SCIENTIFIC ARTICLE

Screw extraction in *Pinus taeda* wood at two different densities

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Abstract

This study evaluates the screw withdrawal resistance in *Pinus taeda* wood of two density classes, defined here as low and high density. Low-density specimens presented values ranging from 0.37 to 0.43 g cm^{-3}, while high-density specimens ranged from 0.51 to 0.60 g cm^{-3}. The samples measured 50 × 50 × 150 mm and were assessed for withdrawal resistance in the axial, radial, and tangential directions. The results showed that screw withdrawal resistance was consistently higher and more uniform in the tangential direction, with mean values of 1993 N and 2863 N for low- and high-density wood, respectively.

Keywords: Timber structures; Joints; Beams.

Introduction

Wood has long been recognized as one of the most versatile construction materials, and its applications in building structures have steadily expanded over time (Hänsel et al., 2022). In recent years, there has been a global trend toward the construction of increasingly taller timber buildings. One of the most iconic projects in Latin America is the six-story experimental Peñuelas Tower in Chile. The versatility of wood also allows its use in hybrid structures, often combined with concrete. For example, in Canada, more than 90% of residential buildings are light-frame timber constructions (Pan et al., 2021). Although hybrid timber–concrete systems are also employed in high-rise buildings, their use is restricted by fire safety regulations, since wood is a combustible material. For instance, the Canadian National Building Code limits timber structures to six stories. A critical aspect in the performance of timber structures is the reliability of the connections between members (Ottenhaus et al., 2021). Similarly, in the furniture industry, joints are essential for assembling structural elements such as corners (Feirer, 1972). Among the most common mechanical joints in timber construction are those using nails or screws, which transfer loads across members (Arriaga et al., 2011). Screw withdrawal resistance is a key property, as fasteners subjected to axial tensile loads tend to be pulled out of the wood. For both design and comparative purposes, reliable data on the withdrawal resistance of these fasteners is frequently required.

The aim of this study was to determine whether density is a decisive factor influencing the screw withdrawal resistance in *Pinus taeda* wood. Two density groups—low and high—were established for comparison. Furthermore, the study sought to assess whether screw withdrawal resistance varies according to the anatomical direction of insertion: axial, radial, or tangential.

Materials and Methods

Commercial kiln-dried sawn *Pinus taeda* boards were obtained from two sawmills located in northern Misiones Province. The material from one sawmill exhibited lower density than that from the other (Figure 1). Samples were selected in such a way as to enable comparison between high- and low-density woods: denser wood presented a higher proportion of latewood and less earlywood, while lower-density wood had the opposite composition. In this study, the former is referred to as "high-density wood," and the latter as "low-density wood." Ten rectangular specimens (50 × 50 × 150 mm) were prepared for each density group, yielding a total of 20 specimens.

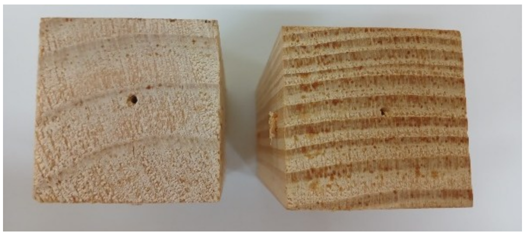

Figure 1. On the left, low-density *Pinus taeda*; on the right, high-density *Pinus taeda*

Density was determined by weighing each specimen on a balance with 0.1 g precision and calculating volume from dimensional measurements taken with a caliper.

Moisture content was determined following IRAM Standard No. 9532, using the oven-drying method. After testing, the specimens were weighed, oven-dried at 103 ± 2°C for 36 h until constant weight, and weighed again to determine oven-dry mass.

$$CH\% = \frac{Ph - Po}{Po} * 100$$

Where:

CH% = moisture content (%)

Ph = wet mass (g)

Po = oven-dry mass (g)

Since moisture content influences screw withdrawal resistance, determining the moisture content of each specimen was necessary to correct the resistance values obtained and adjust them to values standardized at 12% moisture content, according to the equation proposed by ABNT (1997):

$$r_{12} = r_{u\%}\left[1 + \frac{3(U\% - 12)}{100}\right]$$

Where:

r12 = resistance at 12% moisture content

rU% = resistance at measured moisture content

U% = specimen moisture content at testing

Withdrawal tests were performed in accordance with ASTM D-1761. Screws were inserted perpendicularly into the specimens. For each axial face, one value was obtained; for radial and tangential faces, two values were recorded, with screws placed at least 50 mm apart (Figure 2). Each test registered the maximum withdrawal load. Screw positions were kept at least 20 mm from edges and 38 mm from specimen ends to avoid splitting.

Figure 2. Test specimen in the radial direction with two screws placed more than 50 mm apart

Screws were withdrawn at a constant rate of 2 mm/min using a universal testing machine with a maximum capacity of 30 tons, and maximum load was recorded in Newtons (Figure 3).

Figure 3. Test specimen under testing in the universal machine

Screws measured 4 mm in diameter and 50 mm in length, with an embedment depth of 32 mm, achieved using a pilot drill.

Statistical Analysis

Withdrawal resistance was analyzed separately for the axial, radial, and tangential directions. Descriptive statistics were computed for both density groups. Homoscedasticity was assessed in each group as a prerequisite for ANOVA.

All analyses were conducted using InfoStat.

Results and Discussion

The density values of woods classified as low density ranged from 0.37 to 0.43 g cm^{-3}, while those classified as high density ranged from 0.51 to 0.60 g cm^{-3}. The moisture content of low-density wood was higher than that of high-density wood, with average values of 14.8% and 11.8%, respectively. Each screw withdrawal resistance result was corrected for the moisture content of the corresponding specimen using the previously mentioned equation, to standardize the values to a moisture content of 12%. Based on these corrected values, Table 1 was prepared, presenting a descriptive measure of screw withdrawal resistance by anatomical direction and density.

As shown in Table 1, screw withdrawal resistance was higher in the tangential direction for both low- and high-density wood. In the tangential direction of high-density wood, a maximum value of 4466 N was obtained.

Table 1. Descriptive statistics of screw withdrawal resistance (N) at high and low density in axial, radial, and tangential directions

	Low density			**High density**		
	Screw withdrawal resistance (N) in the different directions					
	Axial	**Radial**	**Tangential**	**Axial**	**Radial**	**Tangential**
Mean	1427	1396	1993	1568	2355	2863
Min.	365	472	688	471	395	1811
Max.	2131	2334	3096	4046	4594	4466
Std. Dev.	505	558	674	953	1164	763
C.V. (%)	35	40	34	61	49	27

In Table 1, it can be observed that the coefficients of variation are high for both low- and high-density wood, being greater in the axial and radial directions

This high variability in the axial and radial directions could be due to the fact that the screw may be inserted either into latewood or earlywood, which differ in density, and thus the resistance depends on the density of that specific growth ring rather than on the average property of the specimen (Jovanovski et al., 2005), as can be seen in Photo 4.

Photo 4. Early- and latewood rings. Left: axial direction; right: radial direction

Conversely, in the tangential direction, screws intersect both earlywood and latewood multiple times (Figure 5), producing a resistance value more representative of the overall specimen density.

Figure 5. Insertion across the tangential direction intersects earlywood and latewood bands

Prior to the analysis of variance, Levene's test was performed to determine whether the samples met the homoscedasticity criterion, a necessary requirement for conducting ANOVA. The p-values for the axial, radial, and tangential directions were 0.005, 0.002, and 0.099, respectively. It can be observed that the p-value for the tangential direction is greater than the significance level of 0.05, indicating that the variance of the samples in the high-density group is similar to that of the low-density group, thus fulfilling the homoscedasticity requirement for applying ANOVA. This criterion was not met for the axial or radial directions; therefore, ANOVA was applied only to the tangential direction. The ANOVA results for the tangential direction yielded a p-value of 6.9×10^{-7}, which clearly indicates a statistically significant difference at the 95% confidence level in screw withdrawal resistance between low- and high-density wood. The mean resistance was substantially higher in the high-density group (2863 N) compared to the low-density group (1993 N).

There is abundant literature suggesting that density is a determining factor in screw withdrawal resistance (Reinhard, 2019; Kiliç et al., 2006), and that the surfaces into which screws are inserted yield different values. Aytekin (2008) worked with *Quercus robur* L., *Pinus pinea* L., and *Pinus nigra* Arnold, with densities of 0.696 g cm^{-3}, 0.534 g cm^{-3}, and 0.496 g cm^{-3}, respectively, and obtained withdrawal resistance values of 650 N, 582 N, and 518 N. These results indicate that density has a positive correlation with screw withdrawal resistance.

Conclusion

The average screw withdrawal resistance was higher in high-density *Pinus taeda* wood compared to low-density wood. In the axial and radial directions, variability in the results prevented the performance of an analysis of variance. However, in the tangential direction, the samples exhibited similar variances, allowing for ANOVA, which revealed a significantly greater resistance in high-density wood.

These findings provide valuable insights for the timber construction industry. The conclusion that high-density wood offers higher screw withdrawal resistance in the tangential direction is crucial for designers and builders. This knowledge may influence material selection and the design of joints in timber structures, thereby enhancing the safety and durability of buildings. Furthermore, the data obtained can contribute to the development of specific recommendations for constructing taller and more robust wooden buildings, optimizing the use of timber in combination with other materials, such as concrete.

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