Nativa, Sinop, v. 6, n. 4, p. 402-406, jul./ago. 2018.
Pesquisas Agrárias e Ambientais
DOI: http://dx.doi.org/10.31413/nativa.v6i4.5638
http://www.ufmt.br/nativa
ISSN: 2318-7670

Effect of wood density and screw length on the withdrawal resistance of tropical wood

Marina Lopes RIBEIRO[1], Cláudio Henrique Soares DEL MENEZZI[1]*, Milton Luiz SIQUEIRA[1], Rafael Rodolfo de MELO[2]

[1]Universidade de Brasília, Faculdade de Tecnologia, Brasília, DF, Brasil.
[2]Universidade Federal Rural do Semi-Árido, Departamento de Ciências Agronômicas e Florestais, Mossoró, RN, Brasil.
*E-mail: cmenezzi@unb.br

Recebido em junho/2017; Aceito em março/2018.

ABSTRACT: In most timber connections a metallic pin is required due to lateral forces, but occasionally self-tapping screws are required due to tensile stresses. The aim of this study was to experimentally determine the withdrawal resistance of self-tapping screws in tropical wood species by analyzing the influence of wood density and screw penetration length. For this, withdrawal resistance tests using hex lag screws of 12.7 mm diameter and different thread lengths were performed in specimens of the following species: *Angelim* (*Dinizia excelsa*), *Freijó* (*Cordia goeldiana*), *Ipê* (*Tabebuia sp.*), *Louro-vermelho* (*Nectandra rubra*), and *Marupá* (*Simarouba amara*). It was verified that the maximum load of screw withdrawal increases with increasing screw length inserted in wood and wood density. However, screw rupture may occur in denser species because the withdrawal load exceeds the screw strength limit. Therefore, lower screw lengths are recommended for denser woods.
Keywords: mechanical connections, amazon timber, self-tapping screw.

Efeito da densidade da madeira e do comprimento do parafuso na resistência ao arrancamento em madeiras tropicais

RESUMO: Na maioria das ligações os pinos metálicos estão solicitados por forças laterais, mas ocasionalmente há a necessidade da utilização de parafusos auto-atarraxantes solicitados por esforços de tração. O objetivo deste trabalho foi determinar, de maneira experimental, a resistência ao arrancamento de parafuso auto-atarraxantes em espécies de madeiras tropicais, analisando-se a influência dos seguintes fatores: densidade da madeira e comprimento de penetração do parafuso. Para isso, foram feitos testes de arrancamento com parafusos sextavados de rosca soberba com 12,7 mm de diâmetro e diferentes comprimentos de rosca e corpos-de-prova confeccionados das seguintes espécies: angelim (*Dinizia excelsa*), freijó (*Cordia goeldiana*), ipê (*Tabebuia* sp.), louro-vermelho (*Nectandra rubra*), marupá (*Simarouba amara*). Verificou-se que a carga máxima de arrancamento de parafuso aumenta com o aumento do comprimento do parafuso inserido na madeira e da densidade da madeira. Contudo, a ruptura do parafuso em espécies mais densas pode ocorrer, pois a carga de arrancamento ultrapassa o limite de resistência do parafuso. Dessa forma, comprimentos de parafuso menores são recomendados para madeiras mais densas.
Palavras-chave: ligações mecânicas, madeiras amazônicas, parafuso auto-atarraxante.

1. INTRODUCTION

Wood has an important role in construction because it is a renewable material and combines architectural and structural solutions with aesthetics and thermal comfort. In Brazil, wood is utilized in temporary uses such as molds for concrete, scaffolding and shoring, and definitively as frames (doors and windows), ceilings, floors, house roofing structures and small buildings. The necessary connection between structural parts is generally the critical point of the wooden structures. Thus, experimental studies assessing the actual behavior of the connections are important for designing these structures, as highlighted by Vieira et al. (2009).

Wood may be coupled with various types of connection elements, and metal pins are most commonly used in Brazil. Metal pins are required due to lateral forces for most situations, but occasionally there is a different pin required due to tensile stresses. In these cases, it is recommended to use self-tapping hex lag screws. This screw has a hexagonal bolt and is available on the market with varying diameters and lengths. Generally, this connecting element is utilized in robust parts and must be fixed in the wood after pre-drilling (SOLTIS, 2010). Self-tapping screws penetrate the wood without going through it and are conveniently used when one of the connected material surfaces is inaccessible. The resistance of a wood species to direct screw withdrawal is a measure of its ability to maintain the connection with another object through this connection element.

In Brazil, the structures designing connections using self-tapping screws are hampered by the lack of calculation guidelines in the Brazilian standards of wooden structures (ABNT, 1997) for this type of screw. Some international standards already require the use of this type of screw and offer design criteria. However, these standards were not developed for high-density wood such as those utilized in Brazil, and therefore there are few studies that certify the applicability of these standards for Brazilian timber.

Self-tapping screws are usually utilized to attach robust parts which are submitted to shearing stress or tensile strength. These screws are commercially available in the following sizes: from 5.1 mm to 25.4 mm diameter, and from 25.4 mm to 406.0 mm length. The length of the threaded portion depends on the screw length, ranging from 19.0 mm for screws of 25.4 mm length, and 31.8 mm to half the length of the screw for screws of more than 254 mm. They are usually made of SAE 1010/1020 carbon steel and AISI 304/316 stainless steel. However, it is possible to order lengths and specific materials from the manufacturer to be used for fabricating customized self-tapping screws.

The resistance of a wood species to direct screw withdrawal is a measure of its ability to maintain its connection with another object through this connection element. Many factors affect this resistance, including the physical and mechanical properties of wood; the direction of the wood fibers; the size, shape and surface conditions of the screw; the withdrawal speed; and the existence and nature of pre-drilling (ASTM, 2000).

In this context, this study aims to analyze the length effect of the threaded part of self-tapping screws and the wood basic density in screw withdrawal resistance.

2. MATERIALS AND METHODS

2.1. Wood Material

Five species of Brazilian tropical wood were evaluated: *Angelim-vermelho* (*Dinizia excelsa* Ducke), *Freijó* (*Cordia bicolor* A. DC.), *Ipê* (*Tabebuia sp.*), *Louro-vermelho* (*Sextonia rubra* (Mez.) van der Werff) and *Marupá* (*Simarouba amara* Aubl.). The choice of species considered the Brazilian Federal District wood market offer and covers some range densities of possible wood. Macroscopic identification of species was confirmed by comparison with wood specimens from the Forest Products Laboratory (LPF) xylotheque (*Index Xylarium* FPBw) of the Brazilian Forest Service. Specimens were placed in a climatic chamber (25ºC ± 3°C; 65% ± 3%) until constant mass.

2.2. Withdrawal Test

The samples were prepared with dimensions according to ASTM D1761 (2006): 51 mm x 120 mm x 202 mm (thickness x length x height), wherein the hole distance from the edge was 38 mm, and 19 mm from the side (Fig. 1).

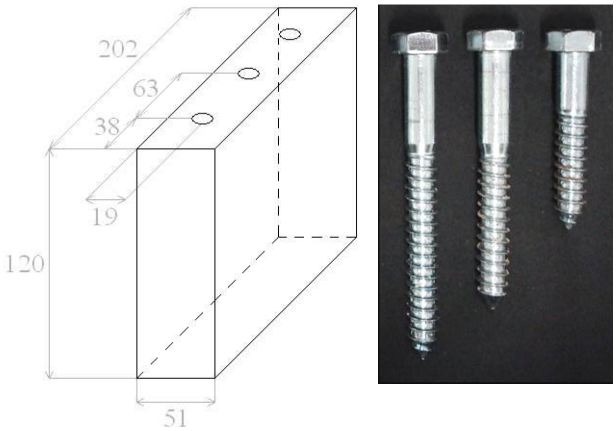

Figure 1. Samples dimensions (mm) and general overview of lag screws used.
Figura 1. Dimensões das amostras e comprimento dos parafusos utilizados.

It was possible to perform three screw withdrawal tests on the same sample due to the minimum spacing (63 mm) between screws. Seven samples were performed for each species. Three types of hex lag screws (self-tapping) were used with a nominal diameter of 12.7 mm, total length of 70 mm, 100 mm and 120 mm, and thread length of 50 mm, 65 mm and 85 mm, respectively.

The pre-drilling was performed according to the specifications in Soltis (2010) using diameters equal to 70% and 85% of the screw nominal diameter, respectively, for low-density and high-density woods. The pre-drilling depth was equal to the tested screw thread length. The holes were performed with the aid of a drill with depth equal to the thread size of the respective screw. The sample density was measured before pre-drilling. Assays were conducted on an Instron 1025 universal testing machine at a speed of 2.54 mm/min. The samples were placed with aid of two independent brackets made of SAE 1020 steel (Figure 2).

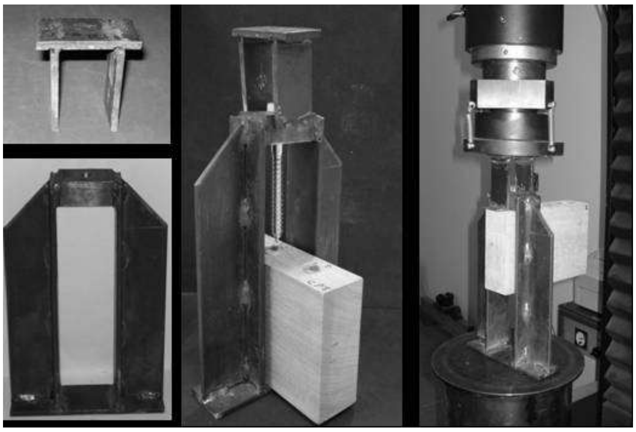

Figure 2. Device used to test the screw withdrawal resistance of wood samples.
Figura 2. Dispositivo utilizado para avaliar a resistência ao arrancamento de parafuso nas amostras de madeira.

One of the brackets has a hole through which the screw was threaded to the timber and the other brackets were placed on the piece of wood transferring the test machine compressive force to the wooden piece and causing it to drive out the screw.

2.3. Experimental Design and Data Analysis

The tests were performed by combining each species with already cited different screw lengths. Seven repetitions were performed for each combination in order to detect the variations due to the timber density and the screw penetration depth in the wood. Only 3 repetitions for each combination were performed for *Angelim-vermelho* because it only had 3 samples (Table 1).

An analysis of variance (ANOVA) with Tukey test at 5% significance was performed for data analysis to examine the screw length effect for each species. Furthermore, a factor variance analysis was carried out with Tukey test at 5% to observe the species and length effect of the screw, in addition to the interaction of these variables on the maximum withdrawal load. The Pearson correlation test and Linear Regression at 5% was performed to better assess the relation to which the screw length and the species influence the maximum withdrawal load, utilizing the density as the main variable for the species effect. The observed values were also compared to theoretical values proposed by Soltis (2010) according to Equation 1:

$$R_{90} = 125.4\ \rho^{3/2}\ \varphi^{3/4}\ L_R \qquad \text{(Equation 1)}$$

where: R90: maximum tensile strength in the direction perpendicular to the fibers, in N; ρ: wood density at 12% moisture; g/cm³; φ: Screw diameter, mm; L_R: length of the screw thread mm.

Table 1. Experimental design.
Tabela 1. Design experimental.

Species	Screw Length (mm)	Number of Samples	Total
Marupá (Simarouba amara)	50	7	
	65	7	21
	85	7	
Freijó (Cordia bicolor)	50	7	
	65	7	21
	85	7	
Louro-vermelho (Sextonia rubra)	50	7	
	65	7	21
	85	7	
Angelim (Dinizia excelsia)	50	7	
	65	7	21
	85	7	
Ipê (Tabebuia sp.)	50	7	
	65	7	21
	85	7	

3. RESULTS

The density and moisture content found in the tested woods are shown in Table 2. Pre-drilling into the *Marupá* and *Freijó* samples (low-density) of 70% of the screw diameter was carried out based on the calculated density, and pre-drilling of 85% of the screw diameter for the other species.

During the screw threading, there was a cracking in one of the *Ipê* samples, thus the data referring to the *Ipê* species were ignored in the data analysis for all screw lengths. For *Ipê* species, there was a screw cracking with 120 mm length in 4 of the 6 samples, where the wood had deep cracks from the screw withdrawal in the two remaining samples. Screw breakage also occurred in two *Angelim-vermelho* samples tested for 85 mm thread length screws.

Table 2. Density and moisture content of the wood samples.
Tabela 2. Densidade e teor de umidade das amostras de madeira avaliadas.

Species	Density (g/cm³)	Moisture Content (%)
Marupá	0.40	14.00
Freijó	0.52	13.70
Louro-vermelho	0.72	15.37
Ipê	1.08	10.53
Angelim-vermelho	1.14	14.48

There was a statistical difference for average load values between different screw lengths, with one exception when *Ipê* specimens were tested. For *Ipê*, there was no significant difference between the maximum withdrawal strength of the 65 mm and 85 mm screws (Figure 3).

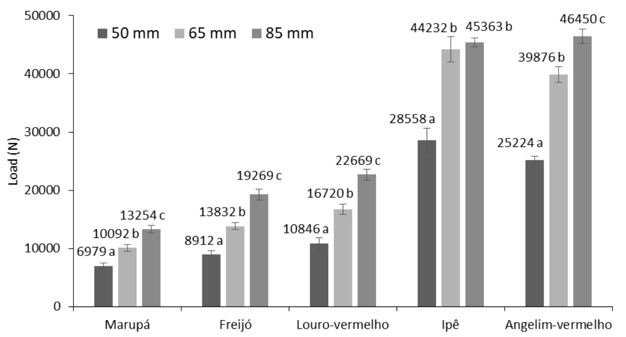

Figure 3. Withdrawal strength values according to wood species and screw length (Means followed by same letter are not statistically different according to Tukey test at α=0.05).
Figura 3. Valores médio de resistência ao arrancamento de parafuso para cada comprimento nas diferentes madeiras avaliadas (valores seguidos por uma mesma letra não diferem estatisticamente – Tukey em α = 0,05).

As non-significant statistical values and breaking occurred in the 85 mm screws for this species, it may be inferred that in 65 mm screws, although it had not been broken, it may have already started to flow at the end of the withdrawal test, even because the maximum screw resistance strength had been exceeded. In addition, it is highlighted that the average data presented for the 85 mm screw for both *Ipê* and *Angelim-vermelho* are assigned to the screw's material limitation and could be higher considering only firewood material. From this statistical analysis we may conclude that the maximum screw withdrawal strength increases with increasing screw length inserted in the wood for the same species. Moreover, it is observed that the screw is the limiting factor when working with denser woods. The variance analysis performed for each species showed a statistical difference between the maximum withdrawal strength average of the three screw lengths utilized ($P < 0.000$). the Tukey test divided the maximum strength data into three statistically distinct groups for all species except *Ipê*. In *Ipê*, the data were divided into two groups with non-significant difference between the maximum withdrawal strength of the 65 mm and 85 mm screw.

The factor analysis revealed that the screw length, the species and the interaction between them are statistically significant for the maximum withdrawal resistance variation (Figures 4 and 5). The interaction significance of the two factors must be due to screw disruption in more resistant species, which masks the species effect in the maximum withdrawal strength. The Tukey test divided the data into three groups for the screw length and five groups for the species. This analysis confirms the trend of increasing the withdrawal strength with the increase of the screw thread length, even without considering the species effect. Furthermore, this analysis demonstrates that the increase of wood density also causes an increase in the maximum withdrawal strength.

The Pearson correlation test revealed that the maximum withdrawal strength presented a significant association with the screw length ($r=0.409$; $P \leq 0.000$) and with the wood density ($r=0.871$; $P \leq 0.000$). The linear regression graph considering the wood density and screw length variables allows for visualizing the relation of the three variables (Figure 6). The equation that shows this relation is given by:

$$R_{90} = 343.183\ L_R + 41064.839\ \rho - 31022.474 \qquad \text{(Equation 2)}$$

where: R90 is the maximum pullout force, N; LR is the length of the screw thread, mm; and ρ is the density of the wood, g/cm³.

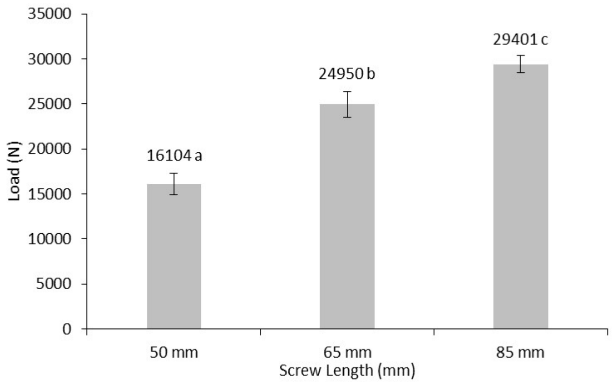

Figure 4. Effect of screw length on the screw withdrawal strength. (Means followed by same letter are not statistically different according to Tukey test at α=0.05).

Figura 4. Efeito do comprimento do parafuso na resistência ao arrancamento (valores seguidos por uma mesma letra não diferem estatisticamente – Tukey em α = 0,05).

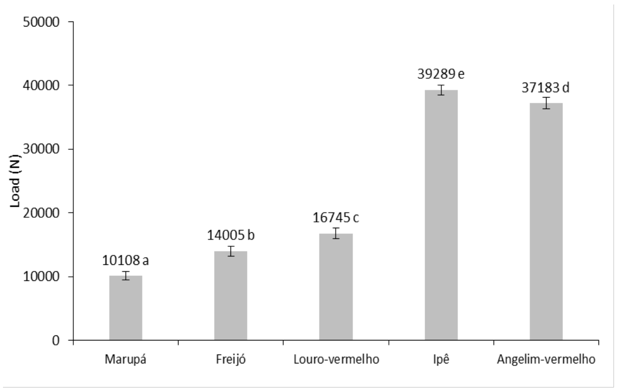

Figure 5. Effect of the wood species on the screw withdrawal strength. (Means followed by same letter are not statistically different according to Tukey test at α=0.05).

Figura 5. Efeito da espécie de madeira avaliada na resistência ao arrancamento de parafuso (valores seguidos por uma mesma letra não diferem estatisticamente – Tukey em α = 0,05).

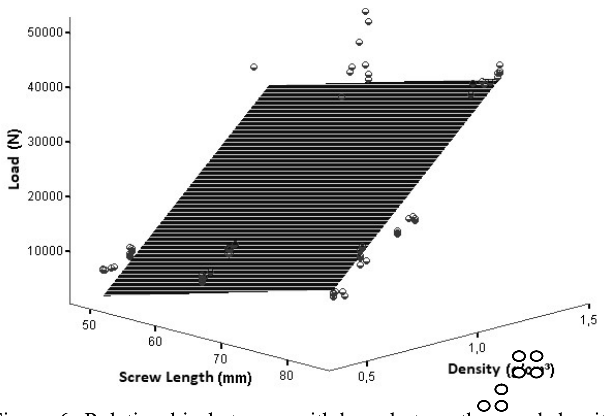

Figure 6. Relationship between withdrawal strength, wood density and screw length.

Figura 6. Relação entre a resistência ao arrancamento de parafuso, densidade da madeira e comprimento do parafuso.

4. DISCUSSION

Due to the higher density, *Angelim-vermelho* was more resistant, and hence presented larger withdrawal maximum strength. This may not have occurred due to other intrinsic factors of the species that affected its withdrawal resistance or due to the broken screw for these species, which does not allow for perfectly assessing the two woods' performance (MITANI & BARBOUTIS, 2015). In this study, an increase of withdrawal maximum strength with increase of screw penetration depth and increase of wood density were also found. However, screw disruption occurred for 65 mm and 85 mm length woods. Thus, it is understood that increasing the screw diameter is an alternative to increasing the screw connection resistance in more dense and resistant timber.

This shows that the species effect is greater than the screw length and indicates a new increase relation of the withdrawal maximum strength with wood density increase. This was expected since density is a more related characteristic with wood resistance. It is highlighted that this equation applies only to this study data, requiring much more data to solve a theoretical equation for tropical timber.

Soltis (2010) provided an adjusted equation to estimate the maximum withdrawal strength. The same standard recommends considering only 1/5 of the estimated value as the permissible value utilized in the wooden structures calculation. The values that would be permissible according to this standard and which are observed leads to lower allowable stress values than the experimental values, which ensures structural safety. However, the ideal equation is an adjusted model for tropical timbers that properly estimates the maximum strength values expected.

Thus, the theoretical equation according to Soltis (2010) may be utilized to estimate the maximum screw withdrawal strength but does not completely fit to the tropical timber data. In this case, this study showed the existence of a linear relation between the maximum withdrawal strength with the screw penetration depth in wood and wood density (Figure 6). However, other parameters such as the screw diameter should enter into the equation, thus increasing its reliability.

5. CONCLUSIONS

The maximum screw withdrawal strength is directly proportional to screw length inserted in the timber and wood density. However, screw disruption in denser species may occur because the withdrawal strength exceeds the screw resistance limit. Based on the performed tests, the use of 85 mm thread length screws for species with low density is recommended to achieve greater resistance of the screw connection. In addition, 65 mm thread length screws are recommended for high density species, thus preventing screw disruption. Further studies are suggested to adjust the equation with a wider range of timber and screw lengths and diameters.

6. REFERÊNCES

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 7190: Projeto de Estruturas de Madeira**. Rio de Janeiro: ABNT, 1997.

AMERICAN SOCIETY OF TESTING AND MATERIALS (ASTM). **D 1761: Standard Test Methods for Mechanical Fasteners in Wood**. Philadelphia: ASTM, 2006.

MITANI, A.; BARBOUTIS, I. Determination of some mechanical properties and nails withdrawal resistance of heat treated fir wood (*Abies borrisi* - Regis). **Proligno**, v. 11, n. 4, p. 344-350, 2015.

SOLTIS, L.A. **Fastenings**. In: UNITED STATES DEPARTMENT OF AGRICULTURE – USDA (Org.). **Wood handbook:** wood as an engineering material. Madison: USDA, 2010.

VIEIRA, S. R. F.; DEL MENEZZI, C. H. S.; SIQUEIRA, M. L. Efeito do torque e do tempo de aperto sobre a carga de ruptura e rigidez da ligação parafusada em peças de maçaranduba (*Manilkara huberi* Ducke A. Chev). **Scientia Forestalis**, Piracicaba, v. 37, n. 84, p. 459-464. 2009.