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# Influence of the apparent density on the shrinkage of 43 tropical wood species

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**ABSTRACT.** Recently, more wood species are gaining space in market. Hence, it is important to enlarge the utilization of non-traditional woods, which shall be able to replace the most popular species, provided that similar performances are respected. In contrast, the sustainable exploitations of natural resources by timber producers demand alternatives to exchange the use of restricted or blocked tropical wood species (e.g. Araucaria angustifolia) by other timbers, which are liable for commercial certification. This research, based on the test results obtained according to the Brazilian Standard prescriptions (NBR-7190 - Annex B), aimed at evaluating the influence of the apparent density on radial and tangential shrinkages, considering the results for forty-three Brazilian tropical wood species. Usually, this parameter is regarded as necessary to define the timber species to different applications. The results showed low dependence among those variables, considering the information from the literature.

**Keywords:** radial shrinkage; tangential shrinkage; density; wood; Brazilian native timber.

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## Introduction

As an important natural resource, wood is present in our daily lives, from construction (Christoforo et al., 2014; Christoforo, Panzera, Silva, Fiorelli, & Lahr, 2014; Almeida et al., 2015), furniture (Lopes, Nolasco, Tomazello Filho, Dias, & Pansini, 2011), paper industry, and musical instruments to packaging and accessories for sports (Christoforo et al., 2014). Timber, arguably the original building material, retains its prime importance within the construction industry due to its versatility, diversity and aesthetic properties (Lyons, 2010).

Despite its widespread utilization, there are still many gaps in the literature about the technological aspects of the employment of wood (Almeida et al., 2014; 2015). As result, in most cases, both producers and consumers ignore the properties of the species sold and used. Jyske, Mäkinen, and Saranpää (2008) emphasize that wood properties determine the quality of the end-product in industrial processes.

Naturally, the knowledge of such properties provides a more rational use of the material. However, if it is considered the high number of species grown in the Brazil, particularly the Amazon rainforest, according to Calil Junior, Lahr, and Dias (2003), and the tests recommended by the Brazilian standard ABNT NBR 7190 (*Associação Brasileira de Normas Técnicas* [ABNT], 1997) for the complete characterization of wood species, there is a convenience in establishing correlations among the properties to enable the performance of the species that have been gaining space in the market, especially those from certified forest areas.

The density is very relevant for the technological characterization of timber, because its variation affects mechanical properties and dimensional stability (Arganbright, 1971).

A good example is delineated by Saranpää (2009), who argues that density is completely related to the suitability of wood to different end-use purposes.

Over time, the importance of wood density has been verified as an index for the use of wood species in many industrial sectors, e.g., construction and furniture.

Today, measurements of wood density – especially for tropical rainforests – have been important to reduce doubts in carbon stocks estimations (Nogueira, Nelson, & Fearnside, 2005). In addition, Besley (1966), Souza, Carpim, and Barrichelo (1986), and Saranpää (2009) pointed out that density is also one of the most important parameters to evaluate the quality of wood, because of its easy determination and the ability to be correlated to other properties, e.g., strength and stiffness.

The strength and stiffness properties are central in the most appropriate selection of any wood species for structures (bridges, silos, gazebos, arenas, hangars, etc.) and housing. For these construction applications, the shrinkage is another significant parameter to classify and evaluate commercial wood species.

Markwardt and Wilson (1935) highlighted that the shrinkage across the grain (in width and thickness) occurs when wood loses some of the absorbed moisture; furthermore, a greater shrinkage is associated with a greater density. Glass and Zelinka (2010) emphasize that timber is an anisotropic material, because it shrinks (or swells) mostly in the direction of the annual growth rings (tangentially), about half as much across the rings (radially), and only slightly along the grain (longitudinally). According to Walker (2010), high-density woods have proportionately more cell wall and less lumen volume, and so they shrink and swell more. Markwardt and Wilson (1935) also remark that all shrinkages are expressed as percentages of the original or green dimensions of the timber. Glass and Zelinka (2010) still observe that the combined effects of radial and tangential shrinkage can distort the shape of wood pieces because of the difference in shrinkage and in the curvature of annual rings.

In this sense, some studies have related wood properties, especially apparent density, with the shrinkage, both in softwoods (Kärki, 2001; Ivković et al., 2009; Grekin & Verkasalo, 2010; Sharma et al., 2015) and in hardwoods (Ofori, Brentuo, Mensah, Mohammed, & Boamah-Tawiah, 2009; Kiaei, 2012; Oleńska, Tarcicki, Mamiński, & Beer, 2014).

In other different approaches, Koponen, Toratti, and Kanerva (1991), Wu, Hayashi, Liu, Cai, and Sugimori (2006), Leonardon, Altaner, Vihermaa, and Jarvis (2010), Almeida, Huber, and Perré (2014) and Schulgasser and Witztum (2015) studied the microscopic effect of wood shrinkage. Furthermore, Lima, Florsheim, and Longui (2009) studied the influence of spacing between trees on some physical properties of Teca wood (*Tectona grandis*), including the apparent density and the shrinkage percentages. In these studies, the correlation among the mentioned variables is not informed.

However, all the aforementioned studies are particularly focused on Northern Hemisphere woods and, for that reason, there is an information gap about timbers from tropical regions, e.g., Amazon and Atlantic forests. Moreover, these works are distinct from the present study, which is focused on the possibility of an influence of apparent density in relation to radial and tangential shrinkages for tropical woods from Brazil.

In one of the studies hitherto performed on the subject, Kollmann and Côté Junior (1968) aimed at correlating the influence of the apparent density (ρbas) on the percentage of volumetric shrinkage (VS) of timber by means of regression models. Over time, this example was unique, and was not explored by other scientists. The ratio between the apparent density and percentage of volumetric shrinkage obtained from Kollmann and Côté Junior study is expressed by Equation 1. This research does not include the parameters for possible correlation among the studied variables.

$$VS = 26 \bullet \rho bas \quad (1)$$

The evaluation of shrinkage is important for projects of timber structures, because if it is familiar to designers and engineers, this structural scaling will be more accurate and with lower incidence of failures. The main reason for this proposal is that the wood shrinkage tests (radial and tangential) are more expensive than the estimation of these values through the apparent density values, because the density tests are simpler and more popular. Thus, regression models were selected to obtain the information in a cheaper way. In this context, this study aimed at investigating the possibility to establishing, for 43 tropical wood species from Brazil, any correlation between apparent density and total radial and tangential shrinkage percentages.

## Material and methods

This study considered the results of apparent density at 12% of moisture ($\rho_{12\%}$)and the total shrinkage percentages in radial (TRS) and tangential (TTS) obtained for forty-three tropical wood species: abuí

(*Pouteria sp*); angelim amargoso (*Vatairea fusca*); angelim araroba (*Vataireopsis araroba*); angelim ferro (*Hymenolobium sp*); angelim vermelho (*Dinizia excelsa*); angelim pedra (*Hymenolobim paetrum*); angelim saia (*Vatairea sp*); angico preto (*Piptadenia macrocarpa*); branquilho (*Terminalia sp*); cafearana (*Andira stipulacea*); cambará rosa (*Erisma sp*); canafístula (*Cassia ferruginea*); casca grossa (*Ocotea odorífera*); castelo (*Callophyllum multiflorum*); catanudo (*Callophyllum sp*); cedro amargo (*Cedrella odorata*); cedro doce (*Cedrella sp*); cedrorana (*Cedrelinga cataeniformis*); champanhe (*Dypterix odorata*); copaíba (*Copaifera sp*); cupiúba (*Goupia glabra*); cutiúba (*Goupia paraensis*); grápia (*Apuleia leiocarpa*); goiabão (*Planchonella pachycarpa*); guaiçara (*Luetzelburgia sp*); guarucaia (*Peltophorum vogelianum*); ipê (*Tabebuia serratifolia*); itaúba (*Mezilaurus itauba*); jatobá (*Hymenaea sp*); louro preto (*Ocotea sp*); maçaranduba (*Manilkara uberi*); mandioqueira (*Qualea parensis*); oiticica amarela (*Clarisia racemosa*); oiuchu (*Pradosia sp*); parinari (*Parinari excelsa*); piolho (*Tapirira sp*); quarubarana (*Erisma uncinatum*); quina rosa (*Chinchona sp*); rabo de arraia (*Vochysia haenkeana*); sucupira (*Diplotropis sp*); tachi (*Tachinalia sp*); tatajuba (*Bagassa guianensis*); umirana (*Qualea retusa*). For each wood species, 12 specimens were obtained, totalizing 516 samples and 1548 determinations.

To determine the apparent density at 12% moisture content (ρ12%) and retraction percentages in both radial and tangential directions, the prescriptions listed in Annex B of the Brazilian standard ABNT NBR 7190 (ABNT, 1997) were followed. The tests were performed in the Laboratory of Woods and Timber Structures (LaMEM) of the Department of Structural Engineering at the School of Engineering of São Carlos (Eesc) of the University of São Paulo (USP).

### Statistical analysis

To correlate the density to shrinkage percentages (radial and tangential) of the wood, linear and exponential regression models were applied, both with the software Minitab®.

The significance and the quality of the estimates adjustments were evaluated by the analysis of variance (ANOVA) of the regression results, with significance level (α) of 5%, having as null hypothesis (H0) the non-significance of the coefficients in the regression models and the significance of the regression models as an alternative hypothesis (H1). In the formulation of the hypotheses, P-value greater than 5% (0.05) implies accepting H0, refuting it otherwise. The linear and exponential regression models used are expressed by Equation 2 and 3, respectively, where Y is the dependent variable (apparent density), the independent variable X (total shrinkage percentages), and finally, a and b coefficients adjusted by the Least Squares Method.

$Y = a \bullet X + b$ (2)

$Y = a \bullet eb \bullet X$ (3)

## Results and discussions

Table 1, 2, 3 and 4 show the mean values of the apparent density, percentage of the total radial (TRS) and total tangential shrinkage (TTS) percentages for the 43 investigated wood species. It is observed that the small adjustments to the density with 12% of moisture content were adopted through the diagram of Kollmann and Côté Junior (1968), as well as the total shrinkage adopted was an average value per species.

The values of the coefficients of variation obtained of density (ρ12%) and percentage of total radial (TRS) and tangential (TTS) shrinkages for the forty-three tropical wood species, respectively, were in the range of [3.2; 6.5%], [18.4; % 24.7], and [16.5; 22.3%].

**Table 1.** Mean values of the investigated physical properties by species (abuí – angelim pedra).

| Species | $\rho_{12\%}$ (g cm$^{-3}$) | TRS (%) | TTS (%) |
|---|---|---|---|
| Abuí | 0.73 | 5.7 | 10.9 |
| Angelim amargoso | 0.77 | 4.5 | 8.6 |
| Angelim araroba | 0.67 | 3.8 | 6.0 |
| Angelim ferro | 1.16 | 5.0 | 8.3 |
| Angelim vermelho | 1.13 | 5.1 | 8.4 |

**Table 2.** Mean values of the investigated physical properties by species (angelim saia – cedrona).

| Species | $\rho_{12\%}$ (g cm$^{-3}$) | TRS (%) | TTS (%) |
|---|---|---|---|
| Angelim saia | 0.76 | 4.3 | 8.0 |
| Angico preto | 0.89 | 4.3 | 7.7 |
| Branquilho | 0.81 | 4.9 | 9.1 |
| Cafearana | 0.68 | 5.5 | 9.9 |
| Canafístula | 0.86 | 4.1 | 7.7 |
| Cambará rosa | 0.68 | 5.8 | 10.6 |
| Casca grossa | 0.79 | 6.0 | 11.5 |
| Castelo | 0.76 | 4.0 | 6.6 |
| Catanudo | 0.80 | 5.4 | 84 |
| Cedro amargo | 0.51 | 4.0 | 5.3 |
| Cedro doce | 0.51 | 3.6 | 5.2 |
| Cedrona | 0.57 | 3.5 | 6.4 |

**Table 3.** Mean values of the investigated physical properties by species (champagne – jatobá).

| Species | $\rho_{12\%}$ (g cm$^{-3}$) | TRS (%) | TTS (%) |
|---|---|---|---|
| Champanhe | 1.09 | 4.0 | 6.4 |
| Copaíba | 0.70 | 3.6 | 7.0 |
| Cupiúba | 0.84 | 4.3 | 7.2 |
| Cutiúba | 1.15 | 4.9 | 7.8 |
| Grápia | 0.92 | 4.3 | 7.6 |
| Goiabão | 0.94 | 8.9 | 18.8 |
| Guaiçara | 1.00 | 4.0 | 6.0 |
| Guarucaia | 0.92 | 4.1 | 8.1 |
| Ipê | 1.07 | 5.1 | 7.8 |
| Itaúba | 0.91 | 3.9 | 8.3 |
| Jatobá | 1.08 | 3.4 | 6.8 |

**Table 4.** Mean values of the investigated physical properties by species (louro preto – umirana).

| Species | $\rho_{12\%}$ (g cm$^{-3}$) | TRS (%) | TTS (%) |
|---|---|---|---|
| Louro preto | 0.68 | 4.1 | 8.1 |
| Maçaranduba | 1.14 | 6.5 | 8.9 |
| Mandioqueira | 0.86 | 4.8 | 9.4 |
| Oitica amarela | 0.76 | 2.5 | 6.2 |
| Oichu | 0.93 | 5.9 | 9.2 |
| Parinari | 0.79 | 5.4 | 8.6 |
| Piolho | 0.83 | 4.6 | 8.6 |
| Quina rosa | 0.84 | 4.7 | 8.1 |
| Quarubarana | 0.54 | 3.6 | 7.2 |
| Rabo-de-saia | 0.73 | 3.7 | 7.2 |
| Sucupira | 1.10 | 5.8 | 7.1 |
| Tachi | 1.05 | 4.3 | 9.4 |
| Tatajuba | 0.95 | 4.2 | 5.8 |
| Umirana | 0.71 | 3.6 | 6.3 |

It is observed that the species showed wide variation in density (between 0.51 and 1.16 g cm$^{-3}$) for greater coverage and representativeness of the results used in the regression models.

The adjusted regression models for estimating the total shrinkage percentages (tangential and radial) as a function of density are shown in Table 5, 6 and 7, wherein R2 is the coefficient of determination and S and NS refer to the significance and non-significance of the coefficients (by ANOVA) contained in the linear and exponential regression models.

The ANOVA results of the tested regression models showed the impossibility of estimating the total radial and tangential shrinkage percentages by apparent density.

**Table 5.** Linear regression models not passing by the origin of the coordinate system.

| Regression Model | $R^2$ | Significance of the model |
|---|---|---|
| TRS = 1.94 . $\rho_{12\%}$ | 0.10 | NS |
| TTS = 2.15 . $\rho_{12\%}$ | 0.03 | NS |

**Table 6.** Linear regression models passing by the origin of the coordinate system.

| Regression Model | $R^2$ | Significance of the model |
|---|---|---|
| TRS = 5.13 . $\rho_{12\%}$ | 0.22 | NS |
| TTS = 9.3 . $\rho_{12\%}$ | 0.32 | NS |

**Table 7.** Exponential regression models.

| Regression Model | $R^2$ | Significance of the model |
|---|---|---|
| TRS = 4.8 . $e^{0.35 \cdot \rho_{12\%}}$ | 0.13 | NS |
| TTS = 3.2 . $e^{0.42 \cdot \rho_{12\%}}$ | 0.12 | NS |

## Conclusion

Based on the presented results, it is impossible to admit the existence of a strong correlation between the apparent density (at 12% moisture content) and the percentage of total radial and tangential shrinkage for the 43 Brazilian tropical species evaluated.

Consequently, it is noteworthy that determinations for each wood species should be performed in order to define the potential of each one according to its purpose. These estimations make it impossible to generalize the results, of which consisted the focus of this research.

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