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AYOUS WOOD: MAIN USES AND SELECTED PHYSICAL AND MECHANICAL PROPERTIES OF AN INCREASINGLY INTERESTING MATERIAL ORIGINATING FROM CAMEROON

Triplochiton scleroxylon K. Schum, commonly named ayous in Cameroon, is a tree typical of secondary forests in subtropical areas mainly below 500 msl, characterized by an uneven distribution of annual rainfall and the presence of disturbance. This species is widely used in the origin area, and the interest of European markets for ayous wood has steadily increased in the last decades. Despite the interest, only a few studies explored the characterization of this wood for its Cameroonian provenience. This study was carried out to provide a general overview of the available information and to determine some selected physical and mechanical properties of ayous wood coming from the department of Boumba et Ngoko in South-east Cameroon. Physical and mechanical properties and colourimetric parameters of ayous wood were determined following the UNI EN and ISO standards to characterize this wood and to compare with the data from literature. Density, 393 kg/m^3 , resulted consistent with the data reported in the literature; the basic density was lower than those reported in the literature and the difference could be related to wood porosity; volumetric shrinkage was among the lower ones detected by other authors. Colourimetric parameters describing the undifferentiated creamy-yellow colour of the wood were $L^* 73.08$, $a^* 7.39$, $b^* 27.88$. Mechanical properties were in the wide range of data reported by other authors; compression strength 36.6 MPa , static bending strength 61.1 MPa and Brinell hardness 12.2 N/mm^2 . These results extend our knowledge on the physical, colorimetric and mechanical properties of the ayous wood. These results can be

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helpful to highlight differences in the physical and mechanical properties due to the influence of origin on wood physical and mechanical properties. Future studies on this topic are needed to better understand the changes in properties and the characterization of the Cameroonian provenance. The results on the properties of ayous wood give an account of the real possibilities of treatments and technologies that can improve the technological characteristics and the environmentally sustainable use of this resource for the origin and importing countries.

Keywords: density, shrinkage, colourimetric parameters, compression strength, static bending strength, Brinell hardness

Introduction

The ayous wood is obtained from the species *Triplochiton scleroxylon* K. Schum, widely spread in the west area of central Africa. From Guinea, in the west limit of the distribution area, to the Democratic Republic of Congo in the east limit. This tree is typical of secondary forests in subtropical areas mainly less than 500 m a.s.l., characterized by an uneven distribution of annual rainfall and presence of disturbance. In fact, ayous can be considered a pioneer tree species that colonizes abandoned agricultural lands and disturbed forest areas, where it is favorite for its rapid growth rate [Palla and Louppe 2002].

This species is widely used in the origin area, and the interest of European markets for ayous wood has steadily increased in the last decades. In the origin area, ayous is the most common accessory species in Cameroonian agroforestry, due to the commercial interest of the timber [Jagoret et al. 2014]; rural communities use it as firewood for energetic purposes, despite the low heating value [Erakhrumen 2009; Adegoke et al. 2014]; the bark is used as roof cover and the leaves have alimentary importance for humans in traditional cuisine, and in some areas used to feed *Anaphe venata* larvae, an important source of proteins [Orimoyegun and Kadeba 1983]. In the European markets ayous wood is commonly used for light carpentry and woodworking, plywood and multi-laminar wood panels, and to construct wood decks and external cladding of buildings, the latter more common in North and Central Europe [Castro and Zanuttini 2004]. The wood of ayous plays a central role in the exportations of forest products. This species is one of the most important in terms of wood

export from Cameroon, Ghana, Nigeria, and the Ivory Coast. For Cameroon and Ghana, *T. scleroxylon* represents the export of main part of the wood products. For example, in 2003, the export of ayous wood from Cameroon was 86.000 m³ of trunks, mainly to Italy and China, and 282.000 m³ of sawn timber, mainly to Italy and Spain [ITTO 2006; Bosu and Krampah 2005]. The timber quality of this species plays a decisive role in workability and production optimization that are related to tree shape [Mayaka et al. 1995; Danwé et al. 2012] or grain type [Giordano 1988; Tsoumis 1991]. This wood, characterized by poor durability, is also interesting for the physical and chemical modifications, finalized to improve its technological features. As a result of these practices, outdoor use of ayous wood can be extended, and innovative technology and processing play a crucial role for future development and diffusion of this material [Gennari et al. 2021]. Despite the interest of the European market on ayous, only a few studies explored the characterization of this wood specifically from Cameroon. This study was carried out to determine some selected physical and mechanical properties and colorimetric parameters of ayous wood coming from the department of Boumba et Ngoko in south-east Cameroon.

Findings on the properties of the ayous wood can contribute to provide interesting data that can be used as an important starting point for setting treatments and technologies capable of improving technological characteristics and possibilities of use. On the other hand, the findings can be used for comparison with other species. Furthermore, the results were compared with those of recent and past literature, to gain a better understanding of the physical and mechanical characteristics of a material that plays an important role both in the African wood feedstock and in the European semifinished wood market.

Materials and methods

2.1. Specimens for physical and mechanical characterization

Wood samples were realized according to the reference standard ISO 3129 [2019] from planks of ayous wood coming from Cameroon, department of Boumba et Ngoko. Defect-free samples were cut from planks supplied by a sawmill. Planks were selected according to the direction of the grain.

Specimen preparation sticks, showing radial and tangential longitudinal surfaces, were taken from 10 planks. The sticks and samples were conditioned at 65% relative humidity and 20 °C for several weeks prior to testing, in order to equilibrate the wood to a moisture content close to 12%. The wood samples used for physical characterization and the ultimate axial compression strength test were 20 × 20 mm in cross section and 30 mm in length. Samples for ultimate static bending strength were 20 × 20 mm in cross section and 300 mm in length. The samples used in the Brinell hardness determination were 50 × 20 mm in cross section and 300 to 400 mm in length. The samples for color measurement were 50 × 10 mm in cross section and 300 to 400 mm in length.

2.2 Determination of moisture content (MC)

The method applied to determine the moisture content of the test pieces was consistent with the reference standard UNI ISO 13061-1 [2017]. The samples were weighted using a precision scale (0.001 g tolerance), then they were dried to a constant mass in a ventilated oven for 24 + 6 h at a temperature of 103 ± 2 °C. The samples were then closed in weighing jars to cool and then again weighted. The moisture content of each sample was calculated using the following formula:

$$W\% = \frac{m_1 - m_2}{m_2 - m_0} * 100$$

Where:

m_0 is the mass of the jar, in g;

m_1 is the mass of the jar containing the sample before drying, in g;

m_2 is the mass of the jar containing the sample after drying, in g.

2.3. Physical properties

Wood density and basic density

To determine the density of wood, the applied procedures follow the reference standard UNI ISO 13061-2 [2017]. The wood density was determined at the moisture content at the time of the test, and then adjusted to 12% of moisture content. Samples were weighted using a precision scale (tolerance 0.001 g) and measured using a caliper (tolerance 0.01 mm). The

moisture content of the samples was determined. The cross section and length of the specimens were collected to determine the volume. The density of wood in the moisture content at the time of the test was calculated using the following formula:

$$\rho_W = \frac{m_W}{a_W * b_W * l_W} = \frac{m_W}{V_W}$$

Where:

m_W is the mass, in kg, of the specimen at moisture content W;

a_W, b_W and l_W are the dimensions, in cm, of the specimen at moisture content W;

V_W is the volume, in m³, of the sample at moisture content W.

To adjust the density to a 12% moisture content was used the following formula:

$$\rho_{12} = \rho_W * \frac{1 + 0.01(12 - W)}{1 + 0.01(12 - W) \frac{\rho_W}{\rho_{H_2O}}}$$

Where:

W is the moisture content at the time of test, in %;

ρ_{H_2O} is water density, 1000 g/cm³.

To determine the basic density the following formula was used:

$$\rho_y = \frac{m_0}{a_{max} * b_{max} * l_{max}} = \frac{m_0}{V_{max}}$$

Where:

a_{max}, b_{max} and l_{max} are the dimensions in m of the sample at a moisture content equal to or greater than the fiber saturation point;

V_{max} is the green volume of the specimen in m³.

Radial and tangential shrinkage

Linear shrinkages were determined following the standardized procedure indicated in the international standard ISO 13061-13 [2016].

The shrinkage anisotropy factor was calculated as the ratio between tangential and radial shrinkages. The samples had a rectangular prism form, with a cross section of 20 × 20 mm and 30 mm along the grain.

To determine the fiber saturation point, the samples were soaked in distilled water until dimensional stability, then the radial and tangential dimensions were measured with an accuracy of 0.02 mm. To determine the dimensions under dry condition, samples were oven dried to constant mass at 103 ± 2 °C for 24 + 8 h. After cooling, the radial and tangential dimensions were measured. The linear shrinkage in percent (β) was calculated with the following formulas for the radial and tangential directions:

$$\beta_r = \frac{l_{r1} - l_{r2}}{l_{r1}} * 100$$

Where:

β_r is the linear shrinkage in the radial direction in percent;

l_{r1} and l_{r2} are the radial dimensions of the test piece in mm, in fully saturated and oven dried conditions, respectively.

$$\beta_t = \frac{l_{t1} - l_{t2}}{l_{t1}} * 100$$

Where:

β_t is the linear shrinkage in the tangential direction in percent;

l_{t1} and l_{t2} are the tangential dimensions of test piece in mm, in fully saturated and oven dried conditions, respectively.

Color characterization

Color was measured using an X-Rite CA22 reflectance spectrophotometer. The measures were performed under the following conditions, as indicated in the CIELAB color system [UNI EN ISO/CIE 11664-4:2019]: illuminant D65, standard observer 10°, geometry of measurement 45° / 0°, spectral range 400–700 nm, measurement diameter 4 mm, white reference supplied with the instrument. 30 points were measured to take into account the variability of the wood colour, as already discussed [Lo Monaco et al. 2011]. For each point, three measures were made; so 180 measures were collected.

2.4 Mechanical properties

Ultimate axial compression strength

The test was carried out according to the reference standard UNI ISO 3787 [1985]. Each sample was measured in the cross section with 0.1 mm

of tolerance, and then the load was applied. The load application gradient agreed to reach the ultimate axial compression strength in 1.5–2 minutes, and the maximum value of the load was collected for each test piece. According to the reference standard, the moisture content of each test piece was collected immediately after the test using the standardized methods reported in UNI ISO 13061-1 [2017]. The ultimate axial compression strength has been calculated for each sample with the following formula:

$$\sigma_W = \frac{P_{max}}{a * b}$$

Where:

σ_W is the axial compression strength, in MPa;

P_{max} is the maximum load applied, in N;

a and b are the radial and tangential dimensions, in mm.

The observed axial compression strength was adjusted to 12% of moisture content, as indicated in the standard for moisture contents of $12 \pm 3\%$, using the following formula:

$$\sigma_{12} = \sigma_W [1 + \alpha (W - 12)]$$

Where:

α is the correction factor for the moisture content, equal to 0.04;

W is the moisture content of wood.

Ultimate tensile strength in static bending

To determine the ultimate tensile strength in static bending, the reference standard ISO 13061-3 [2014] was applied. The test pieces had a cross section of 20×20 mm and a direction parallel to the fiber of 300 mm; width and height of the specimens were measured in the middle span with 0.01 mm of tolerance. The test was carried out with a span of 260 mm, and the transverse load was applied at middle span to the radial surface of the samples. The load was applied continuously at a crescent rate so that the test piece was broken in 1.5–2 minutes from the start of the loading. After the test, as soon as possible, an undamaged portion was collected from each sample to determine the moisture content and density according to UNI ISO 13061-1 [2017] and UNI ISO 13061-2 [2017], respectively. The modulus of rupture of each sample was calculated using the following formula:

$$\sigma_{b,W} = \frac{3 * P_{max} * l}{2 * b * h^2}$$

Where:

$\sigma_{b,W}$ is the modulus of rupture (ultimate strength in static bending), in MPa, at the MC at the time of the test;

P_{max} is the maximum load, in N;

l is the span (distance between the supports), in mm;

b is the width of the test piece, in mm;

h is the height of the test piece, in mm.

The ultimate tensile strength observed in static bending was adjusted to 12% of moisture content, as indicated in the standard for moisture contents of $12 \pm 3\%$ using the following formula:

$$\sigma_{b,12} = \sigma_{b,W} [1 + \alpha (W - 12)]$$

Where:

α is the correction factor for the moisture content, equal to 0.04;

W is the moisture content of the wood.

Brinell hardness

Brinell hardness is determined by applying a specific load to the face of the sample using a spherical indenter with a diameter of 10 mm. After the test, the sample is left to recover; then, the diameter of the residual indentation is used to determine the resistance to indentation. The test conducted to determine the resistance to indentation followed the reference standard UNI EN 1534 [2020]. The samples were equilibrated with a moisture content of 10.4 %. The test pieces had a side of 50 mm and variable length. The indentations were performed in the central area of the samples, and the distance between the center of the indentations and the sides of the sample was at least 20 mm. The load applied to the indenter was 1 kN, the force was applied at an increasing rate to reach the nominal value of 1 kN after 15 ± 3 sec; then, the load was maintained at this value for 25 ± 5 sec. After that, the indenter was immediately removed. The samples were left to recover for at least 3 minutes after the test and then two diameters of the residual indentation were measured, one along the grain direction and the other across the grain direction, with a tolerance of 0.01 mm. Brinell hardness was calculated using the following formula:

$$HB = \frac{2 * F}{\pi * D * [D - \sqrt{D^2 - d^2}]}$$

Where:

HB is the Brinell hardness in N/mm²;

F is the maximum load applied force, in N;

D is the diameter of the indenter, in mm;

d is the residual diameter of the indentation, in mm (average value of the measured two diameters).

Results and discussion

3.1 Physical properties

The main findings of the physical properties are presented in Table 1. The wood density does not show consistent differences with those reported in the literature, with a detected value of 393 ± 20.3 kg/m³ coherent with the range of data for ayous. The basic density is lower than the results reported in the literature (Table 2). The observed difference, ranging from 5 to 21%, could be related to differences in wood porosity due to different widths of the growth rings influenced, for example, by the social position of the tree, density of the stand, and other characteristics [Bosu and Krampah 2005; Giordano 1988; Falemara et al. 2012; Tourunen 2018; Gérard et al. 1988; Allegretti and Ferrari 2007; Gerry and Miller 1954; Reyes et al. 1992; Rijdsijk and Laming 1994; Fabiyi et al. 2011; Bonoma et al. 2010; Jamala et al. 2013; Olorunnisola 2018; Simo Tagne 2014; Ngohe-Ekam et al. 2006].

Table 1. Physical properties of Ayous wood at 12% moisture content

	Samples n.	Mean Value	St. Dev.	Max. Value	Min. Value
Density (kg/m ³)	30	393.4	20.3	447.3	371.7
Basic density (kg/m ³)	30	326.9	17.8	373.2	308.1
Radial shrinkage β_r (%)	30	2.8	0.3	3.4	2.4
Tangential shrinkage β_t (%)	30	5.0	0.3	5.7	4.3
Volumetric shrinkage β_v (%)	30	7.6	0.4	8.5	7.0

Substantial differences were not found between the results of the linear shrinkage tests and the data reported in the literature. However, volumetric shrinkage showed a difference of approximately 2 points % between the results obtained and those reported by some authors (Table 2). The shrinkage anisotropy factor obtained from the test results is 1.8 ± 0.18 . This value is similar to the shrinkage anisotropy factor calculated for ayous wood reported in the literature. It indicates that this material suffers limited deformation (resulting from the tangential and radial shrinkage ratio) due to environmental thermo-hygrometric variations and, coupled with low volumetric shrinkage, greater stability than other similar species. [Bosu and Krampah 2005; Gérard et al. 1988; Allegretti and Ferrari 2007; Gerry and Miller 1954; Jamala et al. 2013; Simo Tagne 2014; Glass and Zelinka 2010; Simpson and TenWolde 1999]. Table 2 provides an overview of the physical properties from the literature. As shown in Table 2, the wood density has a range of variation from 290 to 500 kg/m³; the basic density varies from 345 to 396 kg/m³; radial shrinkage varies from 2.5 to 4.1%; tangential shrinkage varies from 4.2 to 6.6% and volumetric shrinkage has a range of variation from 6.9 to 9.8%. To provide information from another perspective, it can be useful to consider the physical properties of other woods, for example, poplar and birch, commonly substituted by ayous wood. The physical properties of birch reported by Giordano [1988] are from 530 to 780 kg/m³ for wood density, with an average value of 650 kg/m³; also, for poplar, shows for wood density from 260 to 520 kg/m³, with an average value of 340 kg/m³, and a basic density from 280 to 420 kg/m³, with an average value of 290 kg/m³. In addition, Tsoumis [1991] shows for birch a density of 730 kg/m³ and for shrinkages a value of 5.3%, 7.8%, and 14.2% respectively for radial, tangential, and volumetric shrinkages, while, for poplar, a density of 340 kg/m³ and 9.7% for volumetric shrinkage. The characteristics that ayous shares with poplar and birch are low density, light colour and low durability. They are mainly used in products and services that exclude heavy construction or high-stress applications.

Table 2. Physical properties of ayous wood reported in the literature and referred to 12% moisture content

Reference	Origin	Density (kg/m ³)	Basic density (kg/m ³)	Shrinkages (%)		
				Radial	Tangential	Volumetric
Falemara et al. [2012]	Nigeria	407.5	-	-	-	-
Giordano [1988]	unspecified	350- 500 (420)	-	-	-	-
Tourunen [2018]	unspecified	320- 440	-	-	-	-
Gèrard et al. [1998]	unspecified	320- 440	-	2.9	5	9.8
Allegretti and Ferrari [2007]	Gabon/Cameroon	400	-	3.2	5.6	9.1
Glass and Zelinka [2010]	unspecified	-	-	3	5.4	9.2
Gerry and Miller [1954]	unspecified	320- 400	-	2.5	5.1	7.8-9.5
Simo Tagne [2014]	Cameroon	-	396	4	5.4	9.7
Simpson and TenWolde [1999]	unspecified	-	-	3	5.4	9.2
Reyes et al. [1992]	Cameroon/Gabon	320	-	-	-	-
Rijsdijk and Laming [1994]	unspecified	290- 390 (340)	-	-	-	-
Fabiyi et al [2011]	Nigeria	384	-	-	-	-
Bonoma et al. [2010]	Cameroon	342.7	-	-	-	-
Jamala et al. [2013]	Nigeria	372.5	-	-	-	6.9
Olorunnisola [2018]	Nigeria	370- 450	-	-	-	-

Reference	Origin	Density (kg/m ³)	Basic density (kg/m ³)	Shrinkages (%)		
				Radial	Tangential	Volumetric
Ngohe-Ekam et al. [2006]	unspecified	-	345	-	-	-
Bosu and Krampah [2005]	unspecified	320-440	-	2.5-4.1	4.2-6.6	-
Benoit [2014]	unspecified	380	-	3	5.2	8.2

Colour

Ayous wood is indicated with little or no difference in colour between heartwood and sapwood, with a creamy white or pale yellow colour for natural wood [Giordano 1988; Olorunnisola 2018]. To describe the colour in quantitative terms, the CIELAB colour system was used and the colour parameters were determined (Table 3). The component L*, related to the lightness of the colour, the component b* to the yellow component, are significantly higher than the component a* which pertains to the red component of the wood colour. These parameters suggest a light colour with a yellow component.

Table 3. Ayous colour characterization

	L*	a*	b*
Mean	73.08	7.39	27.88
Standard deviation	1.23	0.37	0.65

3.2. Mechanical properties

The results of the mechanical tests conducted, shown in Table 4, are within the range of variation of those reported in the literature. The compression strength ranged from 32.6 to 39.2 MPa, higher than the values reported by Giordano [1988] and Gérard et al. [1998] (Table 5). The mean value of the static bending strength was 61.1 ± 7.7 MPa, and was intermediate between the values found in the literature (Table 5) [Adegoke et al. 2014; Bosu and Krampah 2005; Giordano 1988; Gérard et al. 1998; Jamala et al. 2013]. The Brinell hardness was 12.2 ± 2.1 N/mm² and indicated that this wood is

easily indented. Laskowska [2020] observed that hardness depends on density and Sydor et al. [2020] specified that plastic deformation due to the indenter was higher in low-density wood.

Table 5 provides an overview of the mechanical properties of ayous from the literature. As shown in Table 5, the compression strength and the static bending strength have a range of variation, respectively, from 24 to 43 and from 52 to 110 MPa; for Brinell hardness, the only available value, was similar.

Other species were compared due to similar final use, birch and poplar. Despite the obvious differences in wood density and the consequent effects on mechanical properties, birch was taken into account because it has the same commercial purposes. Mechanical properties of birch registered by Giordano [1988] reported that the compression strength ranged from 41 to 73 MPa, with an average value of 59 MPa; and the static bending strength from 78 to 137 MPa, with an average value of 120 MPa. Furthermore, poplar compression strength was reported to range from 21.5 to 41 MPa, with an average value of 31.5 MPa; and the static bending strength of 39 to 69 MPa, with an average value of 55 MPa. Furthermore, Tsoumis [1991] indicates for birch 50 MPa for compression strength and 144 MPa for static bending strength; for poplar reports 35 MPa for compression strength and 64 MPa for static bending strength.

Interestingly, these report very different values for the mechanical properties studied [Bosu and Krampah 2005; Giordano 1988; Tourunen 2018; Gérard et al. 1998; Jamala et al. 2013] and a very wide range of variation. Furthermore, considering the few studies on the mechanical characterisation of ayous wood and the influence of the growth conditions on the mechanical properties, it is necessary to extend the studies to provide reference values for both the species and the areas of origin. This investigation is an important step in the mechanical characterisation of ayous from Cameroon, since the variation in mechanical properties indicated in the literature is considerably large.

Table 4. Mechanical properties of Ayous wood at 12% moisture content

	Samples n.	Mean Value	St. Dev.	Max. Value	Min. Value
Compression strength (MPa)	35	36.6	1.5	39.2	32.6
Static bending strength (MPa)	40	61.1	7.7	73.7	42.6
Brinell hardness (N/mm ²)	73	12.2	2.1	17.5	8.5

Table 5. Mechanical properties of ayous wood reported in the literature referred to 12% moisture content

Reference	Compression strength (MPa)	Static bending (MPa)	Brinell hardness (N/mm ²)
Giordano [1988]	31	74	-
Tourunen [2018]	-	-	12.7
Gèrard et al. [1998]	30	57	-
Jamala et al. [2013]	-	30.9	-
Bosu e Krampah [2005]	24-43	52-110	-
Adegoke et al. [2014]	-	79	-
Benoit [2014]	30	73	13

Conclusions

The ayous wood from Cameroon studied confirms the general physical characteristics of the species:

- density in the anhydrous state 355 (± 20) kg/m³, density 393 (± 20) kg/m³, basic density 327 (± 18) kg/m³;
- volume shrinkage 7.8% (± 0.4), radial shrinkage 2.8% (± 0.3), tangential shrinkage 5.0% (± 0.3). The shrinkage coefficient was similar to those reported in the literature.
- Ayous from Cameroon is a light wood, with moderate susceptibility to deformation when changing moisture content.
- The creamy colour of this undifferentiated heartwood wood showed the following colour parameters: L* 73.08 (± 1.23), a* 7.39 (± 0.37), b* 27.88 (± 0.65).
- Mechanical properties were compression strength 36.6 MPa, static bending strength 61.1 MPa, and Brinell hardness 12.2 N/mm².

Generally, the data found in this study were in the range of those of the species, but this range is large.

These results extend our knowledge on physical, colourimetric and mechanical properties of the ayous wood. Furthermore, comparison with the data of the selected properties reported in the literature contributes to designing a general overview of this important wood species. These results can be helpful to highlight differences in the physical and mechanical properties due to the influence of provenience on wood technological properties.

The results on the properties of ayous wood give an account of the real possibilities of treatments and technologies that can improve the technological characteristics and the possibilities of environmentally sustainable use of this resource for the origin and importing countries.

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List of standards

- ISO 13061-13:2016** Determination of radial and tangential shrinkage – Physical and mechanical properties of wood – Test methods for small clear wood specimens. International Organization for Standardization, Geneva, Switzerland
- ISO 13061-3:2014** Determination of ultimate tensile strength in static bending - Physical and mechanical properties of wood – Test methods for small clear wood specimens. International Organization for Standardization, Geneva, Switzerland
- ISO 3129:2019** Wood – Sampling methods and general requirements for physical and mechanical testing of small clear wood specimens. International Organization for Standardization, Geneva, Switzerland
- UNI EN 1534:2020** Wood flooring and parquet - Determination of resistance to indentation - Test method. Ente Nazionale Italiano di Unificazione, Milano, Italy
- UNI EN ISO/CIE 11664-4:2019** Colorimetria - Parte 4: Spazio colore L* a* b* CIE 1976. Ente Nazionale Italiano di Unificazione, Milano, Italy
- UNI ISO 13061-1: 2017** Physical and mechanical properties of wood – Test methods for small clear wood specimens Determination of moisture content for physical and mechanical tests. Ente Nazionale Italiano di Unificazione, Milano, Italy
- UNI ISO 13061-2:2017** Physical and mechanical properties of wood – Test methods for small clear wood specimens Determination of density for physical and mechanical tests. Ente Nazionale Italiano di Unificazione, Milano, Italy
- UNI ISO 3787:1985** Wood - Test methods - Determination of ultimate stress in compression parallel to grain. Ente Nazionale Italiano di Unificazione, Milano, Italy

Acknowledgements

Financial support and planks for this research were provided by VASTO LEGNO srl.

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Authors participated equally in research and writing the manuscript. All authors read and approved the final manuscript.

Submission date: 14.04.2021

Online publication date: 31.08.2022