity to static bending MPa.

	Cases	Mean	Homogeneous groups
Cross-laminated timber Finger Joint	6	9081.86	X
Cross-laminated timber solid wood planks	6	13,454.9	X
Contrast	**Sig.**	**Difference**	**+/- Limits**
Cross-laminated timber Finger Joint - Cross-laminated timber solid wood planks	*	-14,373.04	3089.81

* Indicate a significant difference.

planks system presented an MOE of 13,454.9 MPa, with a confidence interval between 9,904 and 14,710 MPa; this value is classified as medium strength according to ASTM standards. These statistical differences between the two manufacturing systems were significant, indicating that the solid wood plank system offers greater rigidity compared to the Finger Joint system. This difference could be related to the fiber continuity in panels made of solid wood planks, which provide greater resistance to bending and better load distribution. Compared to CLT boards made from other species, such as *Pinus ellioti*, *Pinus radiata* and *Pinus taeda*, the values obtained for *Pinus tecunumanii* were higher. According to previous studies by Godoy et al. (2017), Baño et al. (2018) and Li et al. (2021), the CLT panels of these species had MOE values in the range of 6,000-8,000 MPa, which are lower than the results obtained in this study for *Pinus tecunumanii*. On the other hand, for *Pinus sylvestris* wood, results were similar, according to Olsson et al. (2025).

CONCLUSION

CLT boards made of *Pinus tecunumanii* wood are promising, as they suggest that this species can offer a suitable material for the manufacture of CLT in construction, using the two processing systems studied. In relation to dry air density, CLT boards manufactured with *Pinus tecunumanii* exhibit characteristics that meet the standards required for structural applications. The similarity between the values obtained for both manufacturing systems indicates that the choice of system does not significantly affect the density of the boards. Manufacturing systems have a direct impact on the mechanical properties of CLT panels. While both systems showed acceptable values for CLT manufacturing, the solid wood planks system presented advantages in terms of static bending strength, which could make it more suitable for applications where a higher load capacity is required. However, the Finger Joint system may be a viable option for optimizing wood use and maintaining a good strength-to-weight ratio. The values obtained for *Pinus tecunumanii* were higher than those reported for other species, such *as Pinus ellioti*, *Pinus radiata* and *Pinus taeda*, suggesting that this species has considerable potential for structural applications, especially if its properties are optimized through improvement techniques. Finally, it is recommended to carry out additional studies on sheare failure rate, surface quality, and compression parallel to fiber to obtain a more complete characterization of CLT boards manufactured with *Pinus tecunumanii*. Studies that improve the understanding of the mechanical behavior of these panels and their building applications.

ACKNOWLEDGMENTS

The authors wish to thank the company of Cipreses de Colombia S.A. for the donation of the wood material used and to the Laboratory of Forest Products "Héctor Anaya López" of the Universidad Nacional de Colombia, Medellín Headquarters and its staff for their support and collaboration.

REFERENCES

Baño V, Godoy D, Domenech L and Moya L (2018) Influencia de las clases resistentes del Pino Uruguayo en el diseño de paneles de madera contralaminada. En: XVI Encontro Brasileiro em Madeiras e em Estruturas de Madeira IBRAMEM. III Congresso Latino-americano de Estruturas de Madeira LaMEM, Escola de Engenharia de São Carlos EESC USP. São Carlos, Brasil.

Brandner R (2013) Production and technology of cross laminated timber (CLT): State-of-the-art-report. Pp. 3-36. In: Focus solid timber solutions - European Conference on cross laminated timber (CLT). University of Bath, Bath.

Brandner R, Ringhofer A and Sieder R (2024) Out-of-plane bending properties of cross laminated timber (CLT). Construction and Building Materials Volume 438 (9): 136991. https://doi.org/10.1016/j.conbuildmat.2024.136991

Dvorak W and Donahue J (1992) Twelve-year review of the CAMCORE Cooperative: 1980–1992. College of Forest Resources, North Carolina State University, Raleigh, NC, USA.

Dvorak W, Hodge G, Gutiérrez E, Osorio L, Malan F and Stanger T (2000) *Pinus tecunumanii*. pp. 188–209. In: Conservation & Testing of Tropical & Subtropical Forest Tree Species by the CAMCORE Cooperative, College of Natural Resources, North Carolina State University, Raleigh, NC, USA.

Fabrizio C, Sciomenta M, Spera L, De Santis Y, Pagliaro S, Di Egidio A and Fragiacomo M (2023) Experimental investigation and beam-theory-based analytical model of cross laminated timber panels buckling behavior. Archives of Civil and Mechanical Engineering 172(3). https://doi.org/10.1007/s43452-023-00713-8

Ferk H (2013) Some building science aspects for building with CLT. pp. 207-250. In: Focus solid timber solutions - European Conference on Cross Laminated Timber (CLT). University of Bath, Bath.

Glasner D, Ringhofer A, Brandner R and Schickhofer G (2023) Rolling shear strength of cross laminated timber (CLT)-Testing, evaluation, and design. Buildings 13: 2831. https://doi.org/10.3390/buildings13112831

Godoy D, Vega A and Baño V (2017) Characterization of cross laminated timber made from wood of low-mechanical properties of *Pinus taeda* Elliottii. In: Clem + cimad II Congreso Latinoamericano de Estructuras de Maderas II Congreso Ibero – Latinoamericano de la Madera en la Construcción. Universidad Nacional Noroeste NNOBA, Buenos Aires, Argentina.

Heard R, Hendrickson C and McMichael F (2012) Sustainable development and physical infrastructure materials. MRS Bulletin 37(4): 389–394. https://doi.org/10.1557/mrs.2012.7

Hoshmand, R (2006) Design of experiments for agriculture and the natural sciences. Second edition. Chapman and Hall/CRC. https://doi.org/10.1201/9781315276021

Jele M, Varevac D and Raj V (2018) Cross-laminated timber (CLT) – a state-of-the-art report. Građevinar 70: 75-95. https://doi.org/10.14256/JCE.2071.2017

Li X, Ashraf M, Subhani M, Kremer P, Li H and Anwar-Us-Saadat M (2021) Rolling shear properties of cross-laminated timber (CLT) made from australian Radiata pine – An experimental study. Structures 33: 423–432. https://doi.org/10.1016/j.istruc.2021.04.067

Olsson A, Schirén W and Hu M (2025) Dynamic and quasi-static evaluation of stiffness properties of CLT: longitudinal MoE and effective rolling shear modulus. European Journal of Wood and Wood Products 83:16. https://doi.org/10.1007/s00107-024-02185-w

Ramage M, Burridge H, Busse-Wicher M, Fereday G, Reynolds T et al (2017) The wood from the trees: The use of timber in construction. Renewable and Sustainable Energy Reviews (68): 333–359. https://doi.org/10.1016/j.rser.2016.09.107

Saxena A, Buettner W, Kestler L and Kim Y (2022) Opportunities and barriers for wood-based infrastructure in urban Himalayas: A review of selected national policies of Nepal. Trees Forests and People 8 (March): 100244. https://doi.org/10.1016/j.tfp.2022.100244

UNE - Asociación Española de Normalización (2011) UNE-EN 408. Estructuras de madera. Madera aserrada y madera laminada encolada para uso estructural. Determinación de algunas propiedades físicas y mecánicas. Asociación Española de Normalización (UNE), Madrid, España.

Jhon F. Herrera-Builes, Juan C. Sierra, Rodolfo Parra
Physical and mechanical properties of cross-laminated timber made from Pinus tecunumanii wood
Propiedades físicas y mecánica de madera contralaminada fabricada con Pinus tecunumanii

Revista Facultad Nacional de Agronomía Medellín
vol. 78, no. 2, p. 11161 - 11167, 2025
Facultad de Ciencias Agrarias - Universidad Nacional de Colombia,
ISSN: 0304-2847
ISSN-E: 2248-7026

DOI: https://doi.org/10.15446/rfnam.v78n2.114727