

Analysis of the mechanical properties of Caixeta wood in relation to moisture content variations: Implications for ABNT NBR 7190:2022

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Abstract

Due to its high strength-to-weight ratio, wood has significant potential for structural applications. However, as a hygroscopic material, its mechanical properties are influenced by moisture content. This influence is considered in ABNT NBR 7190:2022 through the use of correction factors. The present study experimentally evaluated the influence of moisture content on the mechanical properties of caixeta (*Simarouba amara*), following the testing procedures established by ABNT NBR 7190-3:2022, and compared the results with the values estimated according to Section 5.6 of the Brazilian code for timber structures. The results showed discrepancies between the experimental and estimated values, with different magnitudes among the properties evaluated, reinforcing the need to expand the database on the influence of moisture content on tropical wood species

INTRODUCTION

Wood has considerable potential for structural applications due to its high strength-to-weight ratio, which enables the production of lightweight and efficient structural elements (Bukauskas et al. 2019; Cavaleiro et al. 2026). This characteristic also supports the use of different wood species in engineered wood products, such as glued laminated timber (glulam), including species with lower density (Komariah et al. 2015; Oliveira et al. 2026). In this context, experimental testing and the characterization of native wood species are important steps toward understanding their properties and assessing their potential for structural applications.

However, wood is an anisotropic and hygroscopic material that exchanges moisture with its surrounding environment, resulting in changes in its mechanical properties depending on the environmental conditions to which it is exposed (Mvondo et al. 2022). Below the fiber saturation point, mechanical properties generally decrease as moisture content increases. Studies on Brazilian tropical wood species have shown that the magnitude of this effect varies among the mechanical properties evaluated (Branco et al. 2014; Fraga et al. 2022; Ruthes et al. 2022; Soares et al. 2021). Therefore, properly accounting for moisture content is important both for the characterization of wood properties and for the use of wood in structural applications.

The influence of moisture content is incorporated into procedures for the characterization and design of timber structures through the adoption of reference moisture conditions and correction factors. The Brazilian standard ABNT NBR 7190:2022 establishes 12% as the reference moisture content for the characterization of mechanical properties and provides procedures for adjusting results obtained under different moisture conditions. However, experimental studies indicate that the magnitude of moisture-related changes may vary among wood species and mechanical properties. Branco et al. (2014), Fraga et al. (2022), Ruthes et al. (2022), and Soares et al. (2021) reported different responses among the properties of various Brazilian tropical wood species. Similarly, Nocetti et al. (2015), in their study of *Castanea sativa*, identified differences between experimentally determined values and those estimated using the adjustment factors specified in EN 384. These findings highlight the need for further

experimental investigations into the behavior of different wood species and mechanical properties under varying moisture conditions.

Among tropical wood species of interest, caixeta (*Simarouba amara*) has potential for structural applications, including the production of glued laminated timber (glulam) (Neves et al. 2025). Obtaining information on its mechanical properties under different moisture conditions may contribute to a more comprehensive characterization of the species and provide a basis for its use in engineered wood products. Furthermore, experimentally assessing the influence of moisture content makes it possible to determine whether the strength and stiffness values estimated using the procedures established by ABNT NBR 7190:2022 adequately represent the behavior of the mechanical properties as moisture content varies.

OBJECTIVES

The objective of this study is to experimentally evaluate the behavior of the physical and mechanical properties of caixeta wood (*Simarouba amara*) under different moisture conditions, considering the reference moisture content of 12% adopted by ABNT NBR 7190:2022 and a moisture condition of 25%, defined as slightly above the fiber saturation point experimentally determined for the species. The results aim to contribute to expanding the database on the behavior of the species under different moisture conditions and to assess the representativeness of the correction factors established by the Brazilian Code.

Methodology

The tests for determining the physical and mechanical properties were conducted at the Laboratory of Wood and Timber Structures (LaMEM), Department of Structural Engineering (SET), São Carlos School of Engineering (EESC), University of São Paulo (USP).

The wood samples used in the experiments consisted of caixeta (*Simarouba amara*) obtained from Colíder, in the northern region of the state of Mato Grosso, Brazil. The material was supplied by a timber company located in São Carlos, São Paulo, Brazil, and received in the green condition. It consisted of 13 beams with nominal dimensions of 6 cm × 12 cm × 400 cm.

Following the recommendations of ABNT NBR 7190-3:2022, 30 cm were initially removed from each end of each beam, and the specimens were obtained from the central region. The approximately 340 cm remaining from each beam were divided into two sections of approximately 170 cm. One section was conditioned to obtain specimens at the reference moisture content, close to 12%, while the other was used to obtain specimens tested under a moisture condition slightly above the fiber saturation point. Thus, both moisture conditions were obtained from the same beam, allowing comparison between conditions using material originating from the same piece.

The experimental determination of the fiber saturation point for caixeta resulted in an average value of approximately 24.25%. Considering the proximity of this value to the upper limit of 25% adopted by ABNT NBR 7190:2022 for moisture-content correction procedures, a moisture content of 25% was adopted as the condition close to the fiber saturation point for the analyses performed in this study.

The physical and mechanical properties analyzed in this study are presented in Table 1 and were determined according to the specifications established in ABNT NBR 7190-3:2022. For each evaluated property, 12 specimens were provided for each moisture content, resulting in a total of 360 determinations throughout the study.

Table 1
– Physical and mechanical properties evaluated.

Variável	Description
$\rho(\text{g/cm}^3)$	Apparent density (g/cm^3)
$\epsilon_{rt}(\%)$	Total radial shrinkage (%)
$\epsilon_{tt}(\%)$	Total tangential shrinkage (%)
$f_{c0}(\text{MPa})$	Compression strength parallel to grain (MPa)
$f_{t0}(\text{MPa})$	Tensile strength parallel to grain (MPa)
$f_{t90}(\text{MPa})$	Tensile strength perpendicular to grain (MPa)
$f_{v0}(\text{MPa})$	Shear strength parallel to grain (MPa)
$f_{s0}(\text{MPa})$	Splitting strength (MPa)
$f_m(\text{MPa})$	Conventional bending strength (MPa)
$E_{c0}(\text{MPa})$	Longitudinal modulus of elasticity in compression parallel to grain (MPa)
$E_{t0}(\text{MPa})$	Longitudinal modulus of elasticity in tension parallel to grain (MPa)
$E_m(\text{MPa})$	Conventional modulus of elasticity in static bending (MPa)
$f_{h0}(\text{MPa})$	Hardness parallel to grain (MPa)
$f_{h90}(\text{MPa})$	Hardness perpendicular to grain (MPa)
$W(\text{N.m})$	Toughness ($\text{daN}\cdot\text{m}$)
Source: Prepared by the authors (2026)	

The moisture content was determined, as established by ABNT NBR 7190-3:2022, as the ratio between the mass of water contained in the wood and the mass of oven-dry wood, according to Eq. (1).

$$U (\%) = \frac{m_i - m_s}{m_s} \cdot 100$$

1

Where:

$U (\%)$ is the moisture content of the wood;

m_i is the initial mass of the wood, in grams;

m_s is the oven-dry mass of the wood, in grams.

To assess the representativeness of the moisture correction procedures established in Section 5.6.1 of ABNT NBR 7190:2022, the physical and mechanical property values experimentally obtained at a moisture content of 12% were used to estimate the corresponding values at a moisture content of 25%, adopted as the condition close to the fiber saturation point, using Equations (2) and (3), presented below.

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

2

$$E_{12} = E_U \left[1 + \frac{2 (U - 12)}{100} \right]$$

3

Where:

f_{12} is the strength corrected to a moisture content of 12%;

f_U is the strength obtained from the test at a moisture content other than 12%;

E_{12} is the stiffness corrected to a moisture content of 12%;

E_U is the stiffness obtained from the test at a moisture content other than 12%;

U is the moisture content of the specimen.

Thus, it was possible to compare the experimentally obtained property values at a moisture content of 25% with those estimated from the results obtained at 12%, allowing the representativeness of the correction procedures established by the Brazilian code for *Simarouba amara* wood to be assessed. The

results also allow comparison with those reported in the literature for other wood species, contributing to the analysis of the behavior of the species under variations in moisture content.

Finally, Eq. (4), based on Section 4.6 of ABNT NBR 7190:2022, was used to determine the characteristic value of the compressive strength parallel to grain, (f_{c0}), allowing caixeta to be classified according to the strength classes established by ABNT NBR 7190:2022. For this determination, the 12 specimens used in the compression parallel-to-grain test under the reference moisture condition were considered. The (f_{c0}) values were arranged in ascending order and the expression specified by the code was applied:

$$\max \left(f_{c0,1}; 0,7 \cdot f_{c0,m\u00e9dio} \right) \leq f_{c0,k} \leq f_{c0,m\u00e9dio}$$

$$f_{c0,k} = \left(2 \cdot \frac{\sum_{i=1}^{\frac{n}{2}-1} f_{c0,i}}{\frac{n}{2} - 1} - f_{c0,\frac{n}{2}} \right) \cdot 1,1$$

4

Where:

$f_{c0,1}$ is the first value in the ascending order;

$f_{c0,m\u00e9dio}$ is the mean value obtained from the tests;

$f_{c0,k}$ is the characteristic value.

RESULTS AND DISCUSSION

Table 2 presents the results of the physical and mechanical properties evaluated during the tests on caixeta, considering both moisture conditions: the reference moisture content of 12% (MC-12%) and the moisture content close to the fiber saturation point (MC-25%). It is worth noting that the table presents the mean values obtained from the tests and their corresponding coefficients of variation.

Table 2
– Experimental results obtained for Caixeta.

Variable	TU - 12%		TU - 25%	
	$\bar{x}$	CV (%)	$\bar{x}$	CV (%)
$\rho(\text{g/cm}^3)$	0,35	2,67	0,52	4,05
$\epsilon_{rt}(\%)$	4,35	13,98	4,35	0,14
$\epsilon_{tt}(\%)$	7,27	10,48	7,27	0,10
$f_{c0}(\text{MPa})$	38,37	6,69	31,05	0,07
$f_{t0}(\text{MPa})$	49,98	7,41	40,00	0,07
$f_{t90}(\text{MPa})$	2,46	25,60	1,82	0,24
$f_{v0}(\text{MPa})$	8,15	16,81	5,92	0,24
$f_{s0}(\text{MPa})$	0,40	24,03	0,26	0,31
$f_m(\text{MPa})$	62,36	15,03	53,83	0,14
$E_{c0}(\text{MPa})$	8644,55	24,29	7863,67	0,22
$E_{t0}(\text{MPa})$	8913,79	11,05	8075,58	0,12
$E_m(\text{MPa})$	8858,39	17,85	8026,58	0,15
$f_{h0}(\text{MPa})$	49,94	14,04	43,83	0,13
$f_{h90}(\text{MPa})$	27,78	15,19	23,08	0,12
$W(\text{N.m})$	0,17	41,53	0,30	0,22
Source:Prepared by the authors (2026)				

Based on the results obtained at a moisture content of 12% and the application of Eq. (4), the characteristic value of the compression strength parallel to grain was determined as $f_{c0,k} = 37,59 \text{ MPa}$, classifying caixeta as strength class D30 according to ABNT NBR 7190:2022. This result is noteworthy because ABNT NBR 7190-3:2022 classifies caixeta as a hardwood species belonging to strength class D20. This difference reinforces the importance of expanding the experimental database for native wood species and indicates the relevance of prior evaluation of each timber lot before structural use, in order to verify its strength and enable a more representative classification of the available material.

It can also be observed that the physical and mechanical properties of *Simarouba amara* decrease with increasing moisture content. However, this variation does not occur uniformly among the properties presented. Similar behavior has also been reported in previous studies involving different wood species, in which distinct responses of physical and mechanical properties to variations in moisture content were observed (BRANCO et al. 2014; FRAGA et al. 2022; RUTHES et al. 2022; SOARES et al. 2021).

Table 3 presents a comparison between the experimental values obtained for the mechanical properties of *Simarouba amara* under the condition close to the fiber saturation point and the values estimated using Equations (3) and (4), based on the reference moisture content of 12%. The relative errors between the experimental and estimated values are also presented, allowing the representativeness of the correction factors established by ABNT NBR 7190:2022 to be assessed for the different mechanical properties evaluated.

Table 3
– Comparison of experimental and estimated results for 25% moisture content.

Variável	Experimental	Estimativa	EXP - EST	Erro (%)
	TU - 25%	TU - 25%		
f_{c0} (MPa)	31,05	27,60	3,44	11,09
f_{t0} (MPa)	40,00	35,96	4,04	10,10
f_{t90} (MPa)	1,82	1,77	0,04	2,40
f_{v0} (MPa)	5,92	5,86	0,06	0,95
f_{s0} (MPa)	0,26	0,29	-0,03	11,57
f_m (MPa)	53,83	44,86	8,97	16,66
E_{c0} (MPa)	7863,67	6860,75	1002,91	12,75
E_{t0} (MPa)	8075,58	7074,44	1001,15	12,40
E_m (MPa)	8026,58	7030,47	996,12	12,41
Source: Prepared by the authors (2026)				

The results presented in Table 3 show differences between the experimental values and those estimated using the correction procedure established by ABNT NBR 7190:2022 for the condition close to the fiber saturation point. In general, the estimated values were lower than the experimental values, with differences ranging from 0.95% for f_{v0} to 16.66% for f_m . This behavior, together with the different magnitudes observed among the properties, is consistent with results reported for other tropical wood species, which also indicate distinct responses to variations in moisture content (BRANCO et al. 2014; FRAGA et al. 2022; RUTHES et al. 2022; SOARES et al. 2021).

CONCLUSIONS

The results showed that increasing the moisture content generally led to a reduction in the mechanical properties of caixeta (*Simarouba amara*), although the magnitude of this effect varied among the

properties evaluated. The comparison between the experimental values obtained under the condition close to the fiber saturation point, at 25% moisture content, and the values estimated from the reference moisture content of 12% revealed differences among the properties evaluated. For the conditions and material investigated, the results obtained using the correction factors established by ABNT NBR 7190:2022 differed from the experimentally observed behavior. The expansion and consolidation of experimental results for different species, origins, timber lots, and moisture conditions may contribute to assessing the representativeness of the correction parameters currently established by the standard.

The characterization of the timber lot analyzed resulted in a characteristic compression strength parallel to grain corresponding to strength class D30, in contrast to the D20 classification presented in ABNT NBR 7190-3:2022 for the species. This result highlights the variability that may occur among different lots of the same species and reinforces the importance of expanding the database for the characterization of native wood species.

It should be emphasized that the experimental results obtained refer to only one lot of caixeta from a single origin, with 12 specimens evaluated for each property under each moisture condition. Therefore, the results should be interpreted within the context of the experimental conditions adopted and should not be generalized to different origins, timber lots, or species without expanding the experimental database.

Overall, the results indicate the importance of expanding studies on the behavior of different native wood species from different origins and timber lots under varying moisture conditions. Expanding the experimental database may contribute to a more comprehensive assessment of the applicability of the parameters currently employed and provide a basis for their potential improvement.

Declarations

Author Contribution

N.F. conducted the research and wrote the manuscript under the supervision of F.R. Both authors reviewed and approved the final version of the manuscript.

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Data Availability

The data generated and analyzed during the current study are available from the corresponding author request.

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