Educational Administration: Theory and Practice
2024,30(4), 9186-9202
ISSN:2148-2403
https://kuey.net/

Research Article

Experimental Investigation Of Nail Joint Performance In Micandra Spruceana Wood: Effect Of Nail Length And Configuration

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Citation: Hirbin Félix Céspedes Reynaga 2024), Experimental Investigation Of Nail Joint Performance In Micandra Spruceana Wood: Effect Of Nail Length And Configuration *Educational Administration: Theory And Practice*, *30*(4), 9186-9202
Doi: 10.53555/kuey.v30i4.3316

ARTICLE INFO | **ABSTRACT**

The present study conducts the nail joint load-bearing capacity and the deformation behavior of Higuerilla wood (Micandra Spruceana) to assess the wood's suitability for construction industry. The standardized double shear parallel to the grain test consisted of 240 specimens which were divided into 3 groups each using 2 inches, 3 inches, and 4 inches nails. The nails quantity and design varied according to each case with thirty tests conducted to assess nail extraction resistance, wood density and moisture content. The studies were carried out at the materials testing laboratory of the Faculty of Civil Engineering, National Engineering University (UNI). Results indicate reduced characteristic experimental loads ranging from 30 kg to 66 kg per nail for different nail configurations with 2-inch nails, 45 kg to 130 kg per nail for 3-inch nails, and 65 kg to 126 kg per nail for 4-inch nails. The JUNAC recommendations and the Johansen model were also calculated to obtain theoretical values. The comparative study shows that the ultimate stress values per nail for Higuerilla wood are close to results of group "C" woods such as Punga, Rubber, Catahua Amarilla, Mahogany, and Cumala, with differences only being from 5% to 35% depending on proximity of density between Higuerilla and listed woods.

Keywords: Higuerilla wood, Micandra Spruceana, nail joints, load-bearing capacity, deformation, construction, double shear, basic density, moisture, resistance, JUNAC recommendations, Johansen model.

1. INTRODUCTION

Wood has been integral to various human endeavors, serving as fuel, carpentry material, and a structural component in constructions like houses and boats. Understanding its physical and mechanical properties is crucial for predicting the behavior of wooden structures under different stresses over time. However, the overexploitation of popular timber species like Cedar and Oak has led to ecological imbalance and increased costs. Peru, endowed with diverse forest resources, presents an opportunity to explore lesser-known species like Higuerilla (Micandra Spruceana) for construction purposes, necessitating research to establish their properties and promote sustainable usage. An essential aspect of wooden constructions is ensuring the efficacy of joints between structural elements to guarantee long-term durability. While Peruvian standards provide guidelines for nailed joints, some timber species, like Higuerilla, lack specific recommendations despite their potential for structural use. Experimental research is therefore vital to evaluate the resistance and deformation characteristics of such joints, providing essential data for safe construction practices and regulatory compliance. The complexity of wood construction lies in addressing challenges associated with joint design and performance. Mechanical joints, particularly those utilizing nails, depend on factors such as nail type, quantity, and configuration, influencing joint strength and deformation. By subjecting these joints to standardized double shear tests parallel to the grain, this research aims to elucidate the behavior of Higuerilla

wood, providing insights into its suitability for various structural applications and contributing to the establishment of comprehensive guidelines for its use in construction.
This research is delimited by both spatial and temporal factors. Spatially, it focuses on assessing the strength of nailed joints in Higuerilla wood (Micandra Spruceana) through double shear tests parallel to the grain, along with supplementary tests on basic density, moisture percentage, and nail extraction. These experiments will be conducted at the materials testing laboratory of the Faculty of Civil Engineering, National University of Engineering, located in Lima, utilizing certified wood sourced from Satipo in the central jungle of Peru.
In terms of time, the research is constrained within a 12-month period. This timeframe encompasses various stages, including literature review, search for national and international precedents, thesis planning, acquisition and transportation of wood, specimen preparation and conditioning, conducting tests, processing, and analysing results, and final document preparation. The finite nature of the research ensures a systematic progression from inception to conclusion.

2. OBJECTIVES

The primary goal is to determine the strength and deformation characteristics of nailed joints in Higuerilla wood (Micandra Spruceana) subjected to double shear tests parallel to the grain, while varying nail geometry and configuration.

- Evaluate the strength and deformation of nailed joints in Higuerilla wood using 4, 6, and 8 2-inch nails in double shear tests parallel to the grain.
- Assess the strength and deformation of nailed joints in Higuerilla wood using 4, 6, and 8 3-inch nails in double shear tests parallel to the grain.
- Investigate the strength and deformation of nailed joints in Higuerilla wood using 4, 6.8, and 4-inch nails, maintaining consistent geometric configurations.

This delineation establishes the parameters within which the research will operate, facilitating a focused and comprehensive investigation into the performance of nailed joints in Higuerilla wood.

3. BACKROUND

Research on timber joints has been a globally pursued endeavor, with various countries, including the United States and European nations, leading the way in standardized trials and investigations. These studies have delved into the characteristic strength and behavior of nailed joints, offering insights into failure mechanisms and deformation patterns. For instance, Blass (1994) conducted research on the characteristic values and behavior variations of force-displacement curves in nailed joints, highlighting the significance of understanding deformation limits and load variations. Similarly, Nishiyama and Ando (2003) explored the application of nonlinear analysis in predicting load-displacement curves accurately, underscoring the importance of advanced analytical methods in understanding joint behavior.
In the United States, the Forest Products Society (2004) spearheaded extensive mechanical tests on roof-to-wall joints, shedding light on the structural challenges posed by adverse weather conditions. Additionally, Avila Valdivia's (2008) development of an automated program for designing wooden structural joints based on shear tests marked a significant advancement in joint design processes, streamlining and optimizing structural engineering practices. Furthermore, the Cartagena Agreement Board (1984) provided comprehensive recommendations for woodwork, offering detailed guidelines for structural joint design and construction, thus contributing to standardized practices in the industry.
In Peru, research on timber joints has a rich history dating back to the 1970s, predominantly conducted at the Faculty of Civil Engineering of the National University of Engineering. Studies conducted during this period focused on assessing lateral resistance in nailed joints of various forest species, such as Caspi Sulphur Wood and Cumala Blanca, providing valuable insights into structural and carpentry applications. Recent research endeavors by Daniel Ruiz Mayta (2009), Corrales Porras (2018), and Pezo Mejía (2018) have further expanded the knowledge base on timber joints, with a specific focus on understanding the structural classification, mechanical resistance, and behavior of timber species like Micandra Spruceana. These studies have paved the way for the potential utilization of lesser-known timber species in construction, contributing to the sustainable development of the construction industry in Peru.
Thus, research on timber joints encompasses a wide array of studies conducted internationally and nationally, spanning decades and covering various aspects of joint behavior, strength, and design. These investigations have not only advanced the understanding of wood construction practices but have also contributed to the development of standardized guidelines and recommendations, ensuring the safety and efficacy of wooden structures worldwide.

4. THEORETICAL FRAMEWORK

Understanding the nature of wood is fundamental before delving into its applications in construction. Wood, as the primary constituent material of tree trunks, branches, and roots, possesses unique characteristics that distinguish it from mineral-based construction materials (Urbán, 2013). Its versatility has made it indispensable in various construction applications, from housing to carpentry, and even as a source of fuel for human sustenance (Sánchez, 2009).

4.1 Atomic Composition of Wood

The macroscopic structure of a tree trunk features distinct zones, including the outer sapwood and inner heartwood, with the cambium layer responsible for wood formation situated between them (Urbán, 2013). The cambium undergoes cyclic growth, resulting in the production of thick-walled cells during colder seasons and thin-walled cells during warmer periods. This cross-section configuration is essential for understanding the tree's growth and structure, as illustrated in Figure 01(a)(b). At microscopic level, wood composition differs between coniferous and broad-leaved trees. Coniferous woods, typical of cold and temperate regions, exhibit a homogeneous composition primarily comprising tracheid cells, contributing to both workability and mechanical strength (Sánchez & Ramírez, 2005). Conversely, broad-leaved woods feature heterogeneous fibers with properties varying based on the direction of the cut (JUNAC, 1984). Figures 1(c) and 1(d) depict the microscopic structures of conifer and broad-leaved trees, respectively, providing insights into their internal composition and organization.

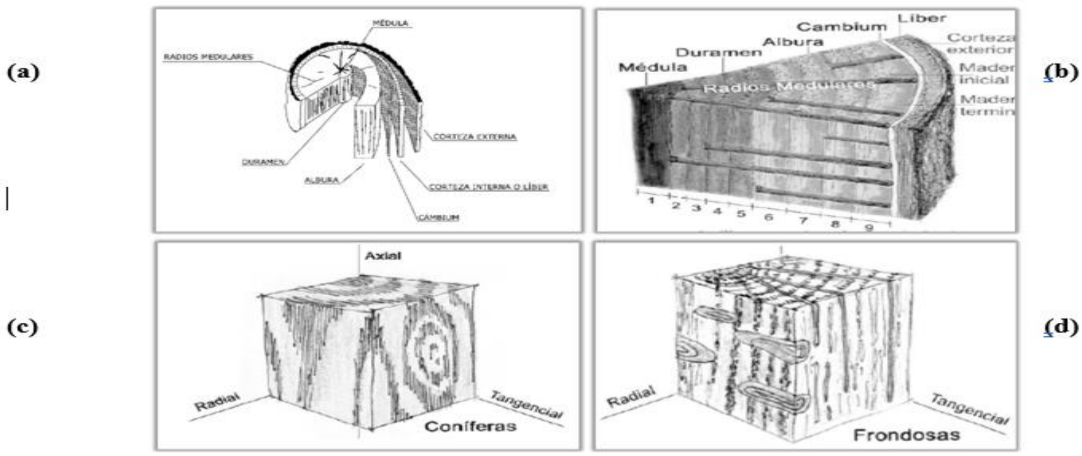


Figure 01: (a) Trunk cross-section [Urbán (2013)]; (b) Macroscopic structure of the trunk [Sanchez, 2009]; (c) Conifer fibres according to cut [Sánchez, Ramírez. (2005)]; (d) Broad-leaved fibres according to cut [Sánchez, Ramírez. (2005)]

4.2 Chemical and mechanical Properties of Wood

Wood possesses a diverse array of chemical, physical, and mechanical properties, each crucial for understanding its behavior and utility in various applications. Chemically, wood comprises cellulose, lignin, and organic components, with cellulose and lignin providing structural integrity (Sánchez, 2009). Essential chemical elements such as carbon, oxygen, and hydrogen, along with secondary elements and mineral compounds, contribute to its composition (Sánchez, 2009). Physically, moisture content plays a pivotal role in wood's properties, affecting its mechanical behavior significantly (NTP 251.010.2014). Variations in moisture content led to changes in mechanical properties, with resistance declining as moisture content rises until reaching saturation (JUNAC, 1984). Basic wood density, closely correlated with mechanical strength, varies across timber species, and influences overall resistance (Alejos & Cáceres, 2008). Mechanical properties encompass tensile, compressive, and bending strengths, with wood's ability to withstand external pressures and forces determining its structural performance (Zanni, 2004).

4.3 Nailed Joints

Nailed joints are ubiquitous in wood construction, facilitating the assembly of wooden elements across various applications, from traditional carpentry to structural components in buildings. Understanding the physical, geometric, and structural behavior of these joints is imperative, as they often bear significant loads, and failure compromises the integrity of the entire structure, posing risks to occupants. Anisotropy, inherent to wood, complicates the study of nailed joints due to properties varying with wood fiber orientation. Hence, tests on each joint load the force parallel or perpendicular to the wood fibers. The efficacy of a joint's connection depends on factors such as the number of nails, their arrangement, and the geometry of wooden pieces. Consequently, shear tests focus on single and double shear configurations, especially in joints involving two cutting sections. The cost-effectiveness of using nailed joints hinges on the type and scale of the structure. While conventional configurations suffice for low-rise buildings, high-rise structures necessitate specialized joint designs to ensure structural robustness.

The performance of nailed joints is influenced by various factors, including the direction of load application, fasteners used, geometric distribution of nails, shearing behavior, and permissible values. Directionality of forces affects joint behavior, with distinct strength characteristics in compression, tangential, and radial directions (Pacini, Wainstein, and Iriso, 2019). Figure 2 visually depicts the significance of load directionality. Nails, serving as primary fasteners, require pre-drilling in wood to prevent cracks and adhere to specific spacing guidelines outlined by Peruvian Technical Standards and the Andean Group's Wood Design Manual (JUNAC, 1984). Shearing behavior, crucial for understanding joint strength, is assessed through shear tests, with load applied parallel to wood fibers. Permissible values of nailed joints are determined through tests considering factors such as charging duration, moisture content variation, and load factors (JUNAC, 1984).

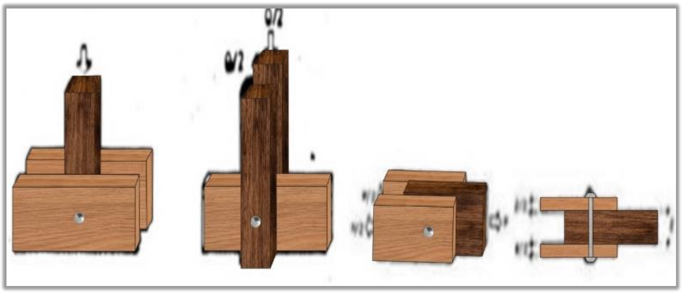


Figure 2: Loaded elements parallel and perpendicular to the grain. [Self-elaboration based on Pacini, Wainstein and Iriso, (2019)]

The Johansen model provides a theoretical framework for calculating joint strength, considering failure modes and plastic ball joint formation on nails (Sosa M, 2015). Thus, nail removal tests, conducted on wood prisms, assess fastener retention under specific conditions outlined by Peruvian Technical Standards (NTP 251.036, 2015). These tests ensure the reliability and safety of joint configurations in structural applications, contributing to the overall understanding and optimization of nailed joint performance.

5. HYPOTHESIS & VARIABLES

Performing Parallel Double Grain Shear Tests on Higuerilla Wood Nailed Joints (Micandra Spruceana) using different types and configurations of nails yields acceptable strength and deformation values for use in the construction industrys. Assumptions are as follows:

i. Performing double shear tests parallel to the grain of joints nailed in fig wood, using 4, 6, and 8 2-inch nails gives strength and deformation values that define its good structural performance.
ii. Performing double shear tests parallel to the grain of joints nailed in fig wood, using 4, 6, and 8 3-inch nails gives strength and deformation values that define its good structural performance.
iii. Performing double shear tests parallel to the grain of joints nailed in fig wood, using 4, 6, and 8 nails of 4 inches gives values of strength and deformation that define its good structural performance.

Dependent Variable: The dependent variable in the research on Parallel Double Grain Shear Tests conducted on Higuerilla Wood Nailed Joints (Micandra Spruceana) is the Permissible Load. This variable represents the maximum load that the joint can withstand according to prevailing regulations and mathematical models. It encompasses various indices such as the force applied, basic density, moisture percentage, and the configuration of nail geometry. Measured in kilograms, the permissible load is crucial for determining the structural integrity and safety of the joints, making it a central focus of the study.

Independent Variables: The study identifies two independent variables: Strength of Nailed Joints and Deformation. The Strength of Nailed Joints denotes the maximum load-bearing capacity of the joint without experiencing failure. It encompasses indicators such as the diameter of nails, applied force, nail geometry configuration, basic density, and moisture content, and is measured in kilograms. The Deformation variable refers to the relative displacement between wood pieces within the joint under load. It encompasses indicators such as nail strength, loading speed, joint geometry, basic density, and moisture content, and is measured in millimeters. Understanding these independent variables is crucial for evaluating the structural robustness and deformation characteristics of the joints in practical construction applications.

To operationalize the variables, we followed a systematic approach. Firstly, we identified the variables as either dependent or independent. Then, we provided conceptual definitions for each variable. Next, we identified indicators for each variable, ensuring that each indicator had at least two indices for a quantitative research approach. We then specified measurable indices with established units to ensure precision in measurement. Finally, we identified tools such as national and international regulations to describe and define the variables, ensuring adherence to standardized testing protocols. This systematic approach ensures clarity, consistency, and reliability in defining and measuring variables in the research context.

6. METHODOLOGY

6.1 Research Method, Level, Type, and Design

This research adopts a deductive approach within a positivist paradigm, aiming to propose and test hypotheses through established scientific research procedures. It is applied research, providing practical solutions by obtaining values for the resistance of nailed joints. The research employs a quantitative methodology, as it involves the measurement of quantifiable values such as strength and deformation. Data collection follows a retrospective approach, conducting tests in the laboratory according to standardized protocols.

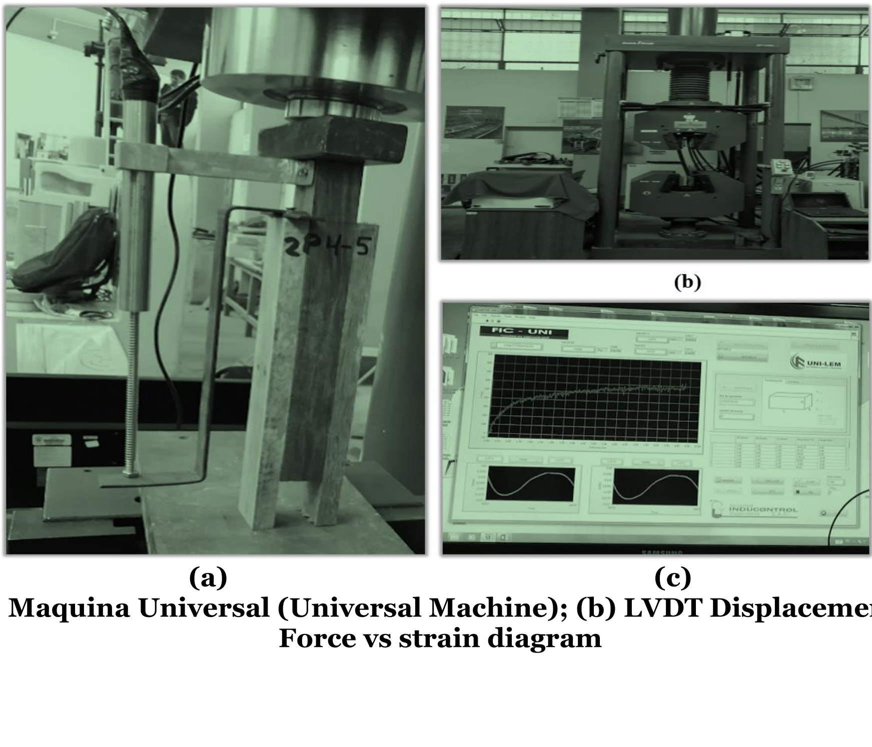
6.2 Population and Sample

The population consists of the total number of specimens (joints) to be tested in the study. For practical reasons, the population size is considered equal to the sample size. The sample size is calculated using Equation 1, considering a reliability coefficient of 95%, equal probabilities for true and false hypotheses, and an estimated error of 5%. Based on previous research and methodological recommendations, a sample size of 40 specimens per sampling unit is chosen. This includes 30 specimens as a minimum recommended for quantitative research and an additional 10 specimens for increased statistical reliability. The total sample size, considering different nail diameters and configurations, amounts to 240 specimens.

$$n = \frac{Z^2.p.q.N}{e^2.(N-1)+Z^2.p.q} \qquad \text{----------------} \qquad \textbf{Equation 1}$$

Where:
n = Sample size
N = Population size
Z = Reliability coefficient for 95% (1.96)
p = Probability that the hypothesis is true (0.5)
q = Probability that the hypothesis is false (0.5)
e = estimated error (5%)

6.3 Data Collection Techniques and Instruments: Data collection for this research involves laboratory tests conducted according to standardized procedures outlined in current regulations. Double shear tests parallel to the grain, as per Peruvian standard NTP 251.011.2014 and ASTM D 1761-2014, will be performed to determine joint resistance in Higuerilla wood. Additional tests for basic density (NTP 251.011.2014), moisture content (NTP 251.010.2014), and nail extraction (NTP 251.036.2015) will also be conducted. Data collection will primarily rely on observation, using validated and standardized formats as per regulations. The instruments used for measurement and data collection are validated by the respective standards and calibrated by the materials testing laboratory of the National University of Engineering, ensuring reliability.



(a) (c)

Figure 3: (a) Maquina Universal (Universal Machine); (b) LVDT Displacement Sensor;(c) Force vs strain diagram

6.4 Description of the Working Procedure: The process dvdvebegins with the conditioning of Higuerilla wood, sourced from the central jungle region of Junín, Peru. The wood's distinctive color characteristics are verified through laboratory tests at the National Agrarian University La Molina. Specimens are then prepared according to standardized dimensions for double shear tests parallel to the grain, ensuring the thickness of wood pieces is at least 5-10 times the nail diameter. Geometric configurations of specimens for different nail diameters (2, 3, and 4 inches) are calculated, considering manufacturing errors of the nails. The preparation involves pre-drilling to prevent wood cracking during nailing. Specimen dimensions and configurations are detailed in tables and illustrated in figures to facilitate understanding and replication of the procedure.

Figure 4: Conditioning of Higuerilla wood

7. SUPPLEMENTARY ESSAYS

7.1 Moisture Content Test

The mechanical properties of wood are closely linked to its moisture content, with studies indicating that resistance decreases as moisture content increases, plateauing once saturation is reached (JUNAC, 1984).
Moisture content tests were conducted following the standard (NTP 251.010.2014). Rectangular specimens measuring approximately 30 mm in width, 30 mm in base, and 100 mm in height were prepared. These dimensions were adjusted for each sample during testing due to inevitable errors during wood cutting. A total of 30 specimens were examined, with one sample per every 5 specimens tested. The specimens were placed in an oven at a constant temperature of 100°C for 24 hours to obtain dry weights after soaking. Values for each sample were tabulated, including measurements and weights, as shown in Table 1.
The moisture content of each sample was calculated using the formula:

$$\textbf{Moisture Content (\%)} = \left(\frac{\textbf{Wet Weight} - \textbf{Dry Weight}}{\textbf{Dry Weight}}\right) \times 100\% \text{ ----- } \textbf{Equation 2}$$

(A) **(B)**

Figure 5: (A) Specimens for moisture testing; (B) Samples in oven at 100°C

Table 1: Moisture content as a percentage

SAMPLE	BASE (mm)	WIDE (mm)	HEIGHT (mm)	Ph (gr)	PS (gr)	% HUMIDITY
M 1	30.56	31.08	99.42	55.8	47.3	18
M 2	31.39	31.22	99.97	52	45.2	15
M 3	30.39	29.75	100.79	67.5	58.7	15
M 4	33.12	30.76	100.6	52.4	45.4	15
M 5	30.9	31.03	99.62	71.7	48.8	47
M 6	30.28	31.43	100.02	52.1	46.6	12
M 7	29	30.96	100.08	82.9	49.4	68
M 8	31.23	30.74	99.8	66.9	45	49
M 9	30.57	31.35	99.55	76.8	49	57
M 10	30.9	30.74	99.75	71.6	48.7	47
M 11	30.88	31.06	100.31	67.1	57.9	16
M 12	30.05	31.02	100.68	75.3	48.2	56
M 13	30.63	30.53	99.96	68.9	46.8	47
M 14	31.27	31.03	101.09	55.5	47.5	17
M 15	31.47	29.67	99.21	63.9	56.5	13
M 16	30.93	31.66	99.83	77.1	48.8	58
M 17	30.79	30.51	99.88	73	47.1	55
M 18	30.81	32.37	98.8	55.3	47	18
M 19	31.02	31.56	100.6	75.7	49.2	54
M 20	30.06	30.02	101.4	81.3	47.5	71
M 21	30.55	30.48	101.04	74.8	48	56
M 22	31.88	61.53	99.7	64.3	55	17
M 23	32.9	30.8	100.17	76.4	53.5	43
M 24	30.51	31.06	100.27	76.3	49.8	53
M 25	30.48	30.51	100.41	63.8	47.3	35
M 26	30.97	30.8	100.45	61.1	53.7	14
M 27	31.03	30.81	100.59	66.8	58.6	14
M 28	30.61	30.74	100.91	58.7	39.4	49
M 29	30.31	27.63	100.91	58.7	39.4	49
M 30	30.31	30.18	100.9	86.9	47.8	82

7.2 Basic Density Test

Basic density tests were conducted on 30 samples with dimensions of approximately 30 mm in width, 30 mm in base, and 100 mm in height. The samples were saturated in water for a week to achieve homogeneous saturation. After saturation, the samples were weighed to obtain wet weights. The volume of each saturated sample was indirectly measured by immersing them in a cylinder filled with distilled water. Subsequently, the samples were dried in an oven at 100°C for 24 hours to obtain dry weights. Density values for each sample were calculated using the below given equation and the results obtained are presented in Table 2.

$$\textbf{Density}\ (\mathrm{g/cm^3}) = \frac{\textbf{Wet Weight (g)}}{\textbf{Volume}\ (\mathrm{cm^3})} \text{ ----------- } \textbf{Equation 3}$$

(A) (B)

Figure 6: (A) Samples for basic density testing; (B) Saturation and drying of samples for basic density assays

Figure 7: Indirect measurement of sample volume and weighing.

Table 2: Basic Density Results for Higuerilla

SAMPLE	BASE (mm)	WIDE (mm)	HEIGHT (mm)	VHS (cm3)	PS (g)	DENSITY (g/cm3)
D1	30	30.8	102.28	128.8	53.8	0.42
D2	30.57	29.51	101.28	108.8	55.8	0.51
D3	29.15	31.18	102.41	111.7	55.5	0.50
D4	30.32	30.73	101.52	112.3	54.8	0.49
D5	29.37	30.93	101.8	111.6	58.5	0.52
D6	30.72	29.33	102.8	111.3	57.3	0.51
D7	30.89	30.29	102.4	112.9	55.9	0.50
D8	31.33	31.76	102.54	112.5	55.4	0.49
D9	30.23	30.83	102.2	116.9	53.1	0.45
D10	29.71	31.86	102.19	112.8	54.1	0.48
D11	29.22	31.01	102.02	119.3	53.3	0.45
D12	28.94	30.89	102.58	110.3	58.3	0.53
D13	30.46	29.93	102.57	112.6	57.3	0.51
D14	30.84	29.77	102.85	112.3	58.8	0.52
D15	30.59	30.27	102.18	111.9	55.6	0.50
D16	29.15	31.18	102.41	111.7	55.5	0.50
D17	30.32	30.73	101.52	112.3	54.7	0.49
D18	29.37	30.93	101.8	111.6	58.5	0.52
D19	30.72	29.33	102.8	111.3	57.3	0.51
D20	29.71	31.86	102.19	112.8	54.1	0.48

D21	29.22	31.01	102.02	119.6	53.3	0.45
D22	28.94	30.89	102.58	110.2	58.3	0.53
D23	30.46	29.93	102.57	112.9	57.3	0.51
D24	30.57	29.51	101.27	108.7	55.8	0.51
D25	29.71	31.86	102.19	112.8	54.1	0.48
D26	30.72	29.33	102.8	111.3	57.1	0.51
D27	30.84	29.77	102.85	112.3	58.8	0.52
D28	29.22	31.01	102.02	119.3	53.3	0.45
D29	30.32	30.73	101.52	112.3	54.8	0.49
D30	29.71	31.86	102.19	112.8	54.2	0.48

7.3 Nail Removal Test

The nail removal test was conducted following the guidelines outlined in the Peruvian technical standard NTP 251.036. Specimens of dimensions 2"x2"x6" (51mmx51mmx152mm) were prepared, with nails driven at right angles into the face of the specimen with a total penetration of 1 1/4" (32 mm). Figure 8 illustrates the arrangement of nails for extraction tests. The resistance to extraction of each nail in different directions was measured, as depicted in Figure 9.

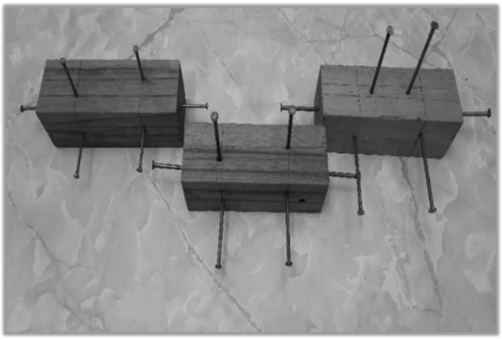


Figure 8: Arrangement of nails for extraction tests. Figure 9: Specimen nail extraction.

The reinforcement force of the nails was calculated as recommended by Sosa M (2015), where F_max represents the maximum extraction load, d denotes the nail diameter, l_p signifies the nail penetration length, and f_ax denotes the nail pulling force. The calculated values for nail pulling force for each nail type are presented in Table 3.

$$f_{ax} = \frac{F_{\max}}{d \cdot l_p} \ (N/mm^2) \text{ ------- } \textbf{Equation 4}$$

Table 3: Nail Pulling Force

Nail Diameter (mm)	2"	3"	4"
Minimum Value	1.3	4.25	7.20
Average Value	6.8	8.12	11.45
Maximum Value	12.51	14.26	17.23
Characteristic Value	4.67	5.72	7.42

7.4 Theoretical Permissible Values of Nailed Joints

The permissible stresses of double-shear joints were calculated following the equations recommended by JUNAC. For the average permissible load, Equation 5 was applied for a maximum deformation of 0.38 mm. The density value used was 0.418 g/cm3, and the results are presented in Table 4.

$$P_{0.38\,PROM} = 66.0\rho^{1.022}\, d^{1.232} \text{ ----------- } \textbf{Equation 5}$$

Table 4: Average Allowable Load for Each Nail Diameter

Nail Diameter (mm)	Density (g/cm3)	Load (kg)	Reduction Factor	P0.38prom (kg)
2"	2.77	0.419	95.18	45.76
3"	3.76	0.419	138.70	66.68
4"	4.57	0.419	176.38	84.80

The ultimate load was calculated using Equation 6 given below, considering a basic density of 0.418 g/cm3. The results for each nail diameter are summarized in Table 5.

$$P_{0.38\,PROM} = 66.0\rho^{1.022}\,d^{1.232} \text{ -------- Equation 6}$$

Table 5: Ultimate Permissible Load for Each Nail Diameter

Nail Diameter (mm)	Density (g/cm3)	Load (kg)	Reduction Factor	PU,min (kg)
2"	2.77	0.419	158.44	45.01
3"	3.76	0.419	236.507	67.19
4"	4.57	0.419	305.438	86.77

The Johansen method, implemented in 1949, provides guidelines for calculating permissible values. This involved determining the crushing strength of the wood and the plastic moment of the nails, among other parameters. The resistance values according to the Johansen model for different nail diameters and thicknesses are presented in Table 6. The permissible values obtained from the Johansen model for the "j" mode are further adjusted considering modification factors and safety coefficients, as illustrated in Table 7.

Table 6: Resistance Values According to Johansen's Model

Thickness "t" (mm)	Nail Diameter (mm)	Resistance Mode "j" (kg)	Resistance Mode "k" (kg)	Strength (kg)	Strength x Nail (kg)
15	2.77	147.21	454.93	147.21	67.94
20	3.76	217.86	612.02	217.86	100.56
30	4.57	350.23	826.37	350.23	161.62

Table 7: Permissible Values According to Johansen's Model

Thickness "t" (mm)	Nail Diameter (mm)	Resistance Mode "j" (kg)	Strength (kg)	Permissible Values x Nail (kg)
15	2.77	147.21	147.21	33.97
20	3.76	217.86	217.86	50.28
30	4.57	350.23	350.23	80.82

8. RESULTS

8.1 Strength and Deformation of Joints with 2" Nails

A total of 40 specimens, each composed of 4 x 2" nails, underwent double shear tests parallel to the grain. The specimens were labeled with a unique code for identification purposes, such as "2P4-5" indicating a joint with 4 x 2" nails and the specimen number. Figure 10 illustrates the initial and final conditions of a representative specimen.

Figure 10: Initial and final condition of specimen 2P4-5

Table 8 presents the summarized results of the double shear tests for the joints with 4 x 2" nails, including the maximum and minimum load values, as well as the corresponding deformations. The average load and characteristic load values were determined to be 675.13 kg and 495.44 kg, respectively, based on the data collected from the tests.

Table 8: Average, Characteristic, and Strain Value with 4 x 2" Nails

Number of Nails	Pmax (kg)	Pmin (kg)	Def.Max (mm)	Def.Min (mm)	Pprom (kg)	PCaract (kg)
4	792.57	492.58	18.68	13.66	675.13	495.44

From the obtained data, the load supported by each nail was calculated by dividing the experimental load value by 2 (due to double shear tests) and then dividing by the total number of nails in the joint. This allowed for the determination of the nail loading values, which are shown in Table 9 alongside the corresponding deformations for each test specimen.

Table 9: Strength and Deformation of 2" Joints with 4 Nails

Test tube	Nail	Number of nails	Deformation (mm)	Load (kg)	Nail Loading (kg)
1	2"	4	14.10	596.03	74.50
2	2"	4	17.75	495.44	61.93
3	2"	4	14.76	505.19	63.15
4	2"	4	14.37	691.08	86.39
5	2"	4	17.33	573.73	71.72
6	2"	4	15.20	525.01	65.63
7	2"	4	15.43	492.59	78.00
8	2"	4	15.21	775.73	96.97
9	2"	4	13.89	782.17	97.77
10	2"	4	17.62	637.05	79.63
11	2"	4	12.30	639.02	79.88
12	2"	4	15.62	677.52	84.69
13	2"	4	18.48	584.55	73.07
14	2"	4	16.30	696.32	87.04
15	2"	4	15.67	644.01	80.50
16	2"	4	14.26	592.13	74.02
17	2"	4	15.19	525.01	65.63
18	2"	4	17.44	575.63	71.95
19	2"	4	15.87	643.01	80.38
20	2"	4	12.55	639.02	79.88
21	2"	4	18.37	580.25	72.53
22	2"	4	14.50	792.58	99.07
23	2"	4	14.10	590.52	73.82
24	2"	4	17.62	637.05	79.63
25	2"	4	15.36	530.01	66.25
26	2"	4	14.37	691.08	86.39
27	2"	4	17.75	505.64	63.20
28	2"	4	18.52	590.55	73.82
29	2"	4	17.75	495.44	61.93
30	2"	4	14.10	596.03	74.50
31	2"	4	15.57	639.01	79.88
32	2"	4	15.60	525.01	65.63
33	2"	4	16.30	696.32	87.04
34	2"	4	13.66	780.57	97.57
35	2"	4	14.10	599.03	74.88
36	2"	4	18.48	584.55	73.07
37	2"	4	14.69	650.01	81.25
38	2"	4	15.50	529.01	66.13

39	2"	4	18.68	583.70	72.96
40	2"	4	17.64	573.73	71.72

The strength and deformation characteristics of joints comprising 6 x 2" nails were evaluated through double shear tests. A total of 20 specimens were tested, each identified with a code like "2P6-2." Figure 11 illustrates the initial and final state of a representative specimen. Table 35 presents the summarized results for the joints with 6 x 2" nails, indicating the maximum and minimum load values, as well as the corresponding deformations. The average load and characteristic load values were determined to be 938.33 kg and 782.08 kg, respectively.

Figure 11: Initial and final state of specimen 2P6-8

Table 10: Average, characteristic and deformation value with 6 2" bald spots

Number of Nails	Pmax (kg)	Pmin (kg)	Def.Max (mm)	Def.Min (mm)	Pprom (kg)	PCaract (kg)
6	1196.15	782.08	18.59	11.37	938.33	782.08

The load supported by each nail in the joints with 6 x 2" nails was calculated similarly to the previous section alongside the corresponding deformations for each test specimen.

Table 11: Strength and Deformation of 2" Joints with 6 Nails

Test tube	Nail	Number of nails	Deformation (mm)	Load (kg)	Nail Loading (kg)
1	2"	6	12.02	986.02	82.17
2	2"	6	11.37	782.08	65.17
3	2"	6	13.29	819.38	68.28
4	2"	6	18.59	1191.94	99.33
5	2"	6	15.42	1196.15	99.68
6	2"	6	15.52	971.94	80.99
7	2"	6	15.18	988.20	82.35
8	2"	6	15.19	798.04	66.50
9	2"	6	14.12	876.70	73.06
10	2"	6	17.71	1012.35	84.36
11	2"	6	11.99	786.06	65.50
12	2"	6	13.36	825.24	68.77
13	2"	6	15.46	1192.56	99.38
14	2"	6	14.16	889.26	74.10
15	2"	6	11.38	826.33	68.86
16	2"	6	15.63	998.24	83.19
17	2"	6	12.26	996.24	83.02
18	2"	6	14.15	818.24	68.19
19	2"	6	13.97	815.37	67.95
20	2"	6	14.14	996.25	83.02

The strength and deformation characteristics of joints composed of 8 x 2" nails were assessed through double shear tests on 20 specimens. Each specimen was identified using a code like "2P8-2." Figure 12 (a) illustrates the initial and final state of a representative specimen. Table 12 presents the summarized results for the joints with 8 x 2" nails, indicating the maximum and minimum load values, as well as the corresponding deformations. The average load and characteristic load values were determined to be 1065.26 kg, consistent with the fifth percentile characteristic load. For joints comprising 4 x 3-inch nails, double shear tests parallel to the grain were conducted. The load was applied upwards at a constant speed of 2.54 mm/s until either a decrease in applied load was detected or the deformation exceeded 38 mm, the regulatory limit. Figure 12 (b) illustrates the initial and final state of a representative specimen, labeled as 3P4-18.

(a) (b)

Figure 29: Initial and final state of specimen (a) 2P8-8 and (b) 3P4-18 specimen.

Table 12: Strength and Deformation of 2" Joints with 8 Nails

Test tube	Nail	Number of nails	Deformation (mm)	Load (kg)	Nail Loading (kg)
1	2"	8	10.58	1418.93	88.68
2	2"	8	13.44	1293.97	80.87
3	2"	8	12.20	1608.44	100.53
4	2"	8	13.56	1236.57	77.29
5	2"	8	12.66	1152.93	72.06
6	2"	8	12.66	1152.93	72.06
7	2"	8	13.98	1090.10	68.13
8	2"	8	12.42	1215.76	75.99
9	2"	8	15.04	1081.30	67.58
10	2"	8	13.15	1256.26	78.52
11	2"	8	12.56	1156.26	72.27
12	2"	8	13.65	1245.26	77.83
13	2"	8	11.24	1410.26	88.14
14	2"	8	13.85	1253.27	78.33
15	2"	8	15.24	1286.32	80.40
16	2"	8	14.03	1065.26	66.58
17	2"	8	13.52	1302.26	81.39
18	2"	8	12.27	1612.26	100.77
19	2"	8	10.55	1398.24	87.39
20	2"	8	12.67	1153.26	72.08

A total of 40 specimens were tested, resulting in a maximum load value of 2069.47 kg and a minimum load value of 1021.03 kg. The maximum deformation recorded was 22.11 mm, while the minimum deformation was 11.79 mm. The average load value obtained for the 40 joints with 4 x 3" nails was 1506.12 kg, while the characteristic load value calculated as the fifth percentile was 1100.45 kg.

Double shear tests parallel to the grain were conducted on joints consisting of 6 x 3" nails. Figure 13 shows the initial and final condition of a representative specimen, identified as 3P6-20. The test results from the 20 specimens revealed a maximum load value of 3689.23 kg and a minimum load value of 1230.71 kg. The maximum deformation recorded was 21.03 mm, while the minimum deformation was 9.26 mm. Table 41 presents the detailed results obtained from the tests, including the load supported by each of the 6 nails in the joint. The average load value obtained for the 20 joints with 6 x 3" nails was 2340.58 kg, while the characteristic load value calculated as the fifth percentile was 1230.71 kg. Double shear tests parallel to the grain were performed on joints comprising 8 x 3" nails. Figure 14 illustrates the initial and final condition of a representative specimen, labeled as 3P8-18.

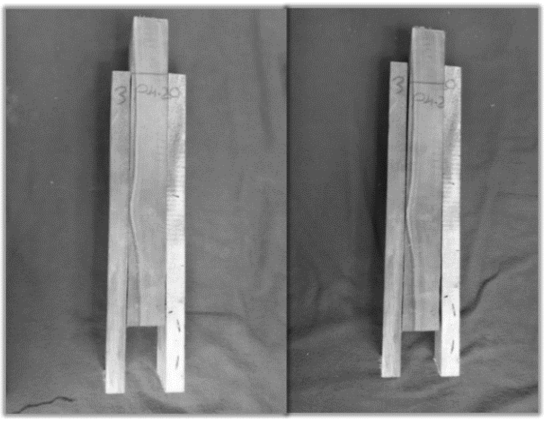
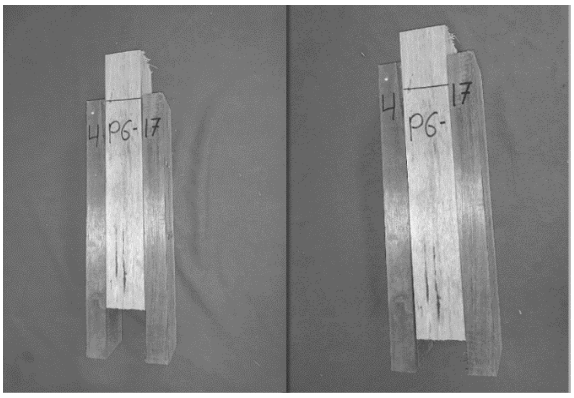


Figure 13: Initial and final condition of 3P6-20 specimen Figure 14: Initial and final condition of 3P8-18 specimen

The test results from the 20 specimens revealed a maximum load value of 3537.14 kg and a minimum load value of 3142.23 kg. The maximum deformation recorded was 19.97 mm, while the minimum deformation was 14.97 mm. Table 43 presents the detailed results obtained from the tests, including the load supported by each of the 8 nails in the joint. The average load value obtained for the 20 joints with 8 x 3" nails was 3338.83 kg, while the characteristic load value calculated as the fifth percentile was 3142.23 kg.



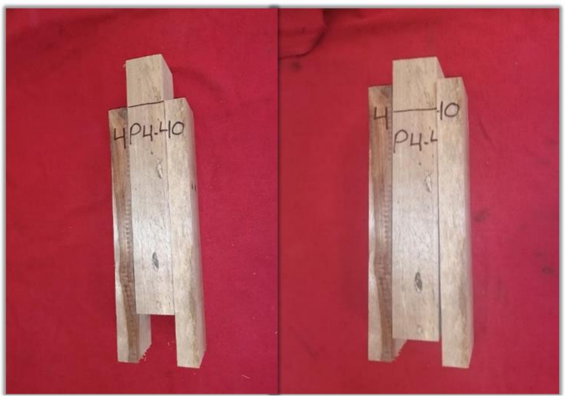


Figure 15: Initial and final state of 4P4-40 specimen Figure 16: Initial and final condition of 4P6-17 specimen

The tests conducted on 40 specimens yielded a maximum load value of 2591.71 kg and a minimum load value of 2105.59 kg. The maximum deformation recorded was 33.98 mm, while the minimum was 25.00 mm. The average load value obtained was 2553.76 kg, with a characteristic load value of 2106.59 kg. Figure 15 illustrates the before and after testing of specimen number 40, comprising 4 nails of 4 inches. The tests conducted on 20 specimens yielded a maximum load value of 4021.67 kg and a minimum load value of 3507.39 kg. The maximum deformation recorded was 32.39 mm, while the minimum was 27.61 mm. The average load value obtained was 3682.55 kg, with a characteristic load value of 3507.39 kg. Figure 16 displays the deformation of specimen 17, composed of 4 x 4-inch nails.

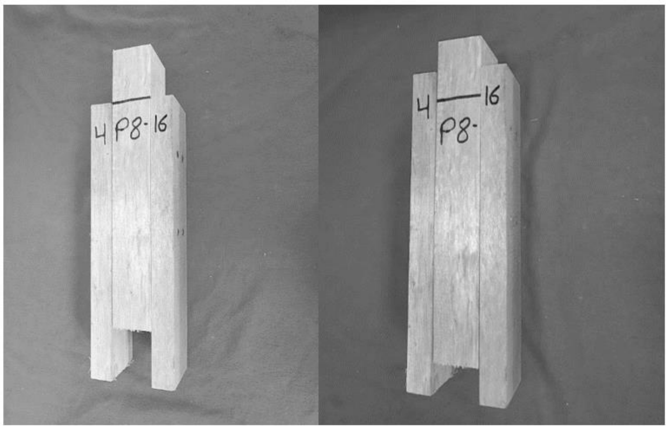


Figure 17: Initial and final condition of 4P8-16 specimen

Observations and data collection were conducted on 20 joints formed by 8 4" nails, with specimen identification code 2P8-2. Figure 17 showcases specimen number 16 before and after testing. The tests yielded a maximum load value of 5156.74 kg and a minimum load value of 4045.96 kg. The maximum deformation recorded was 32.44 mm, while the minimum was 28.25 mm. The average load value obtained was 4641.48 kg, with a characteristic load value of 4045.96 kg.

Table 13: Loading and Deforming 4" Joints with 8 Nails

8 Nails	Pmax (kg)	Pmin (kg)	Def.max (mm)	Def.Min (mm)	Pprom (kg)	PCaract (kg)
4"	5156.74	4045.96	32.44	28.25	4641.48	4045.96

Comparison Between Permissible and Experimental Values

This section presents a comparison between the results obtained from experimental tests on various joints and the permissible load values proposed by JUNAC and the JOHANSEN method. Equations recommended by JUNAC for calculating average and characteristic loads were derived from testing 20 joints considering the lowest wood density obtained from laboratory tests. Similarly, equations used in Johansen's model were deduced from nail deformation during testing to reflect the formation of plastic ball joints. Experimental tests were conducted on 40, 20, and 20 joints of 2-inch nails for configurations of 4, 6, and 8 nails respectively. The same distribution of specimens was maintained for 3-inch and 4-inch nails, resulting in a total sample of 240 tested joints subjected to double shear parallel to the grain.

To account for wood heterogeneity, climatic conditions, and tree growth characteristics, safety factors were applied to reduce experimental loads. A safety factor of Fs = 1.6 and a load duration factor FDC = 1.25 were considered, resulting in an overall safety factor of 2. From the observed tests, reduced characteristic experimental values were obtained. For instance, joints formed with 4 nails of 2 inches yielded a characteristic experimental load per nail of 30.97 kg. Comparatively, permissible values of 45.01 kg, derived from JUNAC recommendations, and 33.97 kg, based on the failure modes described in the Johansen model, were obtained for the same joints. This comparison reveals discrepancies between experimental and theoretical permissible values, underscoring the importance of considering various factors such as wood density, nail configuration, and failure modes in determining safe load limits for joints.

9. DISCUSSION

The comparison presented in Table 52 reveals that the reduced experimental loads for joints formed with 4 nails, whether 2 inches, 3 inches, or 4 inches, are lower than the theoretical permissible values calculated by both the JUNAC recommendations and the Johansen method. Table 53 specifically displays the experimental and permissible values for 4-nail joints. In all other cases, the reduced experimental load exceeds the permissible loads, with values up to 32% higher than the theoretical permissible values. Notably, the JUNAC method appears to be more conservative than the Johansen method, yielding permissible values up to 33% higher for joints formed with 3-inch nails and 7% higher for joints formed with 4-inch nails.

To compare this research with previous studies, parameters such as wood density, test regulations, and nail type and number must be standardized. For instance, a comparison was drawn between the Fig Tree and Pashaco timber species, both subjected to double shear tests parallel to the grain with various nail configurations.

Table 14 presents characteristic load values obtained for both investigations, highlighting the superior breaking load values of the Fig Tree compared to Pashaco. Furthermore, comparisons were made with other woods belonging to structural group "C" of the Peruvian Standard E.010, demonstrating similar final load per nail values for Higuerilla wood.

Table 14: Comparative Table of Characteristic Loads

Nail Type	Diameter (mm)	Number of Nails	Fig Tree (Density 0.41 g/cm³)	Pashaco (Density 0.36 g/cm³)
4”	4.57	4	2106	2012
4”	4.57	6	3507	2653
4”	4.57	8	4045	3469

Additionally, Figure 18 illustrates the ultimate load per nail obtained from double shear tests parallel to the grain for various woods, highlighting the comparable resistance of Higuerilla wood to other woods in structural group "C". However, variations in nail type and configuration must be considered for a comprehensive comparison.

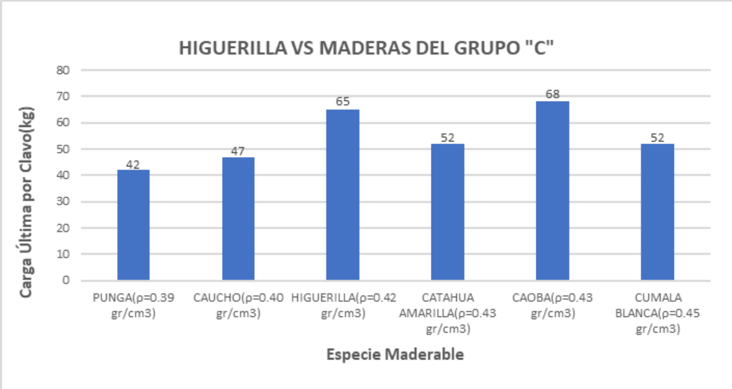


Figure 18: Final Load Per Nail of the Fig Tree vs Group "C" Woods

CONCLUSION

The outcomes of the performance, observation and measurement of the double shear tests along the grain are that in most cases the nailed joints in Higuerilla (Micandra spruceana) wood species are structurally well-behaved, showing values of relative deformations between the wood pieces in the joint less than 38 mm and obtaining resistance (load) values that are greater than the theoretical ones (admissible Test results show that longer and thicker nails correspondingly have more deformation, firstly there is a deformation of 15.24 mm for 2-inch nails and this goes up to 32.44 mm for 4-inch nails with the limit deformation of 38 mm not being exceeded. After the outcome of all the tests was analyzed, it was found that the predicted theoretical permissible values obtained from JUNAC and the Johansen model on one hand and the experimental values on the other hand did not come very close to each other with the theoretical resistances per nail ranging from 8% to 160% lower than the experimental ones for all joints composed of 6 and 8 nails. While of all the specimens made up of 4 nails, experimentally obtained values were 9% to 32% higher than those in the experimental values. A summary of the final load per nail between the Higuerilla (Micandra Spruceana) and the woods from the C group such as Punga, Rubber, Catahua, Mahogany and Cumala concluded that Higuerilla have the same resistance with the woods group C. Besides, the Fig Tree density compared with that of the Pashaco which is below the group “C” tolerance levels, leading to a 16% increase in the characteristic load of the Fig Tree.

RECOMMENDATIONS

For the establishment of joints nailed with Higuerilla wood (Micandra Spruceana), it is recommended to make the holes in advance to avoid the cracking of the wood when nailing the joints. Also it is recommended to use dimensions higher than the minimum required for the preparation of specimens so that the joint has a better behavior at the time of tear. From the results obtained regarding the lowered caga values and permissible loads, it is proposed that the timber species Higuerilla (Micandra spruceana) be used as a structural material safely for the different applications around the construction sector. In order to achieve more reliable results, the recommendation is for a repetition of the double shear tests in the same plane, but with the fiber wood (Micandra Spruceana) at a certain time of day and controlling the temperature and the speed of application of the test force. It is recommended that higher level research studies be conducted at the thesis level in order to study the behavior of the admissible stresses in this wood and to also extend the research, that is, to study the behavior of the wood subjected to shear tests parallel to the grain.

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