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Artigos

Analytical study of the dimensional stability of tropical brazilian wood species

Estudo analítico da estabilidade dimensional longitudinal das espécies de madeira tropicais brasileiras

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ABSTRACT

Brazil owns a large vegetal covering and the best utilization of these materials requires physical and mechanical characterization procedures. Equations found in the literature make easier the wood properties determination. At this context, well known authors developed the equation $\beta_l = \beta_t / 23$, being β_l and β_t the longitudinal and tangential shrinkage percentages, for β_l estimation based on the β_t value specially for wood species from the Northern hemisphere. This paper aims to investigate the accuracy of this equation for fifteen tropical Brazilian wood species covering the entire range of hardwood strength classes according to the Brazilian Normative ABNT NBR7190. The average experimental values of β_l and β_t were 7.71% (CV = 26,71%) and 0.73% (CV = 38,76%), respectively. The non-parametric Kruskal-Wallis ANOVA refuted the hypothesis of equivalence between theoretical and experimental β_l values (p-value = 0.0000). A linear regression model fitted to experimental values provided $\beta_l = \beta_t / 9,84$ as optimal solution (p-value = 0.0000, R^2 = 47,23%). According to results it is possible to conclude that the value of longitudinal shrinkage percentage of tropical Brazilian wood species is statistically 2,34 times greater than the value found in the literature, which impacts the design of timber structures procedures increasing the internal stresses in timber structural elements.

Keywords: Longitudinal shrinkage; Tangential shrinkage; Tropical Brazilian wood

RESUMO

O Brasil possui grande cobertura vegetal e o melhor aproveitamento desses materiais requer procedimentos de caracterização física e mecânica. Equações encontradas na literatura facilitam a determinação das propriedades da madeira. Nesse contexto, autores conhecidos desenvolveram a equação $\beta_l = \beta_t / 23$, sendo β_l e β_t as porcentagens de retração longitudinal e tangencial, para estimativa de β_l com base no valor de β_l especialmente para espécies de madeira do hemisfério Norte. Este trabalho tem como objetivo investigar a precisão desta equação para quinze espécies de madeiras tropicais brasileiras cobrindo toda a faixa de classes de resistência da madeira de lei de acordo com o Norma Brasileira ABNT NBR 7190. Os valores experimentais médios de β_l e β_t foram 7,71% (CV = 26,71 %) e 0,73% (CV = 38,76%), respectivamente. A ANOVA não paramétrica de Kruskal-Wallis refutou a hipótese de equivalência entre os valores de β_l teórico e experimental (p-valor = 0,0000). Um modelo de regressão linear ajustado aos valores experimentais forneceu $\beta_l = \beta_t / 9{,}84$ como solução ótima (p-valor = 0,0000, R^2 = 47,23%). De acordo com os resultados, é possível concluir que o valor da porcentagem de retração longitudinal das espécies de madeira tropical brasileira é estatisticamente 2,34 vezes maior que o valor encontrado na literatura, o que impacta nos procedimentos de dimensionamento de estruturas de madeira aumentando as tensões internas nas estruturas de madeira.

Palavras-chave: Retração longitudinal; Retração tangencial; Madeira tropical brasileira

1 INTRODUCTION

According to Steege *et al.* (2016) Brazil presents about 7694 tropical wood species botanically classified and it is estimated that the total number is more than 12655 wood species. Into this number of botanically classified wood species, only a few of them are already physically and mechanically characterized. In addition, Brazil has the greatest certified forests area (6,2 million hectares) and the second greatest reforestation area (2,72 million hectares), being Malaysia the holder of the largest reforestation area (4,04 million hectares) (ITTO, 2018). Tropical woods present high market value, being very useful in the civil construction industry as structural material and edification components because of their physical and mechanical properties (ALMEIDA *et al.*, 2017; CALIL JUNIOR; LAHR; DIAS, 2003; STOLF *et al.*, 2017).

It is observed in Brazil the international tendency of wood structure industrialization, making possible several possibilities of structural systems, and beyond that, the prioritization of hyperstatic structures replacing the isostatic ones (BRITO *et al.*, 2016).

At this context, it is of significant relevance to assess the representativeness of the equation presented by Kollmann and Côté (1968): $\beta_l = \beta_t/23$ (based on insipient statistical methods), which is about the relation between longitudinal and tangential shrinkage percentages (β_l and β_t, respectively), developed based on experimental data of wood species mostly from the Northern hemisphere. This equation has been used for evaluating the structural elements performance into hyperstatic structures.

Dimensional variation because of the moisture content oscillation, estimated by β_l parameter, generates stresses into the structural elements. According to Cassiano *et al.* (2013), this dimensional variation can reach up to six percentage points in low rainfall periods. Other authors have dealt with related topics of this theme highlighting Genoese *et al.* (2013) and Mariño *et al.* (2009).

It is necessary to consider the longitudinal dimensional variation for hyperstatic structures dimensioning, whose approach based on probabilistic and semi-probabilistic methods requires knowing of the relation between β_l and β_t (LUKACS *et al.*, 2016; SOUSA; LOURENÇO; NEVES, 2010; WACKER *et al.*, 2014).

In addition, when it is evaluated the current stresses in historic edification structures, it will certainly occur the introducing of degrees of redundancy, making it necessary to adopt reliable relation between β_l and β_t values (FERREIRA *et al.*, 2013; HOLZER, 2016). The same happens for design of timber structures submitted to the high possibility of earthquakes (BUCHANAN; CARRADINE; JORDAN, 2011; PARISI; PIAZZA, 2015).

Specificities of new technologies in the timber structures field, especially for thin walls (Cross Laminated Timber), also require the development project based on more detailed knowledge of the physical properties of wood, and among them the relation between β_l and β_t values (GIANOLI; FURRER, 2016; ŠMAK; STRAKA, 2014).

At last, it is important to note that the relation between β_l and β_t values is important when numerical simulations are performed for the previous evaluation of the behavior of timber structures (FUEYO; DOMÍNGUEZ; CABEZAS, 2017; GEBHARDT; KALISKE, 2015).

In the mentioned context, this paper aims to investigate the accuracy of the relation between β_l and β_t proposed by Kollmann and Côté (1968) for tropical Brazilian wood species, determining the relation between experimental values of β_l and β_t for fifteen wood species covering the five hardwood strength classes of the Brazilian Normative ABNT NBR 7190 (ABNT, 1997).

2 MATERIALS AND METHODS

2.1 Sampling

For investigating the theoretical equations accuracy, based on robust experimental data, fifteen tropical Brazilian wood species covering the five strength-classes preconized by the Brazilian Normative ABNT NBR 7190 (three wood species for each strength class) were considered. Table 1 presents the wood species considered here.

Table 1 – Tropical Brazilian wood species considered

Strength Classes	Wood Species	Wood density (g/cm^3)
D20	*Pachira quinata*	0,60
D20	*Cedrela* sp.	0,58
D20	*Erisma* sp.	0,62
D30	*Cassia ferruginea*	0,72
D30	*Calophyllum* sp.	0,72
D30	*Ocotea odorifera*	0,71
D40	*Vataieropsis araroba*	0,85
D40	*Goupia glabra*	0,68
D40	*Vatairea fusca*	0,72
D50	*Qualea albiflora*	0,85
D50	*Gossypiospermun praecox*	0,81
D50	*Bagassa guianensis*	0,78
D60	*Dinizia excelsa*	0,85
D60	*Dipteryx* sp.	0,93
D60	*Mezilaurus itauba*	0,86

Source: Authors (2020)

According to Almeida *et al.* (2016), the five strength-classes of the Brazilian Normative ABNT NBR 7190 (1997) cover the entire range of wood densities, which is important for best conclusions concerning this comparative study between experimental and theoretical approaches of dimensional stability of wood materials.

2.2 Determination of experimental values

Experimental values were determined according to the ABNT NBR 7190 (ABNT, 1997) "Design of Timber Structures", in its ANNEX B, that prescribes procedures for wood properties characterization. Wood tangential and longitudinal shrinkage percentages were determined according to the part 3 of Brazilian Normative (ABNT, 1997). Figure 1 illustrates this procedure. This procedure is about measuring the longitudinal e tangential dimensions of twelve standardized specimens of wood at 0% and Fiber Saturation Point, about 21,6% (ALMEIDA *et al.*, 2020) for Brazilian wood species moisture contents, and after that, calculating the percentual modification of those dimensions.

Figure 1 – Illustration of the wood specimen measurement

Source: Authors (2020)

According to this standard normative, at least twelve repetitions should be performed for each test for wood properties characterization. The total of 180 determinations were performed for each experimental variable considered, which corresponds to 540 determinations (among experimental and theoretical values of the three variables considered).

2.3 Statistical analysis

A summary of experimental and theoretical data was made for best presenting these results. Shapiro-Wilk normality test was carried out at 5% significance level for the choice of parametric or non-parametric comparison test to be performed. The non-parametric Kruskal-Wallis Analysis of variance was performed for comparison between experimental and theoretical results (based on Kollmann and Côté (1968) equation).

A linear regression model was fitted for the experimental data (using the ordinary least square method), trying to estimate the longitudinal shrinkage percentage based on the tangential shrinkage result. This model was tested using parametric ANOVA (Analysis of Variance) and the coefficient of determination made possible to measure the accuracy of this model. The statistical analysis was performed using the software R 4.2.1 (R PROJECT, 2022).

3 RESULTS AND DISCUTIONS

After determining the longitudinal and tangential shrinkage (β_l and β_t, respectively) for the fifteen tropical Brazilian wood species considered, as well as calculating the theoretical values of longitudinal shrinkage (β_l') according to Kollmann and Côté (1968), these results were summarized. Table 2 presents the β_l, β_l' and β_t results.

Table 2 – Summary of results for the fifteen tropical Brazilian wood species

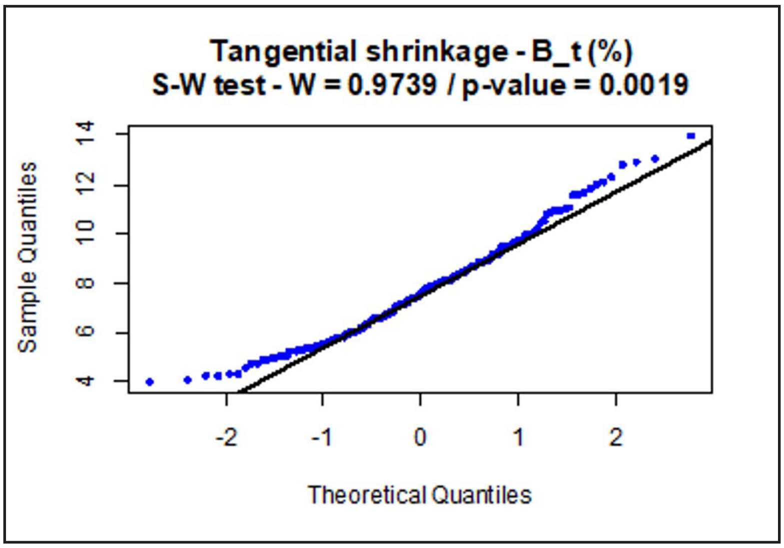
	Mean	CV (%)	Minimum	Maximum	Count
β_t (%)	7.71	26.71	4.02	13.97	180
β_l (%)	0.73	38.60	0.13	1.65	180
β_l' (%)	0.34	26.71	0.17	0.61	180

Source: Authors (2020)

Firstly, to compare the theoretical and experimental values of longitudinal shrinkage determined, it was necessary to evaluate the normal distribution of these data. The Shapiro-Wilk normality test was performed for the three variables studied. Figures 2 to 4 present the normality tests as well as the quantile chart for each variable.

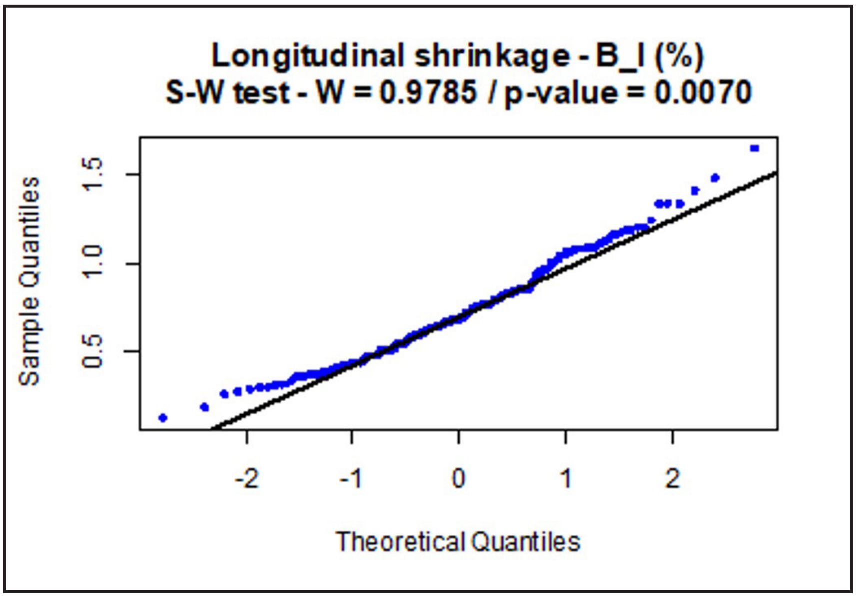
As it can be seen at the Figures 2 to 4, the three normalities tests presented p-values 0.0019, 0.0070 and 0.0011, for β_t, β_l and β_l', respectively. The significant p-values resulted lead to refute the normality distribution of the data. Based on the non-normality of the data and in order to compare experimental and theoretical values of longitudinal shrinkage, the performed the non-parametric Kruskal-Wallis ANOVA at 5% significance level was performed. Figure 5 presents the boxplots of β_l and β_l' data.

Figure 2 – Normality test and quantiles chart for β_t



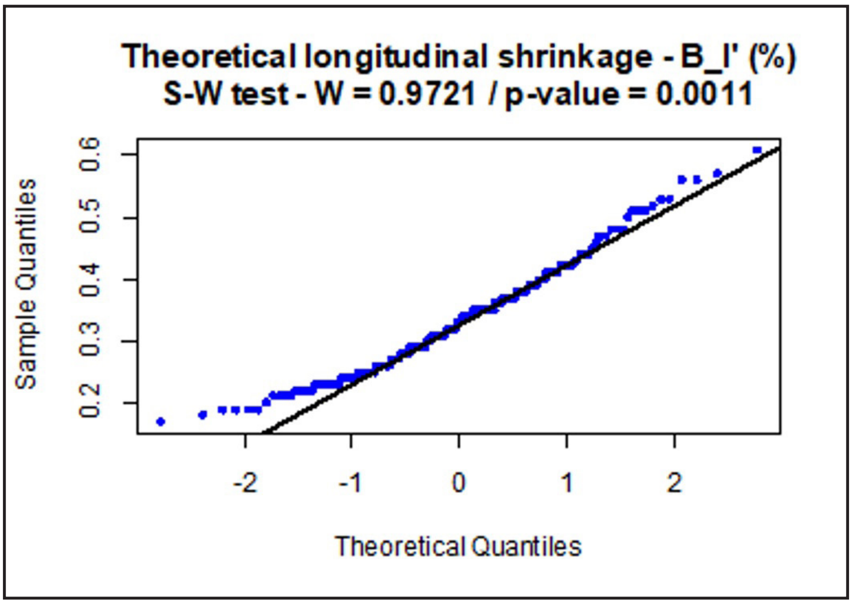
Source: Authors (2020)

Figure 3 – Normality test and quantiles chart for β_l



Source: Authors (2020)

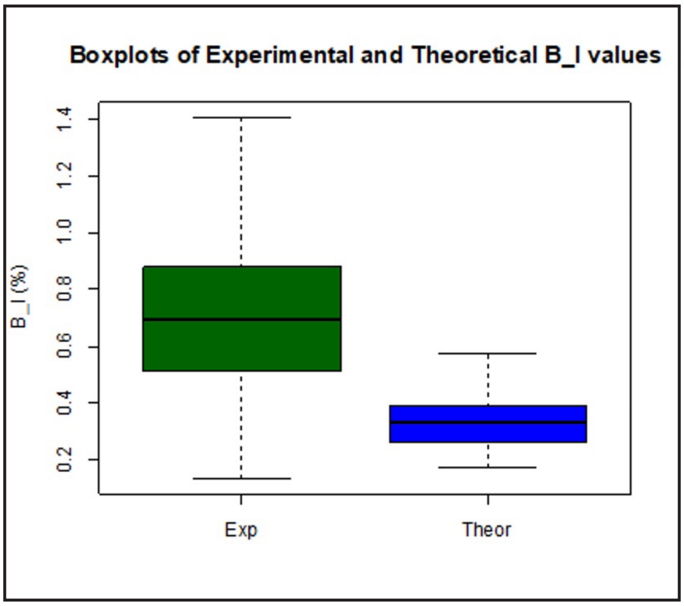
Figure 4 – Normality test and quantiles chart for β_l'



Source: Authors (2020)

The boxplots showed in the Figure 5 brings relevant information about the experimental (green) and theoretical (blue) longitudinal shrinkage percentages. As can be seen here is a large differentiation between these two groups.

Figure 5 – Normality test and quantiles chart for experimental and theoretical values of β_l

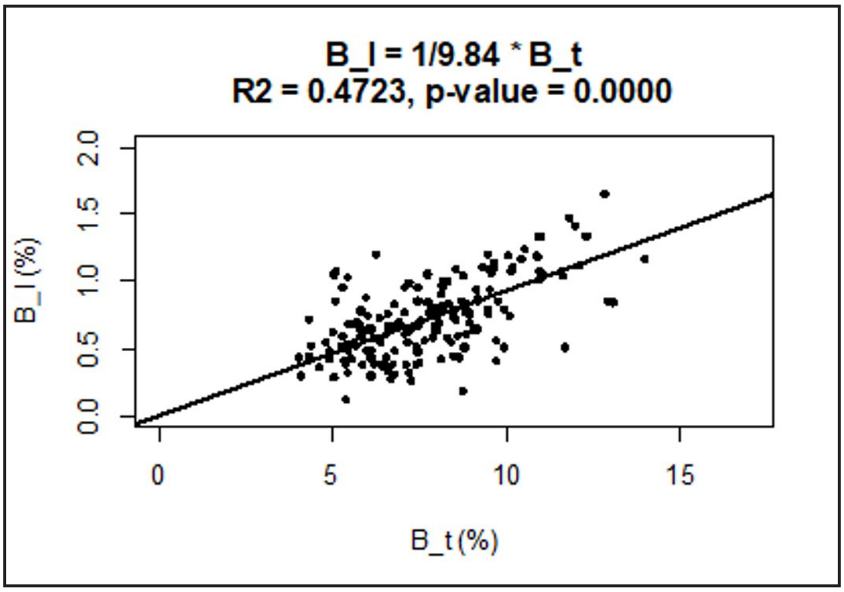


Source: Authors (2020)

Performing the non-parametric ANOVA, the Chi-squared parameter resulted 195,22, being the number of degrees of freedom equal to 1, the p-value resulted was 0.0000. This test leads to refute the null hypothesis (equivalence between groups) and accept that the estimated value of longitudinal shrinkage percentage based on the Kollmann and Côté (1968) equation ($\beta_l = \beta_t/23$) does not provide assertive results for tropical Brazilian wood species.

For β_l estimation based on the β_t, using the ordinary least square method, a linear regression model setting the intercept to zero was fitted. The parametric ANOVA was used for testing the representativeness of this model, in addition, the accuracy of the model can be measured using the coefficient of determination (R^2). Figure 6 presents the linear regression model fitted for β_l and β_t data.

Figure 6 – Scatterplot of β_l and β_t experimental results and the fitted linear regression model



Source: Authors (2020)

As shows the Figure 6, $\beta_l = \beta_t/9.84$ was the best fit for the experimental results of β_l and β_t parameters. This result shows us that the longitudinal shrinkage percentage of the tropical Brazilian wood species covering the entire strength classes of the Brazilian standard Normative is about 2,34 times greater than the theoretical value found in the literature ($\beta_l = \beta_t/23$) (KOLLMANN; COTÉ, 1968), which impacts the design of timber structures procedures. This difference might come from the difference in the microstructure of those materials since amorphous regions of the cellulose are supposed to vary with the wood species considered.

4 CONCLUSIONS

According to results it is possible to conclude that the value of longitudinal shrinkage percentage of tropical Brazilian wood species is statistically 2.34 times greater than the value fund in the literature with 95% confidence level. This information is important for the hyperstatic structures field, where the longitudinal dimensional stability quantity must be used assertively for stresses determinations.

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