Embedment strength of dowels in wood specimens according to ABNT NBR 7190 (1997) and EUROCODE 5 (2004)

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Julio Cesar Molina
Professor Doutor
Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP
Faculdade de Engenharia
Campus Experimental de Itapeva
Itapeva – São Paulo – Brasil
molina@itapeva.unesp.br

Thacyane Katherine Cesar
Graduado em Engenharia Industrial Madeireira
Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP
Faculdade de Engenharia
Campus Experimental de Itapeva
Itapeva – São Paulo – Brasil
thacyane.katherine@grad.itapeva.unesp.br

Carlino Carvalho de Almeida
Graduando em Engenharia Industrial Madeireira
Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP
Faculdade de Engenharia
Campus Experimental de Itapeva
Itapeva – São Paulo - Brasil
carlino.carvalho@grad.itapeva.unesp.br

Ernesto Abel Fernando Friedmann Pallarolas
Mestrando em Engenharia Mecânica
Universidade Estadual Paulista Júlio de Mesquita Filho - UNESP
Faculdade de Engenharia
Campus de Guaratinguetá
Guaratinguetá – São Paulo – Brasil
ernofriedmann@hotmail.com

Abstract

The study of connections for timber structures has been the subject of intense research in Brazil. This work aimed to study the embedment strength of connections made by steel pins (dowels) in specimens of reforested woods. Analytical and experimental evaluations were considered in this study. Initially, tests on specimens made from *Pinus elliottii* (Class C30) and *Eucalyptus salligna* (Class C50) woods with dowels, type 1020, with diameter of 6.35 mm (1/4") were performed. The tests were performed according to the ANBT NBR 7190 (1997) and Eurocode 5 (2004) Standards with subsequent comparison between the analytical and experimental results for embedment strengths. The values of the embedment strength showed that the Eurocode 5 (2004) Standard had greater agreement between experimental and analytical results when compared to the results of the ABNT NBR 7190 (1997) Standard.

Keywords: embedment strength; analytical model; standardization; experimental tests.

1. Introduction

Connections are the critical point of timber structures and require experimental studies to assess their actual behavior (MOLINA, 2010). Among the types of connections used in timber structures some types can be cited, such as, metallic pin connectors, glued connections and bolts. The metal pins are made by nails, screws, dowels and other common steel bars (MOLINA, 2009). The connectors can be metal rings or sheet metal with patterned teeth. According to the ABNT NBR 7190 (1997) when designing connections for metal pins between structural elements, two failure modes are considered: failure of the embedment of the pin on the wood and failure by bending of the pin. However, the Brazilian and European Standards have among themselves different methods for determining the embedment strength. By the ABNT NBR 7190 (1997) the embedment strength of the connection is obtained for a specific deformation value of 2‰. This specific deformation value is obtained by dividing the displacements due to the force applied to the specimen by the dimension 14d

(Figure 1a) of the specimen. According to the Eurocode 5 (2004), that recommends the EN 383 (2007) Standard the embedment strength is determined by the force causing the displacement of 5 mm or the ultimate embedment strength. It can be seen that the Brazilian Standard uses the specific deformation as a parameter for determining the embedment strength, differently from the European Standard, which uses the relative displacement of 5 mm between the metal pin and the wood. The embedment of the metallic pin in the wood is characterized by the displacement of the connection in the direction of a given applied force. Besides, the European Standard recommends a specimen that is easy to make in normal direction to the grain, while the preparation of the embedment specimens for the tests in normal direction to the grain with base in the Brazilian Standard is difficult to be made due to the dimensions of the wood in this direction of the fibers (ALMEIDA, 2014). However, despite the growing interest in the study of connections in wooden structures in Brazil, it is observed that the investigations carried out so far have not produced sufficient information for a proper analysis of their behavior (FRANKE and QUENNEVILLE, 2011; ALMEIDA, 2014; ALMEIDA *et al*, 2014). This work aimed to evaluate the existing methods for the determination of embedment strength of connections made by steel pins (dowels type, steel 1020) with diameter of 6.35 mm in wood pieces proposed by Brazilian and European normative documents with further tests based on these documents.

Standardized test methods

ABNT NBR 7190 (1997) – Wooden structures project

Experimentally, the Brazilian Standard defines the embedment strength of the wood (f_e) as the ratio between the force applied ($F_{e2‰}$, Figure 1b) that is able to cause a residual specific deformation of 2‰ on the connection and the area of embedment of the metal pin on the wood (product between the pin diameter (d) and thickness of the wood piece (t = 2d, Figure 1a), according to Equation (1).

$$f_e = \frac{F_{e\,2‰}}{t \cdot d} \qquad (1)$$

To carry out the embedment test, an estimated resistance is determined from the destructive testing of a similar specimen. After knowing the estimated resistance, the load P (Figure 1c) needs to be applied initially in two charge and discharge cycles (with speed of 10MPa/min) ranging between 10 % and 50 % of the estimated value for the strength (or force) of rupture. Subsequently, the third and last load cycle is applied to the final rupture, which corresponds to the force capable of causing a residual specific deformation of 2‰ on the connection, as shown in Figure 1b. The details of specimen recommended by the Brazilian Standard for the embedment tests is shown in Figure 1a and the instrumentation of the specimen with transducer LVDT (*Linear Variable Differential Transformer*) is showed in Figure 1c.

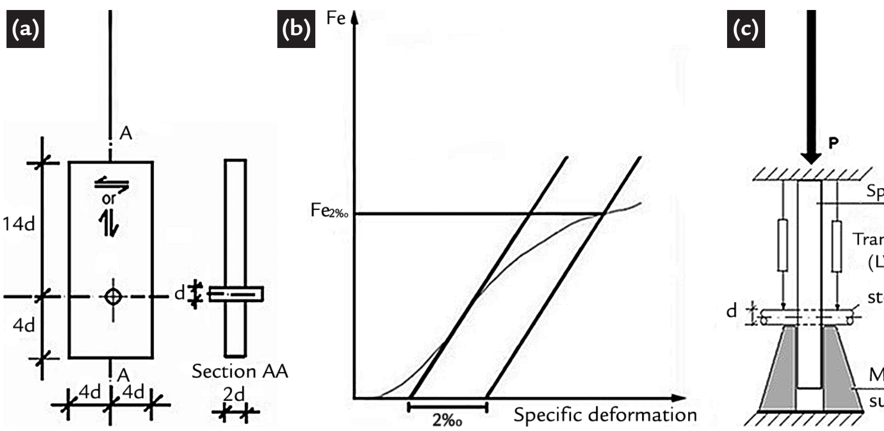

Figure 1
Embedment test in the parallel (0°) and normal (90°) directions to the grain.
(a) Specimens for directions 0° and 90°;
(b) Curve embedment force versus specific deformation for the last load cycle;
(c) Instrumentation of the specimen with LVDT transducer to measure of the displacements in the test.

EN 383 (2007) – Determination of embedment strength and foundation values for dowel type fasteners

The EN 383 Standard is the normative document proposed by the Eurocode 5 Standard for determining the embedment strength. Experimentally, the embedment strength obtained by the European Standard is given according to Equation (2), which is the lowest value obtained between the maximum force resisted by the specimens (F_{max}) or the force that causes the displacement of 5 mm between the metal pin and the wood.

$$f_e = \frac{F_{5mm}}{t \cdot d} \text{ or } f_e = \frac{F_{max}}{t \cdot d} \qquad (2)$$

Where: F_{5mm} is the force that causes the displacement of 5mm in the wood/pin interface.

The specimens proposed by the European Standard have rectangular sections with dimensions 6d (width) x 14d (height) for specimens in the parallel direction of the grain. For the normal direction to the grain, the dimensions are 40d (width) and 10d (height). For both specimens the thickness of the pieces is 2d (where d is the dowel diameter), as shown in the Figure 2.

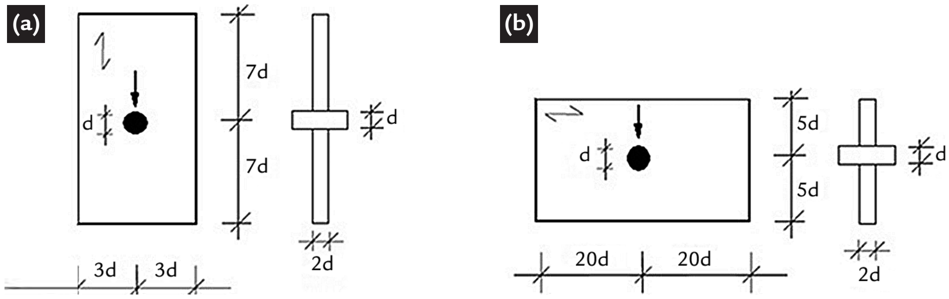

Figure 2
Specimens for the embedment test:
(a) Parallel direction to the grain. (b) Normal (perpendicular) direction to the grain.
Source: EN 383 (2007).

Before the effective performance of the tests, it is necessary to estimate the embedment strength through the destructive testing of a twin specimen. Once estimated the wood embedment strength (f_e), a single load cycle up to 40 % of the total strength is applied to the specimen, keeping it for 30 seconds. After this time, the load is reduced until the value of 10% of the strength, keeping it for 30 seconds. Then a load is applied to force the failure of the specimen or the relative displacement of 5 mm between the metal pin and the wood. Figure 3 illustrates how to obtain the embedment strength of the wood in the second load cycle until the failure of the specimen.

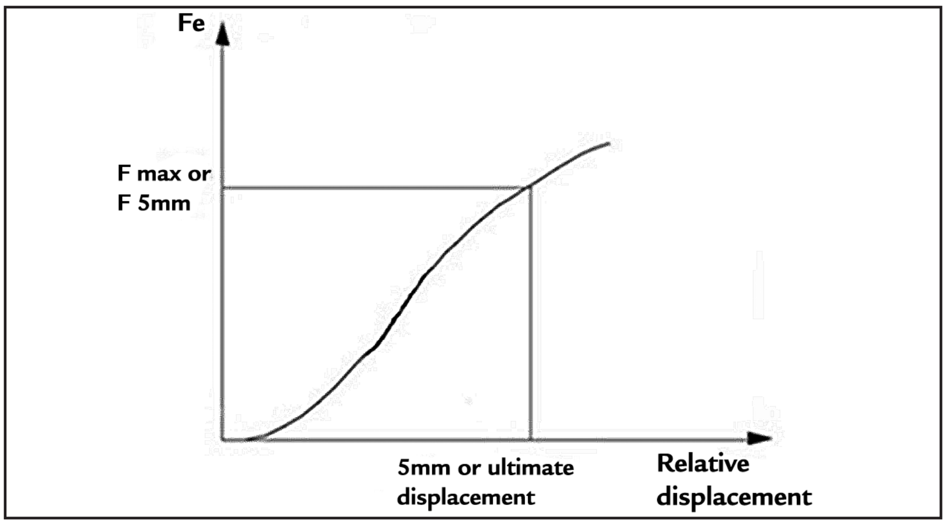

Figure 3
Diagram of embedment force versus relative displacement for the second load cycle.
Source: Almeida (2014).

Analytical embedment strength (calculated resistance)

Each normative document considered has specific equations for determining the embedment strength, which are listed in Table 1.

Analyzed Standard	f_{e0}	f_{e90}
ABNT NBR 7190 (1997)	$f_{e0} = f_{c0}$	$f_{e90} = 0.25 \cdot f_{c0} \cdot \alpha_e$
EUROCODE 5 (2004)	$f_{e0} = 0.082.(1- 0.01d).\rho$	$f_{e90} = \dfrac{f_{e0}}{k_{90} \cdot sen^2\alpha + cos^2\alpha}$

f_{c0}: average value of compression strength parallel to the grain; ; α_e: coefficient given as a function of the diameter of the pin in ABNT NBR 7190 (1997); k_{90}: 1.35 + 0.015d for softwood; k_{90}: 0.90 + 0.015d to hardwood; ρ: average value of the bulk density; d: diameter of the metal pin.

Table 1
Equations for the analytical calculation of the embedment strength from the analyzed standards.

The parameter α_e used to calculate the embedment strength in a direction that is normal to the grain according to the Brazilian Standard is determined in function of the diameter of the metal pin. For intermediate diameter values, the parameter α_e is determined by linear interpolation.

Plasticization of the steel pins

The EN 409 (2009) Spanish Standard proposes a test method to determine the plasticity moment of the steel pins. However, according to Eurocode 5 (2004) Standard, the characteristic yield moment value can be obtained by Equation (3).

$$M_{y,k} = 0.8\frac{f_{u,k} \cdot d^3}{6} \quad (3)$$

Where $f_{u,k}$ is the ultimate tensile strength and d the diameter of the pin.

2. Materials and method

For the embedding tests in this research, two species of reforested wood were used without preservative treatment: *Pinus elliottii and Eucalyptus salligna*. The choice of these woods was based on the scope of two different strength classes defined by the Brazilian Standard and on the availability of these species in the region of Itapeva - SP. For the tests on the wood specimens, common steel bars (dowel), of the type 1020, with a diameter of 6.35 mm (1/4") and length of 12 cm were used. All the samples (specimens of embedment) were tested with moisture content of 12%. Six replications of specimens for each species of wood were considered with each fiber direction and for each specific standard. For the characterization of moisture and density of the wood samples, there was also used a total of six replications of the specimens. For the conduction of the embedment tests, an EMIC (DL30000) universal testing machine was used, with capacity of 300 kN (30 000 kgf), available at the Laboratory of Materials Properties of UNESP Itapeva. In the embedment tests, the application of the load was controlled by the use of a load cell with capacity of 100 kN.

Description of the embedment tests

For the tests in parallel and normal directions to the grain, the samples were made in accordance with the recommendations of the European and the Brazilian Standards. The dimensions for the specimens according to the each standard recommendation used are shown in Figures 4 and 5.

Thus, in both cases, i.e. for the Brazilian and European Standard recommendations, the final dimensions of the wood specimens for the experimental tests are given in function of the diameter of the steel pin.

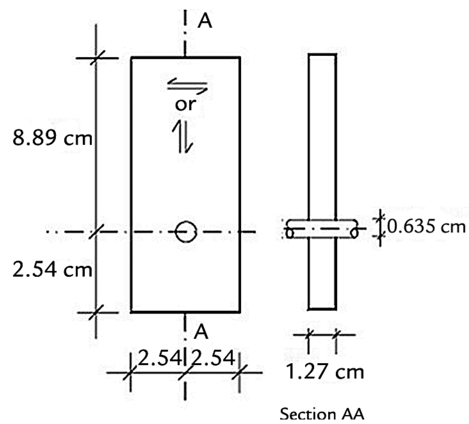

Figure 4
Dimensions of wood specimens for the embedment test in parallel and normal directions to the grain according to the Brazilian Standard.

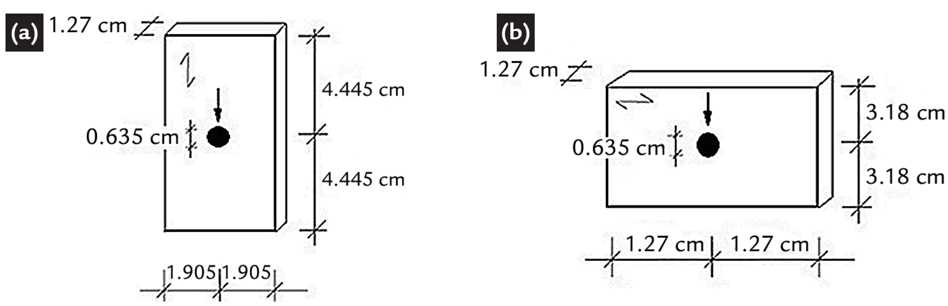

Figure 5
Dimensions of wood specimens for the embedment test according to the European Standard: (a) Parallel direction to the grain. (b) Normal direction to the grain.

The quantification of displacements of the specimens was made by a transducer of displacements (type LVDT) with a maximum of 10 mm of run. Figure 6 shows the details of the instrumentation of the specimens as well as the details of the embedment tests in the EMIC machine. The instrumentation of the specimens was based on the work development by Stamato and Calil Junior (2002). This strategy considered the equipment and the measurement accessories availability for this purpose.

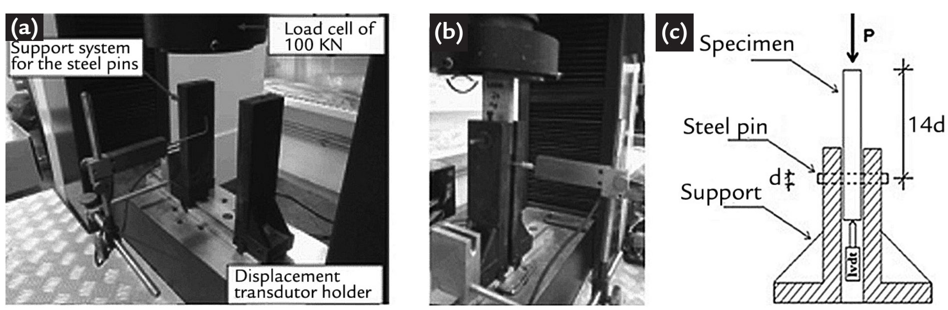

Figure 6
Details of the embedment test.
(a) Instrumentation of the specimen;
(b) Experimental test;
(c) Position of the LVDT transducer for measuring displacement in the test.

The mechanical properties determined for the wood *(Pinus elliottii* and *Eucalyptus salligna)* were compression strength parallel to the grain (f_{c0}), modulus of elasticity in compression parallel to the grain (E_{c0}) and shear strength parallel to the grain (f_{v0}). The physical properties determined in this case for the woods were bulk density (ρ_{ap}) and moisture content (U %). For the steel pin, the bending force ($F_{y,fl}$) was determined from the direct bending tests to simulate the necessary distributed load to cause the plasticization of the metal pin during the embedment tests. A load distributed in a thickness of t_2 was considered in this case (Figures 7a and 7b). The span of the support (t_2) considered for the steel pin, in this case, was equal to the thickness of the specimens used, i.e.; equal to 1.27cm for both standards: ABNT NBR 7190 (1997) Brazilian Standard and EN 383 (2007) European Standard. Figure 7 shows the details of the bending tests and of the tension tests for the steel pins. The characteristic force value of the steel pin (R_k) was also analytically determined from the tension tests according to equations recommended by Eurocode 5 (2004) for obtaining of the plasticizing moment ($M_{y,k}$) according to equation (3) and, consequently, for comparison with the resistance value obtained from the direct bending test of the pin.

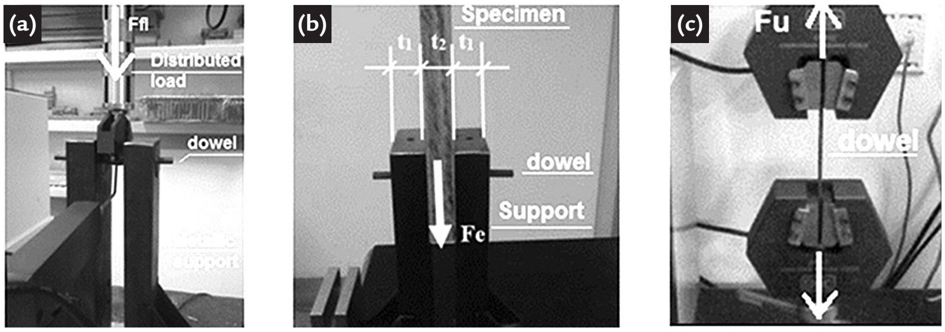

Figure 7
Tests of the steel pin:
(a) Direct bending test;
(b) Dimensions for the calculations of characteristic strength of the pin;
(c) Tension test.

For the analytical calculation of the embedment strengths from the equations of Table 1, it was necessary to characterize the species of wood as well as the steel pin used. The characterization in this case was made according to the details previously shown in this section. For the metal pin used in this work with diameter of 6.35 mm (1/4"), the value used for α_e was 2.52, which was obtained by linear interpolation according to the Brazilian Standard. To calculate the parameter k_{90}, which is used by the European standard that considers the diameter of the metal pin, the *Pinus elliottii* was considered as the less dense wood and *Eucalyptus salligna* as the denser wood.

3. Results and discussion

The main results obtained in this study are presented in sequence. Initially, the characterization results of the steel and wood materials are shown and, subsequently, the results of the embedment strengths obtained analytically and experimentally. In order to enable the comparison of the results, Table 2 shows the equivalent values of the bending forces obtained for the pins from the direct bending tests of the steel pins samples. Tables 3 and 4, respectively, show the results of the mechanical and physical characterization of the woods used. Table 5 shows a comparison of average values of embedment strengths obtained experimentally for the parallel and the normal directions to the grain with the embedment strength values calculated analytically and according to the Brazilian and European Standards. Table 6 shows that experimental values of the embedment resistances were relatively lower than the values for the analytical resistances in the normal direction to the grain for the Brazilian Standard. The percentage difference between the analytical and experimental values of the embedment strengths for each of the analyzed standards were also presented in the Table 6.

Table 2
Results of the characterization of steel pin, type 1020, with diameter of 6.35 mm.

Specimens	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean
$F_{y.fl}$ (N)	3425	3530	3535	3580	2355	3325	3292

The characteristic values (R_k) for the embedment force obtained for the steel pins according to Eurocode 5 (2004) were 3212.11 N and 4024.96 N for *Eucalyptus salligna* in parallel and normal directions to the grain. For the Pinus elliotti the obtained values were 2628.11N and 2053.12, respectively in this case.

	Eucalyptus salligna				*Pinus elliottii*			
Specimens	f_{c0} (MPa)	f_{c90} (MPa)	f_{v0} (MPa)	E_{c0} (MPa)	f_{c0} (MPa)	f_{c90} (MPa)	f_{v0} (MPa)	E_{c0} (MPa)
Sample 1	90.52	8.90	21.78	23669	45.09	4.34	10.80	15091
Sample 2	60.14	7.64	17.67	16169	39.32	2.91	11.89	18869
Sample 3	87.31	7.84	12.66	40330	49.01	4.45	9.20	21734
Sample 4	93.54	8.03	15.15	22038	51.45	4.42	7.09	17040
Sample 5	65.00	8.58	18.44	31413	41.87	4.80	13.13	19832
Sample 6	61.21	7.61	13.29	18849	40.83	4.68	8.48	13521
Sample 7	90.91	7.53	12.63	36192	-	2.87	8.13	-
Mean	78.38	8.02	15.95	26952	44.59	4.07	9.82	17681

f_{c0}: compression strength parallel to the grain; f_{c90}: compression strength perpendicular to the grain; f_{v0}: shear strength parallel to the grain; E_{c0}: modulus of elasticity parallel to the grain.

Table 3
Characterization results of woods in the moisture of 12 % according to the Brazilian Standard.

Eucalyptus salligna (kg/m^3)

Specimens		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean
ABNT NBR 7190 (1997)	Paralell	690.71	672.85	744.83	714.62	738.50	701.97	710.58
	Normal	666.13	662.87	654.41	595.54	629.15	679.94	648.01
Euro-code 5 (2007)	Paralell	685.10	709.46	706.78	755.93	737.42	775.54	728.37
	Normal	726.94	706.95	720.01	722.56	733.22	752.99	727.11

Pinus elliottii (kg/m^3)

Specimens		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Mean
ABNT NBR 7190 (1997)	Paralell	527.23	553.61	460.30	461.29	522.23	550.38	521.51
	Normal	478.49	439.89	447.76	448.08	490.40	484.83	464.91
Euro-code 5 (2007)	Paralell	522.49	515.30	555.73	535.66	531.58	532.20	532.16
	Normal	549.95	581.89	509.94	545.31	514.04	499.68	533.47

Table 4
Bulk density (U = 12%) of woods for the determination of the analytical embedment strength.

Standard	Direction of the fibers	Embedment strength f_e (MPa)			
		Eucalyptus salligna		*Pinus elliotti*	
		Experimental	Analytical	Experimental	Analytical
ABNT NBR 7190 (1997)	Parallel	49.30	78.38	29.36	44.57
	Normal	20.34	48.60	19.36	27.63
EUROCODE 5 (2004)	Parallel	69.51	55.96	52.03	40.89
	Normal	79.71	56.27	40.67	28.30

Table 5
Comparison of the analytical and experimental values for embedment strength (U = 12 %).

From the analysis of Table 5 for the European Standard, the experimental values of the embedment strength were higher than the values obtained analytically in both directions parallel and normal to the grain. In the parallel and normal directions to the grain of the *Eucalyptus salligna* woods the greater proximity between the analytical and experimental values were observed for the European Standard followed by the Brazilian Standard. In the parallel direction to the grain for the *Pinus elliotii* woods was found the greater proximity between the analytical and experimental results for the European Standard. It was observed for the Brazilian Standard the greater proximity between the analytical and experimental results in the normal direction to the grain in *Pinus elliottii* woods.

Table 6
Percentage differences between the analytical and experimental embedment strength (U = 12 %).

Standard	Direction of the fibers	Embedment strength fe (MPa)	
		Eucalyptus salligna	*Pinus elliotti*
		%	%
ABNT NBR 7190 (1997)	Parallel	37.10% (experimental < analytical)	34.13% (experimental < analytical)
	Normal	58.15% (experimental < analytical)	29.93% (experimental < analytical)
EUROCODE 5 (2004)	Parallel	19.49% (experimental > analytical)	21.41% (experimental > analytical)
	Normal	29.40% (experimental > analytical)	30.42% (experimental > analytical)

Table 7 shows a comparison between the average of the bending force obtained directly on the steel pin and the mean embedment forces obtained experimentally according to each analyzed standards.

Table 7
Mean values of embedment forces of the pin in the wood and the necessary forces to start bending the metal pin during the test.

Forces verified in the tests (N)	*Eucalyptus salligna*		*Pinus elliottii*	
	Parallel	Normal	Parallel	Normal
Force on the pin (F_{fl})	3292.00	3292.00	3292.00	3292.00
ABNT NBR 7190 (1997) (F_e)	3964.50	1719.17	2404.67	1592.67
Eurocode 5 (2004) (F_e)	7235.00	7948.33	5177.67	4057.83

The behavior of the curves that relate the applied forces on the embedment specimens until the limits of displacement or residual specific deformation established by each of the standards analyzed are shown in the Figures 8 and 9. As example, these curves are shown just for the *Pinus elliottii* woods in the normal and parallel directions to the grain. The behavior of the curves force versus relative displacement for the metal pin during the bending tests are shown in Figure 10.

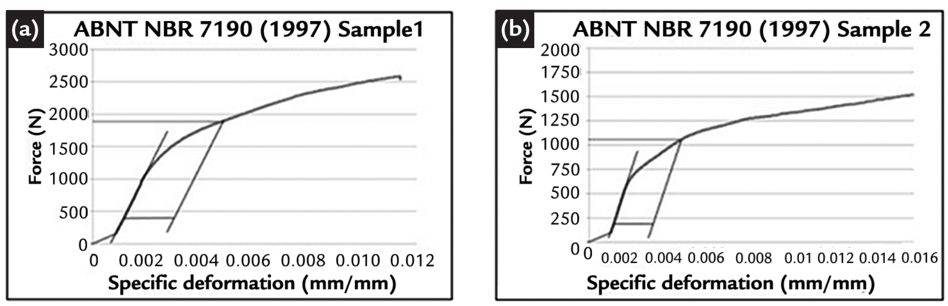

Figure 8
Curve of embedment force versus specific deformation (2‰) to *Pinus elliottii* according to the Brazilian Standard: (a) Parallel direction to the grain. (b) Normal direction to the grain.

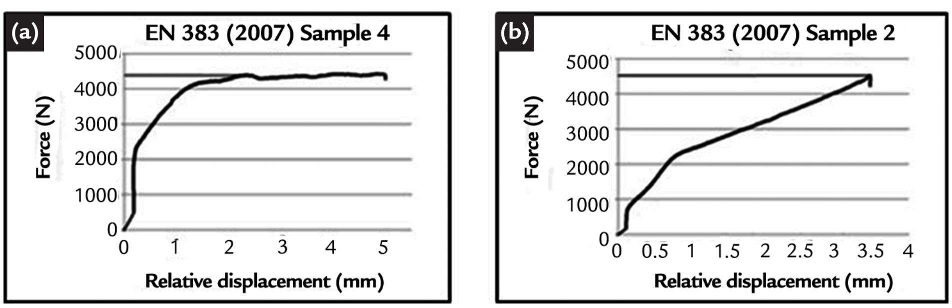

Figure 9
Curve of embedment force versus relative displacement to *Pinus elliottii* according to the European Standard: (a) Parallel direction to the grain. (b) Normal direction to the grain.

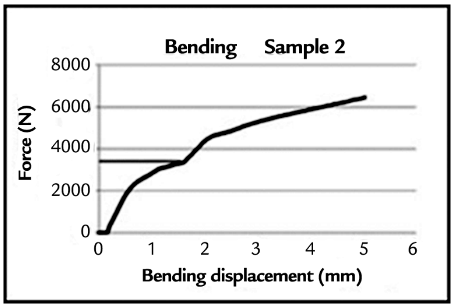

Figure 10
Curve of force (F_{fl}) versus relative displacement of the steel pins in the bending tests.

All the samples for wood tested to generate the curves for force versus relative displacement (or specific deformation) had a similar behavior to the one shown in the Figures 8 and 9. Similarly, all metal pins performed in the direct bending had a similar behavior to the one showed in the Figure 10.

4. Conclusions

For both wood species *Eucalyptus salligna* and *Pinus elliotii*, the highest average values of embedment strength were obtained by the European method. This is due to the Brazilian normative document using an experimental method that has as its base the specific deformation value of 2‰, leading to lower embedment strength values compared to the European method, in which the embedment strength value is determined based on the relative displacement of 5 mm. In a practical situation of design for timber structures, a smaller value for the embedment strength can lead to a higher number of connectors on the connections, when compared with other international normative documents such as the European, for example. Thus, a recommendation for the review process of the Brazilian Standard, in this case, is the adoption of a value of displacement in mm instead of a value of specific deformation. In this case, the value of 5 mm is suggested for the determination of the embedment strength experimental value. The adoption of maximum embedment strength or the force that causes the relative displacement of 5 mm between the metal pin and the specimen as a criterion for determining the wood's embedment strength by the European Standard was adequate.

The analytical and experimental results for both standards analyzed showed significant differences when compared. These differences can be also attributed to the influence of the bending of the pin associated with the embedment of the pin in the wood as the final response of the experimental test, since it was opted to use a more flexible pin as the starting point of this research.

For woods of *Pinus elliottii* (considered in this study as softwood, class C30), the bending of the pin had less influence on the final result of embedment. The analytic and experimental results were closer to each other compared to the results of *Eucalyptus salligna* (considered as hard wood, class C50) for which the bending of the pin had greater influence on the final results of the embedment strength.

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