CHARACTERIZATION OF PIN FASTENINGS WITH FOUR AMAZON TROPICAL TIMBER SPECIES

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Abstract. *The objective of this work is to characterize the structural wood fastenings with commercial pins of 9.5 mm, 12.5 mm, 16.0 mm and 19.0 mm diameters and commercial cross section timber of four hardwood species. The studied species were ipê (Tabebuia serratifolia), cumaru (Dipterix odorata), maçaranduba (Manilkara huberi) and angelim vermelho (Dinizia excelsa). The woodpins connections for the parallel test were arranged with two wood members sized 2.5x15.0x20.0 cm and one member of 5.0x15.0x20.0 cm and the perpendicular ones with two wood members of 2.5x15.0x36.0 cm and another one of 5.0x15.0x25.0 cm, each connected by two pins of same diameter. The average values obtained (five to twelve by test) were compared to the maximum load capacity of each pin diameter as determined by the Brazilian standard NBR 7190/97(1997). The load capacity per pin was above the obtained values set forth by the standard, except to wood species with straight grain.*

Keywords*: timber pins connectors; load capacity; tropical timber; NBR 7190/97 standard.*

1. INTRODUCTION

The use of timber in the construction normally presents limitations imposed by its cross section and length. That is sufficiently significant in the members in bending, where there is the natural tendency of reaching the largest possible span and in the plane or spatial reticulates as well.

For assembling structural elements in building construction the wood members must be joined together by means of metallic fasteners. In the members in bending the most efficient connection is the composition of glued laminates. In reticulates the most used types of connections are screws, nails, and bolts, followed by indented plates, metallic rings, and sheet metal fasteners (Ambrose, 1994).

The rigidity and resistance of a connection depend on the load orientation in relation to the grain direction, the wood species, the thickness of the element, the amount and disposal of the connection elements, speed and duration of the load, the humidity content, type of grain etc. (Carrasco, 1986; Rodrigues Jr, 1998).

The influence of these factors varies in function of the type of connection demanding specific tests for the evaluation and development of a calculation method and sizing for the diverse possibilities of combinations of geometry and properties of the elements to be connected (Gesualdo, 1986; Matthiesen, 1986).

In spite of the importance of these connections in conventional wood structures, there is no available data concerning the characterization of existing wood species in the market to the moment.

Due to this, this work was conducted specifically for a constant thickness of commercial section of four wood species of high density, using four different diameters of smooth pins, which characterization was undertaken in specimens prepared with two pins in a way to determine its strength parallel and perpendicular to grain. The use of pins as fasteners is to prevent the influence of the tension and attrition strength when screws with nut and washer are used.

2. MATERIALS AND METHODS

Wood species of ipê (*Tabebuia serratifolia*), cumaru (*Dipterix odorata*), maçaranduba (*Manilkara huberi*) and angelim vermelho (*Dinizia excelsa*) were selected, as being the species most used in the timber structures in general. Lumber of 6x16 cm commercial section acquired on the local market, in green condition, was randomly processed, without defects, and cut into the dimensions of specimens for load capacity testing. The pieces were maintained in tanks with water until their complete saturation and then cut into specimens.

The specimen for the compression parallel to grain test consisted of a three-member joint with two outer members sizing 2.5x15.0x20.0 cm, and one middle one of 5.0x15.0x20.0 cm, and the specimen for the compression perpendicular to grain test of two outer members of 2.5x15.0x36.0 cm, and one of 5.0x15.0x25.0 cm in the middle, both joined by two pins of equal diameter (Fig. 1 and 2). This methodology of tests has as origin the first proposal that would be incorporated into the current standard of calculation and sizing of wood structures (NBR 7190/97, 1997).

Five to twelve tests per wood species were conducted per type of connection and per pin diameter. Commercial smooth pins with diameters of 9.5 mm, 12.5 mm, 16 mm and 19 mm, without nuts and washers, to prevent the influence of the attrition in the resistance of the connection were used (JUNTA DEL ACUERDO DE CARTAGENA, 1982).

The diameter of the pilot hole, drilled in the wood for placing the pin, was 2 mm bigger than the pin diameter. The tests were carried out in an universal machine Instron 1127. The speed of load application was 2.5 mm/minute, where the deflection and corresponding load in the proportional limit and the maximum load at rupture were measured.

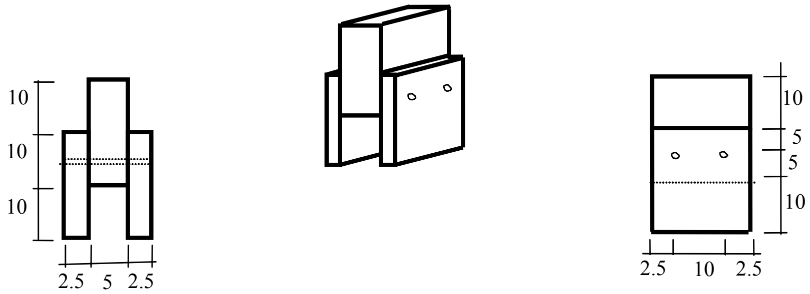


Figure 1. Specimen for the test of connections with tension parallel to grain. Units in cm.

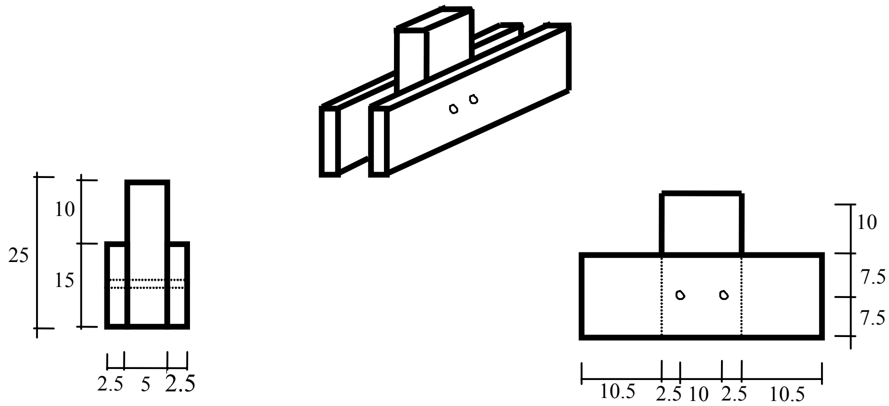


Figure 2. Specimen for the test of connections with tension perpendicular to grain. Units in cm.

Some physical and mechanical properties of the characterized species are indicated in Table 1 with average values determined in accordance with COPANT/72 (1972) standards (Commission Pan-American of Norms Techniques). The apparent density ($D_{ap.}$) at 12% of humidity (U_i) content was determined from the volumetric shrinkage (CV_{ui}) and basic density (D_b) of the species in accordance with Eq. (1):

$$D_{ap} = \left(\frac{1 + \frac{U_i}{100}}{1 - \frac{CV_{U_i}}{100}} \right) D_b \quad \text{with } U_i < 30\% \text{ of humidity content.} \qquad (1)$$

Table 1. Physical and mechanical properties of the four characterized wood species.

Wood species	Density (g/cm^3)			Volumetric Shrinkage (%)	Condition of testing	Yield Strength (MPa)		Tensile Strength (MPa)		
	Basic	Green	Apparent [7]			C_{Perp} [3]	MOE[4]	Static Bending	C_{Paral} [5]	Shear [6]
Ipê *T. serratifolia*	0.92	1.20	1.12	13.2	Green [1] Dry [2]	16.1 16.1	20 400 22 000	157.9 177.5	72.5 91.1	14.8 14.4
Cumaru *D. odorata*	0.91	1.28	1.11	13.5	Green Dry	16.0 21	16 200 18 300	136.4 176.4	69.3 98.7	16.9 22.4
Maçaranduba *M. huberi*	0.87	1.27	1.08	16.0	Green Dry	16.8 17.3	15 400 17 400	127.2 179.7	68.3 110.9	12.5 17.1
A. vermelho *D. excelsa*	0.83	1.26	1.02	14.5	Green Dry	10.5 15.1	15 300 17 300	122.0 160.0	61.5 87.3	13.4 18.0

Note: (1): saturated in water; (2) (7): at 12% of humidity content; (3): compression perpendicular to grain; (4): modulus of elasticity; (5): compression parallel to grain; (6): shear parallel to grain.

3. RESULTS

In Tables 2 and 3 are presented the results of the tests of the connections with two pins carried out in the green condition (saturated in water), with loads in the directions parallel or perpendicular to the grain. No tendency was observed in relation to the resistance of the connection, possibly due to the small variation of the density between the wood species.

Even though maçaranduba is of straight grain it did not present significant variation of resistance in relation to the other species that possess reverse grain. The coefficients of variation of the results of tests lay inside of the intervals normally found in literature.

Table 2. Strength parallel to grain - Results of tests of connections with two pins.

Wood species	Pins of 9.5 mm		Pins of 12.5 mm		Pins of 16.0 mm		Pins of 19.0 mm	
	Load at PL [a] (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)
Ipê *T. serratifolia*	22 490	52 360	37 663	67 211	42 850	78 900	66 927	99 527
	(13.0) [b]	(5.3)	(15.1)	(7.4)	(6.1)	(5.3)	(11.1)	(7.8)
Cumaru *D. odorata*	24 020	48 640	32 056	60 511	44 340	75 970	67 900	95 317
	(10.7)	(8.0)	(12.0)	(9.9)	(8.5)	(8.4)	(7.4)	(6.9)
Maçaranduba *M. huberi*	19 450	40 079	24 467	53 289	36 020	63 410	54 320	76 550
	(13.7)	(15.8)	(14.7)	(9.1)	(10.2)	(11.4)	(15.1)	(6.7)
Angelim vermelho *D. excelsa*	21 375	44 767	26 320	49 440	44 858	72 642	39 717	71 550
	(14.6)	(7.8)	(9.7)	(3.1)	(8.4)	(3.5)	(14.0)	(6.3)

(a): Load at proportional limit; (b) Numbers in parenthesis are coefficients of variation (in %).

Table 3. Strength perpendicular to grain - Results of tests of connections with two pins.

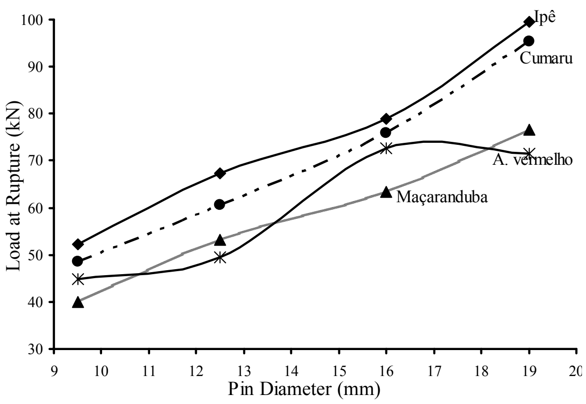
Wood species	Pins of 9.5 mm		Pins of 12.5 mm		Pins of 16.0 mm		Pins of 19.0 mm	
	Load at PL [a] (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)	Load at PL (N)	Load of Rupture (N)
Ipê *T. serratifolia*	17 011	38 911	25 190	45 500	42 350	73 500	58 960	85 570
	(17.8) [b]	(15.4)	(12.9)	(12.6)	(11.0)	(6.0)	(8.3)	(8.4)
Cumaru *D. odorata*	23 589	47 500	27 389	51 567	39 042	69 575	50 530	83 100
	(11.9)	(5.9)	(11.7)	(4.8)	(5.9)	(6.2)	(9.1)	(5.8)
Maçaranduba *M. huberi*	19 528	40 125	24 875	46 550	34 000	64 164	40 650	63 840
	(14.3)	(9.2)	(15.5)	(8.0)	(7.8)	(4.8)	(8.5)	(13.1)
Angelim vermelho *D. excelsa*	23 930	46 662	26 380	41 930	39 110	65 250	34 700	43 500
	(12.6)	(9.1)	(13.6)	(13.1)	(4.5)	(8.1)	(7.3)	(9.8)

(a): Load at proportional limit; (b): Numbers in parenthesis are coefficients of variation (in %).

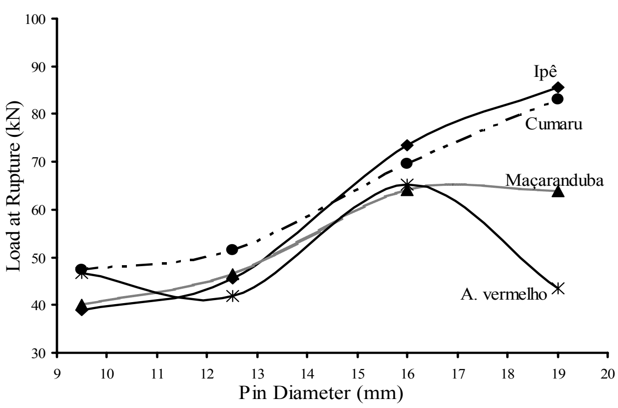
Table 4 shows the variation between species of the resistance in the rupture of the connections for the four diameters of pins. Graphs 1 and 2 display more clearly this variation.

Table 4. Average values of the load of rupture of connections in the parallel and perpendicular to the grain directions.

Wood species	Load at rupture parallel to grain (N)				Load at rupture perpendicular to grain (N)			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	52 360	67 211	78 900	99 527	38 911	45 500	73 500	85 570
Cumaru *D. odorata*	48 640	60 511	75 970	95 317	47 500	51 567	69 575	83 100
Maçaranduba *M. huberi*	40 079	53 289	63 410	76 550	40 125	46 550	64 164	63 840
A. vermelho *D. excelsa*	44 767	49 440	72 642	71 550	46 662	41 930	65 250	43 500



Graph 1. Load of rupture of connections with strength parallel to grain per pin diameter.



Graph 2. Load of rupture of connections with strength perpendicular to grain per pin diameter.

As a comparison with the results of the tests, the allowable loads per pin were calculated in accordance with the NBR 7190/97 (1997) standard. To exemplify the calculation for wood of ipê, a connection with pin of 9.5 mm parallel and perpendicular to grain was used, taking into account the properties from Table 1:

$f_{co,k}$ = 0.70 $f_{co,m}$ = 0.70 x 91.1 = 63.7 MPa
$k_{mod.1}$ = 0.70 (long term loading)
$k_{mod.2}$ = 0.80 (class of humidity 3 – tested in the green condition)
$k_{mod.3}$ = 1.0 (timber quality)
γ_c = 1.4 (tension of compression parallel to grain)
$f_{y,k}$ = 240 MPa (Minimum yield stress)
γ_s = 1.1 (Safety factor)
$f_{y,d} = f_{y,k}/ \gamma_s$ = 240/1.1 = 218 MPa
$f_{co,d} = (k_{mod.1}\ k_{mod.2}\ k_{mod.3})\ f_{co,k}/\gamma_c$ = 0.70 x 0.80 x1.0 x 63.7/1.4 = 25.5 MPa
α_e = 1.95 for the pin of 9.5 mm diameter

As $f_{e0,d} = f_{c0,d}$ = 25.5 MPa
$f_{e0,d}$ = 25.5 MPa = 2 550 N/cm^2
$f_{e90,d} = 0.25\ f_{c0,d}\ \alpha_e$ = 0.25 x 25.5 x 1.95 = 12.4 MPa = 1 240 N/cm^2

β = t/d = 2.5 cm/0.95 cm = 2.63 (Where: t is the smaller value between t_1 = 2.5 cm e $t_2/2$ = 5 cm/2).

$$\beta_{lim.} = 1.25\sqrt{\frac{f_{y,d}}{f_{eo,d}}} = 1.25\sqrt{\frac{218}{25.5}} = 3.65 \text{ --------------------(tension parallel to grain)} \quad (2)$$

$$\beta_{lim.} = 1.25\sqrt{\frac{f_{y,d}}{f_{e90,d}}} = 1.25\sqrt{\frac{218}{12.4}} = 5.24 \text{ --------------------(tension perpendicular to grain)} \quad (3)$$

As $\beta < \beta_{lim.}$ Crushing in the wood will take place.

Resistance per pin per sample cross section:

$$R_{vd,1} = 0.40\frac{t^2}{\beta} f_{e0,d} = 0.40\frac{(2.5)^2}{2.63} 2\,550 = 2\,424 \text{ N} \text{ --------(tension parallel to grain)} \quad (4)$$

$$R_{vd,1} = 0.40\frac{t^2}{\beta} f_{e90,d} = 0.40\frac{(2.5)^2}{2.63} 1\,240 = 1178 \text{ N} \text{ --------(tension perpendicular to grain)} \quad (5)$$

As there are two sections of cut t=2.5 cm and two pins in the connection, with pins of 9.5 mm, the following resistance per specimen is obtained, taking into account results from Eq. (4) and (5):

$R_{vd,1}$ = 2 424 N x 2 x 2 = 9 696 N --------------------------- (tension parallel to grain).
$R_{vd,1}$ = 1 178 N x 2 x 2 = 4 712 N --------------------------- (tension perpendicular to grain).

Tables 5 and 6 are results of this routine of calculation for all the pins diameters and characterized wood species.

Table 5. Strength parallel to grain - load Capacity per test specimen obtained by the NBR 7190/97 standard.

Wood species	Load Capacity per test specimen according to NBR 7190/97 standard (N)			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16.0 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	9 696	12 750	16 346	19 318
Cumaru *D. odorata*	10 509	13 820	17 718	20 939
Maçaranduba *M. huberi*	11 802	15 520	19 897	23 515
Angelim vermelho *D. excelsa*	9 293	12 220	15 667	18 515

Table 6. Strength perpendicular to grain - load Capacity per test specimen obtained by the NBR 7190/97 standard.

Wood species	Load Capacity per test specimen according to NBR 7190/97 standard (N)			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16.0 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	4 712	5 350	6 218	6 818
Cumaru *D. odorata*	5 122	5 805	6 730	7 379
Maçaranduba *M. huberi*	5 752	6 515	7 564	8 288
Angelim vermelho *D. excelsa*	4 528	5 130	5 955	6 523

Tables 7 and 8 show the comparison of the numerical values obtained by NBR 7190/97 (1997) standard for pins of different diameters with the results of tests in proportional limit between load and deformation to a level of 5% of exclusion (average value of the test - 1.65 x standard deviation of the average value of test).

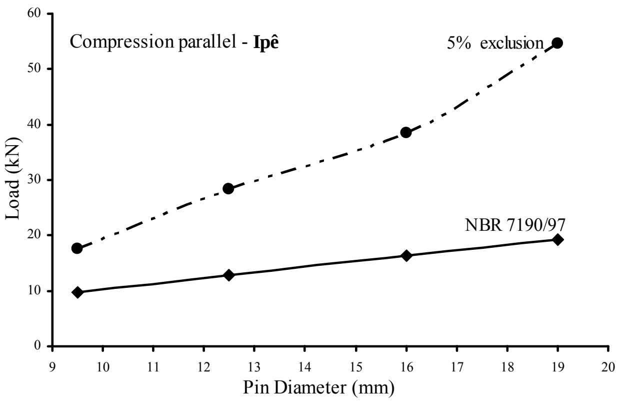
Table 7. Strength parallel to grain - Comparison of the load capacity per test specimen obtained by the NBR 7190/97 standard with the values to the level of 5% of exclusion on the results of tests in the proportional limit.

Wood species	Values calculated according to NBR 7190/97 (N)				Values of lower limit of 5% exclusion on the results of tests at proportional limit (N)			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16.0 mm	Two pins of 19.0 mm	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16.0 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	9 696	12 750	16 346	19 318	17 682	28 299	38 534	54 620
Cumaru *D. odorata*	10 509	13 820	17 718	20 939	19 794	25 687	38 157	55 890
Maçaranduba *M. huberi*	11 802	15 520	19 897	23 515	15 044	18 532	29 955	40 787
Angelim vermelho *D. excelsa*	9 293	12 220	15 667	18 515	16 222	22 103	38 685	30 561

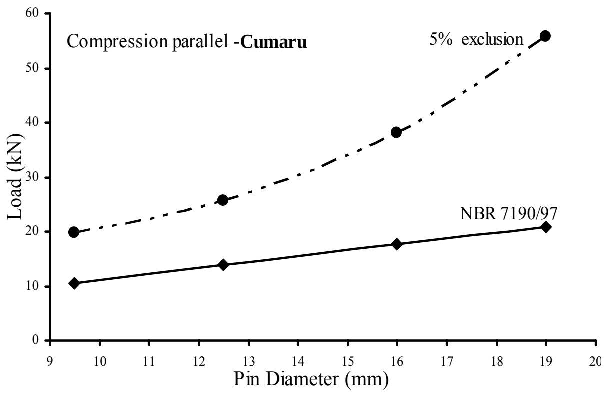
Table 8. Strength perpendicular to grain - Comparison of the load capacity per test specimen obtained by the NBR 7190/97 standard with the values to the level of 5% of exclusion on the results of tests in the proportional limit.

Wood species	Values calculated according to NBR 7190/97 (N)				Values of lower limit of 5% exclusion on the results of tests at proportional limit (N)			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	4 712	5 350	6 218	6 818	12 023	19 819	34 644	50 915
Cumaru *D. odorata*	5 122	5 805	6 730	7 379	18 944	22 084	35 212	42 927
Maçaranduba *M. huberi*	5 752	6 515	7 564	8 288	14 915	18 534	29 627	34 962
Angelim vermelho *D. excelsa*	4 528	5 130	5 955	6 523	18 973	20 445	36 178	30 535

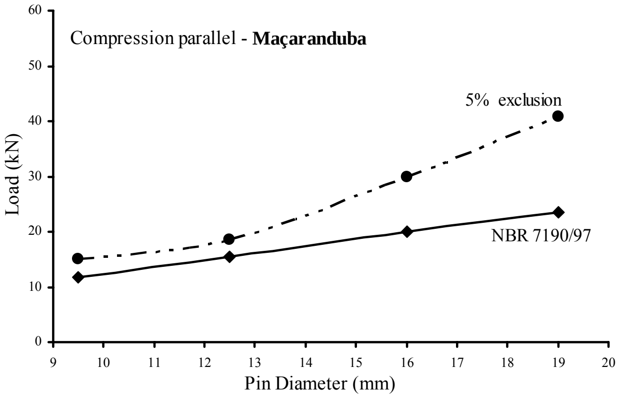
The values of Tables 7 and 8 are plotted in Graphs 3 to 10 to allow for clearer visualization of this variation.



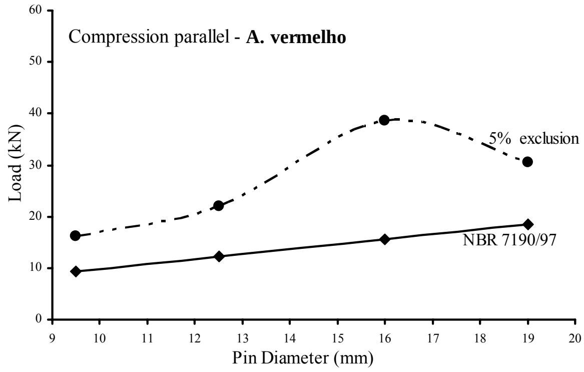
Graph 3. Compression parallel to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Ipê.



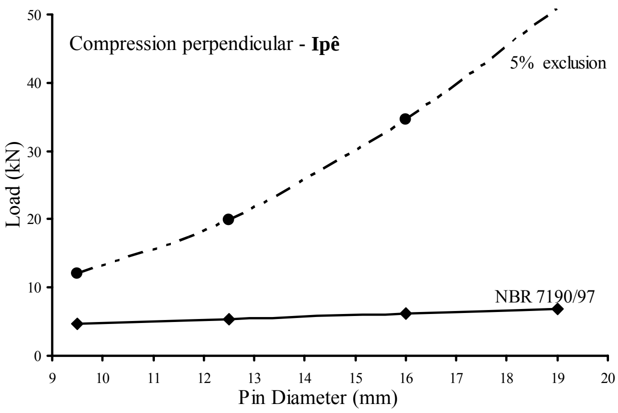
Graph 4. Compression parallel to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Cumaru.



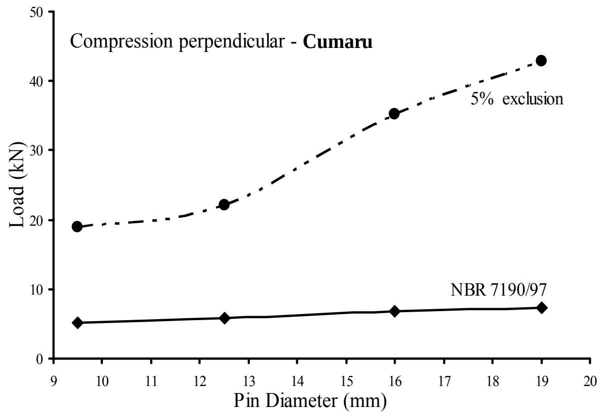
Graph 5. Compression parallel to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Maçaranduba.



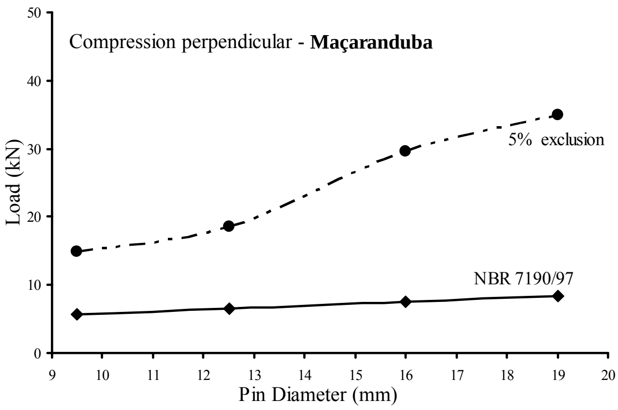
Graph 6. Compression parallel to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Angelim vermelho.



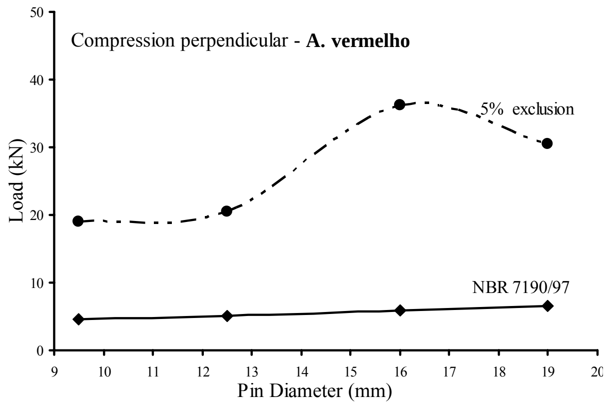
Graph 7. Compression perpendicular to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Ipê.



Graph 8. Compression perpendicular to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Cumaru.



Graph 9. Compression perpendicular to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Maçaranduba.



Graph 10. Compression perpendicular to grain - Comparison of the load capacity of connections obtained by the 7190/97 NBR standard and the value of characterization to a level of 5% of exclusion on the load in the proportional limit for Angelim vermelho.

Tables 9 and 10 show the quantitative variation of the values of the load capacity obtained by the NBR 7190/97(1997) standard and average values of tests in the proportional limit to a level of 5% of exclusion and the average values of rupture. In the perpendicular to grain compression the resistance of the connection increases in well larger ratios than in the results obtained by the standard.

Table 9. Relation between the average values of connections in the lower limit of exclusion of 5% on the results of tests in the proportional limit and the values calculated by the NBR 7190/97 standard, for two pins.

Wood species	(Values of lower limit of 5% exclusion on the results of tests at proportional limit) / (Values calculated according to NBR 7190/97)							
	Compression parallel to grain				Compression perpendicular to grain			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	1.82	2.22	2.39	2.83	2.54	3.70	5.65	7.47
Cumaru *D. odorata*	1.88	1.86	2.18	2.67	3.70	3.81	5.30	5.82
Maçaranduba *M. huberi*	1.28	1.20	1.53	1.74	2.59	2.84	3.97	4.22
Angelim vermelho *D. excelsa*	1.75	1.81	2.50	1.65	4.19	4.00	6.15	4.68

Table 10. Relation between the average values of the load of rupture of the connections tests and the values calculated by the NBR 7190/97 standard.

Wood species	(Load at rupture obtained by the tests) / (Values calculated according to NBR 7190/97)							
	Compression parallel to grain				Compression perpendicular to grain			
	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm	Two pins of 9.5 mm	Two pins of 12.5 mm	Two pins of 16 mm	Two pins of 19.0 mm
Ipê *T. serratifolia*	5.40	5.27	4.89	5.15	8.23	8.50	11.98	12.55
Cumaru *D. odorata*	4.63	4.38	4.34	4.37	9.27	8.89	10.47	11.26
Maçaranduba *M. huberi*	3.40	3.43	3.23	3.26	6.97	7.14	8.59	7.70
Angelim vermelho *D. excelsa*	4.82	4.04	4.70	3.86	10.30	8.17	11.10	11.26

4. CONCLUSION

Although the tests have been done with only four species, the results show the importance of specific tests of the load capacity of fastenings connections. For the sake of comparison, the values of resistance of the fastenings connections were obtained by the tension of parallel to fibers compression, due to the difference of methodology and number of test specimens specified by NBR 7190/97 (1997) standard. The values are lower than those of the tests, mainly in relation to the perpendicular to grain compression. For other wood species, a larger number of tests and also the inclusion of species with straight grain must be characterized so that safe subsidies are supplied for the revision of the methodology of sizing of the Brazilian standard.

5. ACKNOWLEDGEMENTS

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