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2 **EVALUATION OF THE VARIABILITY OF COMPRESSIVE**  
3 **STRENGTH PARALLEL TO THE FIBERS OF HARDWOOD**  
4 **SPECIES**

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15 **ABSTRACT**

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17 Wood has several advantages as structural material. For this use to be applied in a safe way,  
18 it is necessary to know the statistical behavior of the mechanical properties. Some works  
19 and normative codes, such as the “Brazilian timber standard” (as well as its review project),  
20 accepts a normal distribution model for determining the characteristic value of compressive  
21 strength parallel to wood fiber, with the adoption of a coefficient of variation for this  
22 property equal to 18 %. This work evaluates the distribution model of compressive strength  
23 parallel to the fibers, as well as the coefficient of variation of this property. Tests and  
24 statistical treatment were performed in compression parallel to the fibers for 7 species of  
25 hardwood commonly found in Brazil. It was observed that the compressive strength of  
26 wood actually follows a normal distribution, and the adoption of an average coefficient of  
27 variation equal to 18 % is acceptable and in favor of safety.

28 **Keywords:** *Aspidosperma polyneuron*, compression tests, *Caryocar villosum*, *Goupia*  
29 *glabra*, *Hymenaea* spp., *Paratecoma peroba*, *Tabebuia serratifolia*, *Vochysia* spp.,  
30 wood properties.

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## INTRODUCTION

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Timber is a material of natural origin with a wide variety of possibilities of use, including structural employment. Among the materials commonly used in structures, timber is renewable, has a high strength to weight ratio, and its production generates few environmental impacts.

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To harness the advantages of timber as a structural material and to meet the structural performance requirements established by modern normative codes, it is necessary to know its mechanical properties as well as the variability of these properties.

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Several studies present results related to the mechanical characterization of wood species and their variability, such as: Aquino *et al.* (2018), Couto *et al.* (2018), Gherardi Hein *et al.* (2012), Koman *et al.* (2017). Besides these, we can highlight the studies of Lima *et al.* (2018) and Silva *et al.* (2018) that evaluated the variability of physical and mechanical properties of wood as a function of the geographical origin, as well as the studies of Lima Junior *et al.* (2018) and Zeidler *et al.* (2014), which investigated the variability of the mechanical properties of wood extracted from different positions in a tree. When specifically evaluated the variability of compressive strength parallel to the wood fibers, Kretschmann (2010) has a mean coefficient of variation equal to 18 %. This value is also indicated by the Brazilian standard of timber structures, NBR 7190:1997 (ABNT 1997), as well as in its review project, PNNBR 7190 (ABNT 2013b).

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Another important factor in the use of timber in structures is the statistical distribution of its mechanical properties. It is usually considered the characteristic value of a certain strength as the value corresponds to the quantile of fifth percentile of the

55 distribution of strengths. The distribution will influence the definition of the characteristic  
56 strengths.

57 The NBR 7190 (ABNT 1997) and UNE-EN 14358 (CEN 2016) allow the adoption  
58 of a normal or lognormal distribution for compressive strength parallel to the wood fibers.  
59 Some scientific studies evaluate both the variability of compressive strength parallel to the  
60 fibers of the wood, as to the form of its statistical distribution.

61 Espinosa *et al.* (2004) and Pinto *et al.* (2004) observed in a sample of *Eucalyptus*  
62 *grandis*, that the resistance does not follow a normal distribution and that the lognormal  
63 distribution was better suited to the data under study. The research also indicated a  
64 coefficient of variation equal to 26,5 %.

65 Logsdon *et al.* (2010) found through tests of 100 specimens of Angelim Pedra  
66 (*Dinizia excelsa*), that the distribution of compressive strength parallel to the fibers does not  
67 follow a normal distribution, but is equivalent. It was also observed that the upper limit of  
68 the coefficient of variation of the distribution of compressive strength parallel to the fibers  
69 was close to 18 %.

70 The available literature presents few results about the evaluation of the distribution  
71 of wood compressive strength parallel to the fibers, as well as on the variability of these  
72 values, represented by the coefficient of variation. The data presented in Brazilian Standard  
73 of timber structures were obtained based on the analysis of few wood species and the  
74 literature consulted by the authors found the study of only two species of wood, the  
75 *Eucalyptus grandis* and the Angelim Pedra. It is, therefore, important the evaluation of  
76 more wood species.

77 This work evaluates the type of distribution followed by compressive strength  
78 parallel to the wood fiber, as well as the coefficient of variation for this property. A greater  
79 number of species was used than in the consulted literature, encompassing species of the  
80 hardwood group commonly used in timber structures in the Brazilian market; including:  
81 Casca Grossa (*Vochysia* spp.), Cupiúba (*Goupia glabra*), Ipê (*Tabebuia serratifolia*), Jatobá  
82 (*Hymenaea* spp.), Pequiá (*Caryocar villosum*), Peroba do Campo (*Paratecoma peroba*),  
83 and Peroba Rosa (*Aspidosperma polyneuron*).

## 84 MATERIAL AND METHODS

85 Compression tests were performed parallel to the wood fibers following the  
86 methodology for defect-free specimens presented in the project of ABNT standard PNBR –  
87 02:126.10-001-1 (ABNT 2013a). The experimental analysis was carried out in the Wood  
88 and Timber Structures Laboratory of the Structures Department of the São Carlos School of  
89 Engineering (LaMEM/SET/EESC).

90 The samples were cut randomly from sawn pieces. The specimens were taken at a  
91 distance from the edge 5 times the smallest cross section dimension, since greater than 30  
92 cm, following PNBR – 02:126.10-001-1 (ABNT 2013a) recommendations.

93 The specimens with square cross section with 5 cm side and length equal to 15 cm,  
94 were tested to compression parallel to the fibers in the Amsler universal machine, following  
95 the cycle of loading and unloading presented in PNBR – 02:126.10-001-1 (ABNT 2013a).  
96 In this cycle, the test body is loaded up to 50 % of its rupture force, remaining for 30 s. at  
97 this loading level. Then the load is reduced to 10 % of the rupture force, remaining at this  
98 loading level for another 30 s. After this phase, the force is elevated until the rupture of the  
99 structural element.

100 After the compression tests, the specimens were placed in an oven with a maximum  
 101 temperature of  $103 \text{ }^{\circ}\text{C} \pm 2 \text{ }^{\circ}\text{C}$  for drying and subsequent determination of moisture. The  
 102 compressive strength was corrected to the humidity of 12 % from the ratio present in NBR  
 103 7190 (ABNT 1997), presented in Equation 1.

$$104 \quad f_{12} = f_{u\%} \left[ 1 + \frac{3(U\% - 12)}{100} \right] \quad (1)$$

105 In equation 1,  $f_{12}$  is the resistance of wood with 12% moisture,  $f_{u\%}$  is the resistance  
 106 of wood in moisture  $U\%$ .

107 The species used in this work, as well as the amount of test specimens of  
 108 compressive strength parallel to the fibers for each species, are presented in table 1.

109 **Table 1:** Quantity of compressive strength test specimens parallel to the fibers.

<i>Species</i>	Scientific name	Amount of test specimens
Casca Grossa	<i>Vochysia spp.</i>	34
Cupiúba	<i>Goupia glabra</i>	34
Ipê	<i>Tabebuia serratifolia</i>	34
Jatobá	<i>Hymenaea spp.</i>	35
Pequiá	<i>Caryocar villosum</i>	35
Peroba do Campo	<i>Paratecoma peroba</i>	33
Peroba Rosa	<i>Aspidosperma polyneuron</i>	35
Total		240

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111 After the experimental analyses, statistical analyses were performed with the aid of  
 112 the program SISVAR (Ferreira 2011). For each of the tested species, the normality of the  
 113 strength distribution was verified by means of the Shapiro-Wilk (S-W) and Kolmogorov-  
 114 Smirnov (K-S) tests. Also determined were the mean values, characteristic (NBR 7190) and  
 115 Coefficients of variation of the compressive strength parallel to the fibers of the wood.

116 The Shapiro-Wilk test, proposed in 1965, is based on a statistic (W) calculated on  
117 the squared ordered sample values, seeking to assess whether a random sample originates  
118 from a Normal distribution (Shapiro and Wilk 1965).

119 The Kolmogorov-Smirnov normality test, statistic (D), for a sample is an adherence  
120 test, ie it checks the degree of agreement between the distribution of a set of sample values  
121 and a specific theoretical distribution.

122 According to Torman *et al.* (2012) the S-W and K-S tests provide the parameter  
123 value of the test (p-value (W and D), p-value or significance), which can be interpreted as  
124 the measurement of the degree of concordance between the data and the null hypothesis  
125 (H0), and H0 corresponds to the Normal distribution. The value of W and D refers to the  
126 statistics of Shapiro-Wilk and Kolmogorov-Smirnov, respectively.

127 The test part of the null hypothesis (H0) considering the distribution of the data to  
128 be Normal. Given a level of significance, usually established in 5 % if the test rejects the  
129 hypothesis, then the distribution of the data is not normal. That is, if the P-value is less than  
130 the established level 5 %, then there are indications to discard the normality of the data. On  
131 the other hand, if the P-value of the test is above the 5 % established, or another pre-defined  
132 level, this means that the hypothesis of normality cannot be rejected. For each species, the  
133 resistance values obtained experimentally were divided by the mean value of the type. This  
134 was done to enable the grouping of all data and consequently, to obtain a single coefficient  
135 of variation for all species in relation to the compressive strength parallel to the wood  
136 fibers.

137 The confidence interval (CI) of the coefficients of variations was also obtained, with  
138 the purpose of verifying the reliability of the estimates (probable range of estimates), using  
139 a coefficient of confidence equal to 95 %.

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**RESULTS AND DISCUSSIONS**

142 In table 2, the compressive strength parallel to the fibers is presented after correction  
 143 to the reference humidity of 12 % ( $f_{c0,12}$ ), obtained in the tests of the 7 species analyzed. In  
 144 table 3, the normality test of the distribution of compressive strength parallel to the fibers of  
 145 the 7 species analyzes is presented.

146 **Table 2:** Compressive strength parallel to the fibers ( $f_{c0,12}$ ) of the specimens in  
 147 ascending position (moisture content of 12 %).

Specie	$f_{c0,12}$ (MPa)									
Casca Grossa	82	87	89	93	93	95	98	103	105	106
	108	109	113	115	116	117	120	121	125	129
	130	131	133	135	136	141	142	143	145	150
	155	161	167	195						
Cupiúba	30	34	35	39	39	39	41	42	42	46
	46	47	47	48	49	50	50	51	51	51
	56	58	58	59	61	61	63	66	66	66
	69	71	73	73						
Ipê	50	54	55	56	59	62	64	68	69	70
	72	72	73	74	74	77	77	77	78	78
	78	80	80	80	82	82	83	84	84	85
	85	88	93	99						
Jatobá	75	78	80	80	85	85	88	88	90	91
	91	92	92	92	92	93	94	95	95	96
	96	96	97	97	98	98	99	102	102	103
	103	104	105	106	109					
Pequiá	28	32	32	33	33	34	34	35	36	36
	37	37	37	38	38	38	39	39	39	40
	41	42	42	42	43	43	44	44	45	48
	50	50	51	52	58					
Peroba do Campo	37	43	44	46	46	46	48	48	49	50
	51	51	51	51	51	51	52	54	54	57
	59	59	59	59	60	60	61	65	65	66
	66	72	77							
Peroba Rosa	31	36	39	40	40	42	43	44	46	47
	47	47	48	50	49	52	52	53	53	53
	53	55	56	56	57	60	61	61	62	64
	64	65	65	66	69					

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149 Based on the results, presented in table 3, of the S-W and K-S, with 95 %  
 150 confidence, tests, it is possible to decide the normality of all samples ( $W \cong 1$ ,  $pr < W > 5\%$   
 151 and  $D \cong 0$ ,  $pr < D > 5\%$ ), since the obtained values of significance, p-value, of the tests is  
 152 above the 5 % established. It was possible to confirm the statement in the Brazilian  
 153 standard of timber, NBR 7190 (ABNT 1997), that the wood resistance follows a normal  
 154 distribution. The test results are corroborated by the frequency histograms and polygons of  
 155 figures 1 and 2 as they approach the normal distribution curve.

156 **Table 3:** Results of the normality tests of the distribution of the samples.

Species	Tests			
	Shapiro - Wilk		Kolmogorov - Smirnov	
	W	pr < W	D	pr < D
Casca Grossa	0,9699	0,4611	0,0662	0,9976
Cupiúba	0,9671	0,3857	0,1308	0,5756
Ipê	0,9641	0,3197	0,1372	0,5131
Jatobá	0,9718	0,4951	0,1033	0,8288
Pequiá	0,9626	0,2732	0,1201	0,6653
Peroba do Campo	0,9683	0,4354	0,1518	0,4022
Peroba Rosa	0,9781	0,6963	0,0823	0,9650

157  
 158 The 7 species studied, the following results were obtained: arithmetic mean of the  
 159 samples ( $f_{c0,m}$ ); Characteristic resistance of the population, admitting quantile of 5 %, ( $f_{c0,k}$ )  
 160 and coefficient of variation ( $\delta$ ). These values are shown in table 4. In Figures 1 and 2,  
 161 histograms and frequency polygons are presented for the species Casca Grossa and Peroba  
 162 Rosa, respectively. The histograms and frequency polygons of the other species were  
 163 omitted for the sake of space.

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**Table 4:** Statistical analysis of the tested species.

Results	Species						
	Casca Grossa	Cupiúba	Ipê	Jatobá	Pequiá	Peroba do Campo	Peroba Rosa
$f_{c0,m}$ (MPa)	123,18	52,26	74,76	93,91	40,29	54,79	52,14
$f_{c0,k}$ (MPa)	85,50	32,80	52,80	77,25	31,00	40,90	34,75
$\delta$ (%)	20,72	22,64	15,11	8,69	16,37	16,02	18,17

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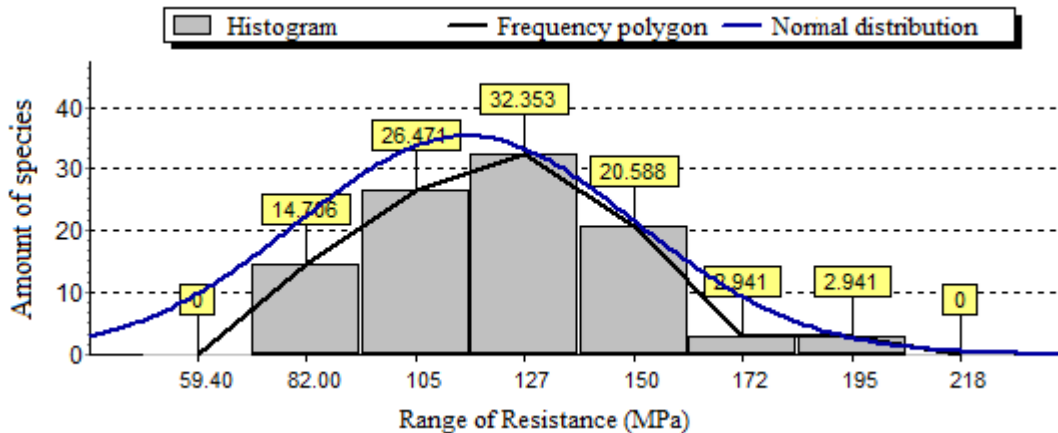
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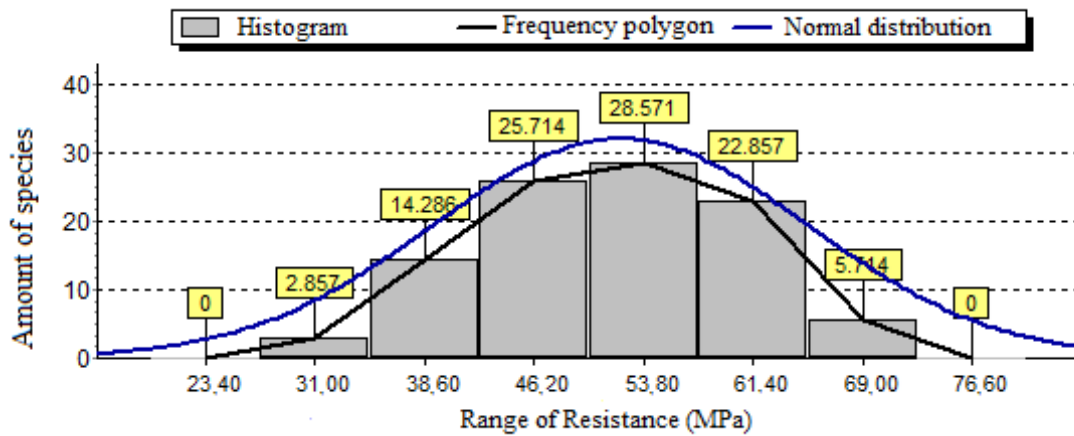
To ascertain the value of the coefficient of variation recommended by NBR 7190 (ABNT 1997) and confirmed by Kretschmann (2010), which is worth 18 %, the confidence interval was performed, using the confidence coefficient equal to 95 % with the values of coefficients of variation of the 7 species analyzed. A confidence interval between 12,67 % and 20,97 % was obtained, with a mean value equal to 16,82 %. Thus, the quoted value is within the confidence interval and very close to the value of 18 % obtained, so that it can be considered a representative value for the calculation of the characteristic resistance to the wood compression, as proposed by NBR 7190:1997.



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**Figure 1:** Histogram and frequency polygon of the species Casca Grossa.



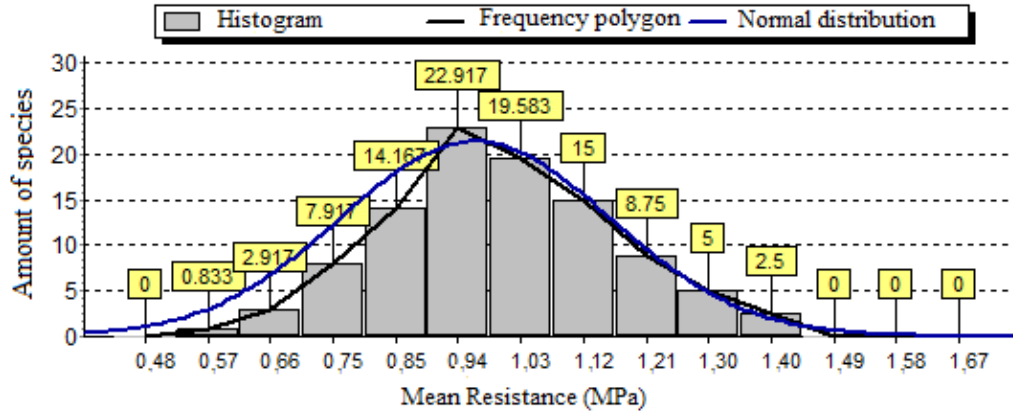
180 **Figure 2:** Histogram and frequency polygon of Peroba Rosa species.

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182 It is possible to observe in the results presented in table 4 that Casca Grossa and  
183 Cupiúba were the species presented the highest coefficients of variation, being even higher  
184 than 18 %. These species have reverses fibers (fibers not parallel to the workpiece axis), or  
185 irregular grain, due to the irregular or very fast growth of wood, a common fact in tropical  
186 species. This fact according to Almeida *et al.* (2018), can lead to higher coefficients of  
187 variation.

188 Alternatively, we proceeded with the data of the 7 species in order to obtain a single  
189 coefficient of variation. For this purpose, the ratios of compressive strength of 240 samples  
190 were used for their respective values. With the aid of the SISVAR software, the coefficient  
191 of variation of the data was calculated, obtaining a value equal to 17,11 %, and the  
192 histogram and frequency polygon were generated as shown in Figure 3.

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**Figure 3:** Histogram and frequency polygon for resistance/mean value for all 7 species.

### CONCLUSIONS

In this research, the normality of the distribution of compressive strength parallel to the wood fibers was confirmed for 7 species of wood using the Shapiro-Wilk and Kolmogorov – Smirnov normality tests.

The results corroborated the methodology presented in the NBR 7190, which considers the resistances of wood as random variables that can be represented by the Normal distribution, Gauss curve, and that its characteristic values correspond to the Quantile of 5 % of the respective distribution.

This work also addressed the coefficient of variation of compressive strength parallel to the wood fibers. Two methodologies were used for this analysis, and two coefficient of variation values were used: in the first, the mean variation coefficients of the 7 species were considered and the confidence interval was also determined, while in the second the 7 species were grouped, considering the ratio between resistance and average

211 resistance of each species and the set of data formed was obtained a single coefficient of  
212 variation for the sample.

213 For the first methodology, a mean coefficient of variation of 16,82 % was found in a  
214 confidence interval between 12,67 % and 20,97 %. The second methodology provided a  
215 coefficient of variation equal to 17,11 %. The value recommended by the Brazilian  
216 standard of timber structures is within the confidence interval determined using the first  
217 methodology, and is slightly higher than the value obtained using the second methodology.  
218 Thus, it is concluded that the adoption of the coefficient of variation equal to 18 % is  
219 acceptable.

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