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Impact Strength in Dinamic Bending as a Function of the Strength in Static Bending of Wood

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Abstract Wood is a natural, renewable and abundant material in Brazilian territory. But its use in civil construction is still commonplace. When compared to materials such as steel and concrete, it has many advantages, such as its resistance to density ratio. Where it is possible to observe a high resistance, equivalent to concrete of high performance with a much smaller density. Due to the heterogeneity of the woods, very different behaviors may occur in response to the various requests. Thus, for a better use of its capacity is essential knowledge of its properties. Among them is impact strength in bending. Impact strength in bending knowledge is fundamental in structures that will be exposed to short-lived impact loads, such as bridges. But due to some factors this is not a mechanical property that is very accessible to most research centers. The objective of this research was to use linear, exponential, logarithmic and geometric regression models to verify if it is possible to obtain a relation between the resistance modulus in the static bending, which is more easily obtained, and the impact strength in bending values. Ten Brazilian wood species were selected and static bending and impact in bending tests were performed according to ABNT NBR 7190:1997. All tests were done in the Wood and Timber Structures Laboratory (LaMEM), in the Department of Structural Engineering of the Engineering School of São Carlos, University of São Paulo. According to the results and the statistical analysis performed, it was possible to conclude that the Strength in static bending does not seem to be a good estimator of the impact strength in bending of wood.

Keywords Impact strength, Static Bending, Wood

1. Introduction

Physical and mechanical wood characterization has the most important for better utilization of this material, bring development to the build system and to the use of this as a construction material [1-3]. Characterization process follows the procedures of the Brazilian code ABNT NBR 7190:1997 "Timber Structures Design" in its annex B" Determination of Wood properties for Structure Design". So, this code prescribes procedures to determining of properties of wood and design manufacturing of Timber Structures, presenting great importance to the Brazilian wood sector [4-8].

In the item B.16 entitled "Impact Strength in bending", are described the procedures to determining the energy necessary to the rupture of a wood sample presenting specific dimensions in bending, using a test mechanism based on the energy of a pendulum swinging as shown the figures 1 and 2. Figure 1 shows the used machine developed for SIQUEIRA [12] based on a similar machine from the FPL (Forest Product Laboratory). This machine has a pendulum connected in a chain applying the force at the center of the sample supported in two points [9-13].

Figure 1. Impact in bending machine

Figure 2 shows the scheme of the used machine for determining the rupture energy. Gravity center of the pendulum presents length equal to *l* from the rotation axis O.

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When the test is started the pendulum is placed on the height *hi*. The pendulum is abandoned, and the force is applied on the sample through the chain that connects the sample and the pendulum mechanism. Because of the energy absorption in the sample rupture, this difference can be determined gathering the difference between the final position of the pendulum rupturing a sample and without a sample [2].

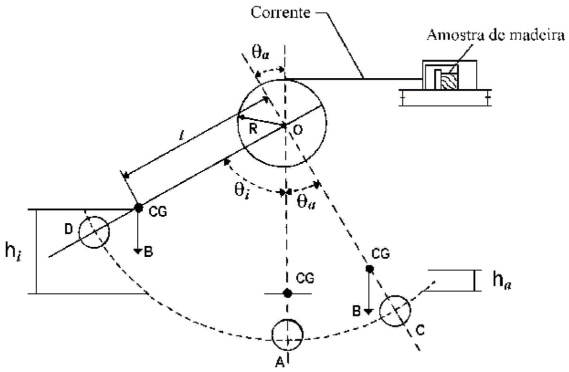

Figure 2. Impact in bending test scheme. Fonte: Stolf [1], adopted from Siqueira [12]

Equations 1 and 2 can be used to calculate the rupture energy *W* and the impact strength in bending f_{bw}, respectively.

$$W = B\,l\,(\cos\theta a - \cos\theta i) \tag{1}$$

Which: *W* is the rupture energy [J], *B* is the pendulum weight in [N], *l* is the pendulum length in [m], and the final and initial angles.

$$f_{bw} = \frac{1000\,W}{b\,h} \tag{2}$$

Which: f_{bw} is the impact strength [kN/m^2], and *b* and *h* are the transversal section of the sample.

This property determination presents some difficulties for the need of a specific machine as shown the figure 1, and because of it, this value is not determined in some cases.

Static bending test shown in the figure 3, can be done using a Universal test machine, being used for determining the conventional value of strength and the modulus of elasticity in static bending [4]. This work was focused on the strength of woos in static bending, and the equation 3 can be used for calculating it.

Figure 3. Static bending test

$$fm = \left(\frac{\left(\frac{Fmax}{2}\right)\left(\frac{L}{2}\right)}{\frac{bh^3}{12}}\right)\left(\frac{h}{2}\right) \tag{3}$$

Which: *fm* is the strength in static bending, *Fmax* is the rupture, *L* is the length in static bending, and *b* and *h* are the transversal section of the sample.

The objective of this research was to use linear, exponential, logarithmic and geometric regression models to verify if it is possible to obtain a relation between the strength in static bending, which is more easily obtained, and the impact strength in bending values.

2. Material and Methods

In order to try estimate the impact strength of wood and the rupture energy through strength of wood in static bending, those testes were carried out using wood gathering the whole range of Strength classes according to the Brazilian code. Table 1 presents these woods as well as their scientific names and correspondent Strength Class. All woods were at 12% moisture content.

Static bending tests were carried out at the Wood Laboratory and Timber Structures (LaMEM), Department of Structural Engineering (SET), School of Engineering of Sao Carlos, University of Sao Paulo. The equipment used to the static bending was the AMSLER 25,000 kgf, capacity. Impact strength tests were carried out in the same laboratory using an impact in bending machine.

To correlate the values found for rupture energy and impact strength (f_{bw}) with strength in static bending (f_m) values, regression models were used (equation 4 until equation 7), which "a" and "b" are the parameters of the functions adjusted by the minimum squares method, "Y" is the independent variable and "X" is the dependent variable. These equations are about Linear, Exponential, Logarithmic and Geometric regressions, respectively.

$$Y = a + b\,X \tag{4}$$

$$Y = a + e^{b\,X} \tag{5}$$

$$Y = a + b\,\ln(X) \tag{6}$$

$$Y = a\,X^b \tag{7}$$

For the determination of the regression model quality, these were evaluated according to analysis of variance (ANOVA); being the non-representativeness of the models admitted as null hypothesis and the representativeness as an alternative hypothesis. The models were considerate with 5% level of significance (α). For a P-value greater than the level of significance, it was considered that the model is not representative and for a P-value less than 5%, it was considered that the model is representative. To evaluate the correlation between the independent variable and the dependent variable was used the coefficient of determination (R^2), this way it was possible to determine which of the models considered best fit the relation tested.

Finally, to calculate and analyze results the Microsoft Excel and Matlab® version 14 were used, respectively.

Table 1. Wood species considered in this work

Specie	Scientific Name	Strength Class
Cedro	*Cedrela fissilis*	D20
Cambará Rosa	*Erisma sp*	D20
Cedro arana	*Cedrelinga catenaeformis*	D30
Catanudo	*Calophyllum sp*	D30
Cupiúba	*Goupia glabra*	D40
Angelim Saia	*Parkia pendula*	D40
Tatajuba	*Bagassa guianensis*	D50
Guaiçara	*Luetzelburgia sp*	D50
Cumaru	*Dipteryx odorata*	D60
Angelim Vermelho	*Dinizia excelsa*	D60

3. Results

Regression models were used to find a correlation between the determined properties. Linear, exponential, logarithmic and geometric relationships between data were analyzed to find a function that best represents their behavior. Tables 2 to 21 presents the regressions determined for the studied species as well as for each combination of the properties analyzed.

Table 2. Regressions to Cedro - f_{bw}

Cedro D20 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	402.266	465.153	120.534	342.806
b	11.410	0.0132	171.778	0.1916
R^2	13.32%	6.50%	9.67%	4.39%
P-value	0.2433	0.4237	0.3252	0.5135

Table 3. Regressions to Cedro - *W*

Cedro D20 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	436.203	486.755	324.128	429.840
b	25.063	0.0282	152.004	0.17
R^2	10.36%	4.77%	8.20%	3.89%
P-value	0.3076	0.4953	0.3572	0.5391

Table 4. Regressions to Cedro arana - f_{bw}

Cedro arana D30 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	559.942	553.903	552.082	547.878
b	-0.0296	-0.0005	0.071	0.0001
R^2	0.03%	0.03%	0.00%	0.00%
P-value	0.9571	0.9561	0.9945	0.9994

Table 5. Regressions to Cedro arana - *W*

Cedro arana D30 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	533.020	527.776	497.536	495.366
b	0.2789	0.005	28.454	0.0508
R^2	0.44%	0.44%	0.86%	0.86%
P-value	0.8375	0.837	0.7744	0.7737

Table 6. Regressions to Cupiúba - f_{bw}

Cupiúba D40 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	509.076	536.688	87.166	303.275
b	16.151	0.0217	251.847	0.34
R^2	69.61%	69.16%	75.53%	75.61%
P-value	0.0007	0.0008	0.0002	0.0002

Table 7. Regressions to Cupiúba - *W*

Cupiúba D40 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	531.634	553.255	366.308	441.854
b	37.977	0.0511	229.923	0.3107
R^2	65.26%	64.80%	71.85%	72.06%
P-value	0.0015	0.0016	0.0005	0.0005

Table 8. Regressions to Tatajuba - f_{bw}

Tatajuba D50 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	912.448	889.764	912.428	899.219
b	-10.469	-0.0119	-41.028	-0.0525
R^2	3.69%	2.92%	2.28%	2.29%
P-value	0.5499	0.5957	0.6393	0.6385

Table 9. Regressions to Tatajuba - *W*

Tatajuba D50 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	940.723	---	---	949.843
b	-35.843	---	---	-0.1577
R^2	9.34%	---	---	13.61%
P-value	0.3339	---	---	0.2378

Table 10. Regressions to Cumaru - f_{bw}

Cumaru D60 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,672.817	1,760.949	1,797.740	2,350.990
b	-0.043	-0.0015	-37.147	-0.0931
R^2	0.03%	0.67%	0.06%	0.80%
P-value	0.9604	0.7998	0.9399	0.7816

Table 11. Regressions to Cumaru - *W*

Cumaru C60 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,637.503	1,716.079	1,671.593	2,014.572
b	0.0483	-0.0027	-0.7529	-0.0712
R²	0.01%	0.34%	0.00%	0.49%
P-value	0.9821	0.8568	0.9876	0.8288

Table 12. Regressions to Cambará Rosa - f_{bw}

Cambará Rosa D20 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	482.353	464.588	299.182	331.511
b	19.071	0.0362	163.068	0.3044
R²	4.88%	5.86%	6.67%	7.75%
P-value	0.49	0.4484	0.4177	0.3808

Table 13. Regressions to Cambará Rosa - *W*

Cambará Rosa D20 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	572.034	547.412	557.952	536.072
b	21.017	0.0419	72.122	0.137
R²	1.08%	1.44%	1.62%	1.95%
P-value	0.7475	0.7104	0.6934	0.665

Table 14. Regressions to Catanudo - f_{bw}

Catanudo D30 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	543.978	556.038	-135.139	229.280
b	0.8624	0.0114	277.816	0.3637
R²	16.51%	15.16%	16.29%	14.70%
P-value	0.1898	0.2109	0.1932	0.2185

Table 15. Regressions to Catanudo - *W*

Catanudo D30 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	542.878	554.001	129.480	321.684
b	22.229	0.0295	276.914	0.3656
R²	17.46%	16.21%	16.84%	15.46%
P-value	0.1764	0.1943	0.1851	0.2059

Table 16. Regressions to Angelim Saia - f_{bw}

Angelim Saia D40 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	156.471	467.498	-941.692	177.545
b	84.830	0.0752	850.878	0.752
R²	36.85%	31.76%	33.87%	29.03%
P-value	0.0363	0.0563	0.0471	0.0706

Table 17. Regressions to Angelim Saia - *W*

Angelim Saia D40 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	702.059	777.055	551.913	685.538
b	94.706	0.078	385.604	0.3189
R²	9.67%	7.20%	10.08%	7.56%
P-value	0.3252	0.3989	0.3146	0.3869

Table 18. Regressions to Guaiçara - f_{bw}

Guaiçara D50 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,227.845	1,191.499	1,120.857	1,045.568
b	-0.0157	0.0003	26.454	0.0376
R²	0.01%	0.02%	0.09%	0.22%
P-value	0.9823	0.9675	0.9282	0.8853

Table 19. Regressions to Guaiçara - *W*

Guaiçara D50 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,277.132	1,241.484	1,268.339	1,198.117
b	-0.3217	-0.0017	-16.707	0.0021
R²	0.32%	0.11%	0.03%	0.00%
P-value	0.861	0.9174	0.9563	0.9939

Table 20. Regressions to Angelim Vermelho - f_{bw}

Angelim Vermelho D60 f_{bw} (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,111.231	1,110.014	1,191.683	1,219.337
b	-0.0195	-0.0003	-23.492	-0.0288
R²	0.05%	0.17%	0.35%	0.59%
P-value	0.9445	0.8991	0.8555	0.8125

Table 21. Regressions to Angelim Vermelho - *W*

Angelim Vermelho D60 *W* (f_m)				
	Linear	**Exponential**	**Logarithmic**	**Geometric**
a	1,100.372	1,098.302	1,146.785	1,159.894
b	0.0067	-0.0003	-15.587	-0.0208
R²	0.00%	0.02%	0.16%	0.31%
P-value	0.9924	0.9639	0.9031	0.8627

As we can see, only to Angelim Saia and Cupiúba f_{bw} values, the models were significant, showing that, in general, the variation of the strength in static bending does not cause effect on the rupture energy values and the impact strength values. These results can be compared with the ones reached by Moreira et al. [13], that evaluated the possibility of estimate those energy parameters using the strength of wood in compression parallel to the grain. It is important to outstanding that to Tatajuba rupture energy was not possible to determine the Exponential and Logarithmic models.

4. Conclusions

Based on the methodology employed and the results achieved, it was possible to conclude that the conventional value of strength in static bending seems not to be a good estimator of the rupture energy and the impact strength in bending, once most of the model were not significant for the woods considered in this research.

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