The physicomechanical and thermal properties of Algerian Aleppo pine (*Pinus halepensis*) wood as a component of sandwich panels

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Aleppo pine (*Pinus halepensis* Mill.) is the main forest species of Algeria occupying more than 35% of the total forest area of the country. However, the physicomechanical and thermal characteristics of Algerian *P. halepensis* wood are not well-known. This research investigates the physical (moisture, density, swelling, and shrinkage), mechanical (bending strength and modulus of elasticity), and thermal (mass loss under combustion and pyrolysis as well as thermal conductivity) properties of *P. halepensis* wood from the Darguina (Bejaia) forest in Algeria. The results showed that Algerian *P. halepensis* wood with a mean density of 540 kg m^{-3} has good dimensional stability in swelling and shrinkage, with 116.43 MPa bending strength and a modulus of elasticity of 17,520 MPa. The wood shows a good thermal resistance under low-temperature range and has a thermal conductivity of 0.21 W m^{-1} K^{-1}. The overall results indicate that Algerian *P. halepensis* wood may be commercially exploited for construction and insulation applications, namely in the production of sandwich composites.

Keywords: Density, Bending Strength, Thermal Conductivity, Shrinkage, Swelling

Introduction

Wood is a natural cellular material characterized by heterogeneous structural features, porosity and high hygroscopicity. The mechanical behavior of wood depends on its specific anatomical structure, density and moisture content as well as on tree related variables such as age and growth characteristics (Tsoumis 1991, Ross 2010). The properties of wood are species specific and a careful characterization is therefore necessary prior to application of wood.

The Aleppo pine (*Pinus halepensis* Mill.) belongs to the *Pineaceae* family and is a species that quickly colonizes abandoned lands (Fekih et al. 2014, Mauri et al. 2016). It is a pyrophyte species naturally distributed throughout the Mediterranean basin, including North Africa, Spain, France, and Italy (Liphschitz & Biger 2001). More than 2.5 million hectares of *P. halepensis* are lo-

cated in semi-arid and arid regions (Maestre & Cortina 2004), at low altitudes and along the coast (Mitsopoulos & Dimitrakopoulos 2007). *P. halepensis* is considered as the most important and dominant forest tree species in Algeria, covering an estimated area of 1,158,533 ha (Benouadah et al. 2019) growing in all bioclimatic zones, with a predominance in the semi-arid zone, from East to West, and from sea level to the major mountain ranges (Ricard & Oliva 1995). Its detailed distribution in Algeria is as follows: in the Eastern region: in the forests of the Tébessa and Aures mountains; in the Central region: in the forests of Ouarsenis; in the Western region: in the wooded mountains of Saida, Mascara, Sidi Bel Abbes; and the Atlas Sahara: in the forests of the Ouled Nail mountains, near Djelfa and Djebel Amour, near Aflou (Nahal 1962).

The easy adaptation of *P. halepensis* to various eco-climatic conditions and poor soils makes the species a desired tree for reforestation programs in Mediterranean countries (Elaieb et al. 2017, Liphschitz & Biger 2001, Montero et al. 2001, Sghaier & Ammari 2012). Silvicultural treatments of the species have been investigated in different countries (Montero et al. 2001) for forest management. The chemical properties of *P. halepensis* wood showed that it is a rich source of resin acids and cyclic polyols (Benouadah et al. 2019). Its physicomechanical properties are similar to those of maritime pine wood (*Pinus pinaster* – Thibaut et al. 1992). Therefore, a replacement of maritime pinewood with *P. halepensis* wood may be considered for the production of construction timber, plywood, and particle board, particularly for North African countries.

In recent years, *P. halepensis* wood has been studied as face (skin) layers for the production of cork sandwich composites because it is a renewable and widely available material in Algeria (Lakreb et al. 2015a, 2015b, Limam et al. 2016). The sandwich composites or sandwich panels are interesting materials for construction because they have high strength-to-weight ratio, high flexural stiffness, and low weight (Gibson & Ashby 1999); therefore, they find a variety of applications in construction. The material properties of sandwich panels including dimensional stability, thermal conductivity, and mechanical strength depend on the properties of face and core layers (Gibson & Ashby 1999). The current research on the wood characteristics of *P.*

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halepensis wood is still scarce namely regarding the wood physicomechanical and thermal characteristics of the species in Algeria.

The aim of this study is to fill this gap and for the first time determine the physical and mechanical as well as the thermal properties of Algerian *P. halepensis* wood to lay the groundwork for development of future applications and further research, particularly on cork-based sandwich composites.

Material and methods

Materials

The *P. halepensis* wood samples were obtained from the region of Darguina (Bejaia, Algeria) by felling two 70-year-old trees with straight stems having an acceptable sanitary state and over 40 cm diameter at 1.50 m above the ground. The Darguina region has an annual temperature of 16.2 °C, an annual precipitation of 771 mm, and a climate type of "Csa" according to Köppen and Geiger classification. Sawing of the wood, sample preparation and physicomechanical tests were performed at the Research Unit of Processes, Material and Environment (URMPE) of the University of Boumerdès (north Algeria). The sampling methods adopted in this work comply with French and international standards (B51-003 1985 and ISO-3129 2019, respectively).

The tree stems were cut into logs and conditioned at ambient air conditions during a week to remove part of its natural moisture. The logs were then cut with a chain saw into two longitudinal planks, which were planned to obtain smooth surfaces and peeled into 1.5 × 0.5 m² veneer sheets for the determination of thermal conductivity (Fig. 1). The *P. halepensis* solid wood samples used for the physicomechanical characterizations did not differentiate the sapwood and the heartwood.

Fig. 1 represents an overview of the sampling procedure adopted for the physical and mechanical tests on the wood of *P.*

halepensis. A total of 20 solid wood specimens were produced with radial × tangential × longitudinal dimensions of approximately 20 × 20 × 300 mm for mechanical tests. The physical and mechanical properties, namely density, moisture content, dynamic elastic modulus, as well as thermal degradation and thermal conductivity were determined according to the respective standards, as explained in the following sections. The wood samples were conditioned under 65% relative humidity and 20 °C temperature to obtain approximately 12% moisture content in wood samples before the physicomechanical and thermal tests.

Physical characterization

Moisture mapping

The water content of the wood was determined as the proportion of free and bound water relative to the dry weight of sample by the standard B51-004 (1985). A 20 mm wide wood stem cross-section was cut from the *P. halepensis* logs and immediately cut into 45 small prisms of 20 × 20 × 40 mm, covering the whole cross-section and numerated according to the location of each sample in the disk. Each prism was weighed using a balance with a 1 mg accuracy (moist-weight), dried in a stove at 103 ± 2 °C until equilibrium and weighed again.

The cross-sectional mapping of moisture in the *P. halepensis* stem was established using a Visual Basic™ computer program based on the reconstitution of the moisture content after calculating the moisture content of the prisms based on their position, followed by estimating the moisture content for each point on the disk using the form function (El Haouazali 2009).

Determination of density

For the determination of density, a total of 12 *P. halepensis* wood specimens with dimensions 20 × 20 × 20 mm were weighed and their dimensions measured with a digital caliper, as specified by the French stan-

dard B51-005 (1985).

Determination of swelling

A total of 12 specimens (20 × 20 × 20 mm) were placed in water during 12 days. During this period, the specimens were removed from the water, wiped and daily weighed until constant weight was reached, corresponding to maximum moisture content. The swelling of wood in different directions were calculated from swellings of the wood between the dry state and above the fiber saturation point (FSP).

The volumetric swelling of wood was expressed by the sum of radial, tangential, and longitudinal swelling values (Gryc et al. 2008).

Determination of shrinkage

A total of 12 specimens (20 × 20 × 20 mm) above fiber saturation moisture content were placed in an oven at 103 °C. The weight and dimensional changes of the specimens were monitored daily, according to B51-006 (1985) standard. The measurement of the dimensions was made with a digital caliper (accuracy: 0.01 mm).

The anisotropy of shrinkage (A) is expressed by the ratio of tangential shrinkage to radial shrinkage. It gives an indication of the distortions that may occur in wood during drying below the fiber saturation point. The volumetric shrinkage (R_v) is defined as the relative change in volume between the saturated state and the dry state (Erten & Sözen 1996).

Mechanical characterization

Bending strength and modulus of elasticity

The 3-point bending test (B51-009 1985) was carried out using a Zwick universal machine provided with a force sensor using a 10 kN load at a speed of 2 mm min⁻¹. A total of 20 samples with 20 × 20 × 300 mm dimensions were used in the bending test. The machine was computer controlled and the software testXpert® v. 12.0 (ZwickRoell, Genoa, Italy) was used for data acquisition.

For the determination of bending strength (modulus of rupture, MOR), the following equation was used based on DIN-52186 standard (DIN-52186 1978, Siegel et al. 2020 – eqn. 1):

$$\sigma = \frac{3 \cdot F \cdot l}{2 \cdot b \cdot h^2} \tag{1}$$

where *b* is width, *h* is thickness, *l* is the distance between the centers of the supports, and *F* is the maximum force applied. The bending modulus of elasticity is the ratio of stress to corresponding strain within the elastic region and was calculated based on EN-310 (1993) standard using the following formula (eqn. 2):

$$MOE = \frac{l^3}{4 \cdot b \cdot h^3} \cdot \frac{\Delta F}{\Delta f} \tag{2}$$

In this equation the elastic range was calculated between 10% and 40% of the maxi-
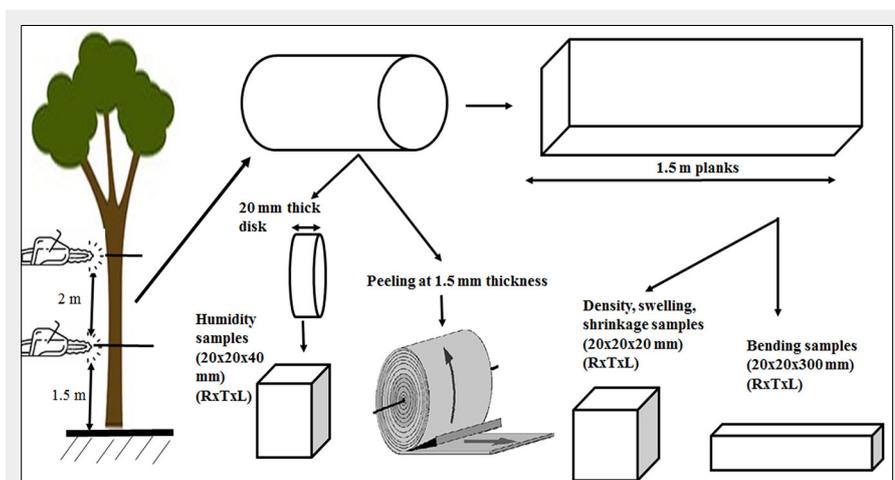

Fig. 1 - Preparation of specimens for physical and mechanical characterization (directions: R, radial; T, tangential; and L, longitudinal).

mum force. ΔF shows the variation in the force (N) and Δf shows the variation in the deflection (mm – Siegel et al. 2020).

Thermal properties

Low-temperature thermal degradation

The thermal behavior of the *P. halepensis* wood was analyzed with particle (approximately 5 mm) and powder (<250 μm) wood samples at temperatures between 25 and 250 °C using a thermogravimetric analyzer. A four step heating program was used under air and Argon gas flow conditions: heating from 25 to 100 °C at a heating rate of 10 °C min⁻¹, an isothermal step at 100 °C for 30 min, heating from 100 to 250 °C at a heating rate of 10 °C min⁻¹, and finally an isothermal step at 250 °C for 5h. Air or Argon gas flow rates were set to 60 ml min⁻¹.

Thermal conductivity

The thermal conductivity of the materials used was measured using a thermal conductivity analyzer (TC-Meter). In the measurement, through a combination of a heating element and a temperature sensor, the temperature increase in the wood sample was measured during a pre-defined heating power and heating period in a transient state. The sensor wire is placed between the two test samples of the same material. This probe is disposed in a kapton membrane connected in series with a voltmeter and a current generator that measures, through the Joule's law, the heat emitted at the surface of the test material.

The thermal conductivity analyses were performed on *P. halepensis* wood veneer samples in the longest and smallest directions by triplicate measurements. The test samples (15 × 15 × 2 cm) have been obtained from veneers of 1.5 × 0.5 m² dimensions and a thickness of 1.5 mm. The ISO-8894-1 (2010) standard was followed in the measurement of thermal conductivity.

Results and discussion

Moisture mapping and density

The average moisture was 96% in the green wood, in agreement with the generally found moisture content in recently felled trees (Tsoumis 1991). The moisture mapping shows that the water content distribution was not homogeneous along the cross-section while being more variable in the sapwood and more uniform in the heartwood (Fig. 2). Moisture content increases gradually from the center of the log to outside in accordance with the previous observations in softwoods (Tsoumis 1991).

The water content was maximal in the area of the sapwood (moisture content between 60% and 160%) while the less moist heartwood contained moisture levels between 30% and 60%. These findings are in accordance with those reported in the literature (moisture contents of 30-40% and 60-100% for heartwood and sapwood, re-

spectively – Daoui et al. 2007).

Tab. 1 summarizes the range, mean and standard deviation of density of Algerian *P. halepensis* wood, as well as the values from a comparative study with *P. halepensis* wood from different Mediterranean countries. The mean density of Algerian *P. halepensis* wood was 540 kg m⁻³ which is within the range reported. For instance, Nahal (1962) reported a density (without specifying the moisture content) between 532 and 866 kg m⁻³, while Erten & Sözen (1996) found an air-dry density of Turkish *P. halepensis* wood between 540 and 614 kg m⁻³. Similarly, Langbour et al. (2008) reported the density of French *P. halepensis* wood between 530 and 580 kg m⁻³. Another similar density value (580 kg m⁻³) was reported by Limam et al. (2016). These values suggest that the reported density values may vary as high as 60% for *P. halepensis* wood. This variation occurs possibly due to the differences in measuring density (oven-dry basis or air-dry basis) and differences in moisture content and chemical composition between the tested *P. halepensis* woods (Tsoumis 1991).

Swelling properties

The variation in wood dimensions (in longitudinal, radial, and tangential directions) and wood mass during water immersion of the *P. halepensis* wood is shown in Fig. 3. The mass increase due to water absorption was significant in the first 24 h, then de-
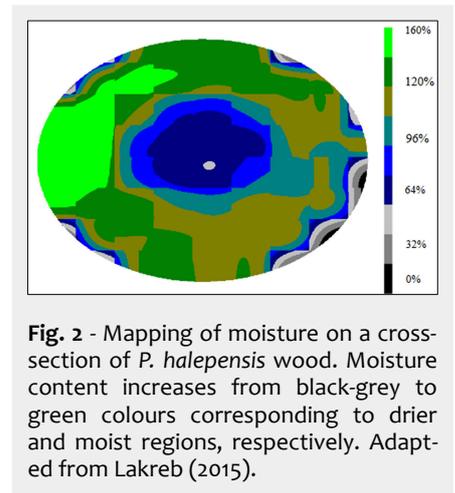
Fig. 2 - Mapping of moisture on a cross-section of *P. halepensis* wood. Moisture content increases from black-grey to green colours corresponding to drier and moist regions, respectively. Adapted from Lakreb (2015).

creased sharply and attained a rather stable condition after 5 days.

The wood dimensional variation along time shows that most of the swelling occurred in the first two days of immersion. Also, a clear anisotropy in swelling was observed with a very small swelling in the longitudinal direction (0.3% after 11 days of immersion) and the highest value for the tangential direction (5.0% and 1.6% for the tangential and radial swelling respectively). The volumetric swelling was 6.9% (Tab. 2).

The results indicate that the swelling of Algerian *P. halepensis* wood is smaller than that of Turkish *P. halepensis* wood (7.2-9.4% and 5.0-5.7% for tangential and radial

Tab. 1 - Density of Algerian *P. halepensis* wood and comparison with other *P. halepensis* woods from the Mediterranean area.

Provenances	References	Density range (kg m⁻³)	Average density (kg m⁻³)
Algeria	This work	500-580	540
Algeria, Lebanon, France	Nahal (1962)	532-866	724
Tunisia	Quiquandon (1966)	-	560
France, Italy, Spain, Portugal, Tunisia, Morocco, Israel	Thibaut et al. (1992)	-	570
Turkey	Erten & Sözen (1996)	540-610	575
France	Langbour et al. (2008)	450-580	515
Algeria	Limam et al. (2016)	-	580
Tunisia, Italy, Spain, Israel	Elaieb et al. (2017)	520-620	570
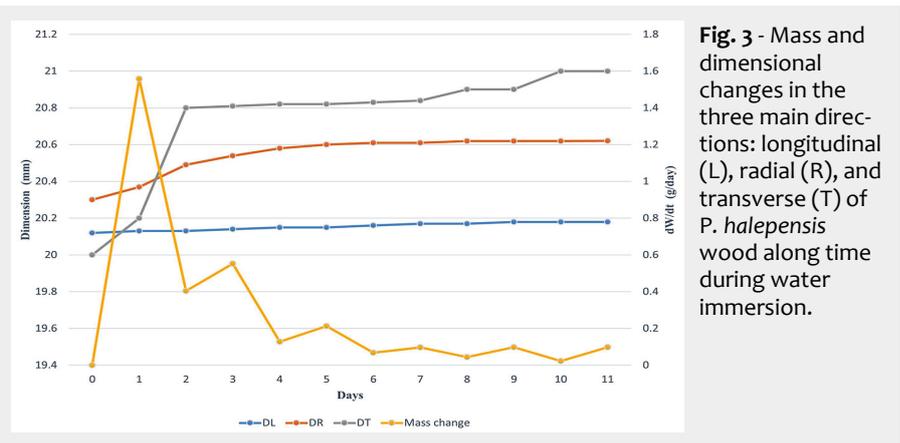
Fig. 3 - Mass and dimensional changes in the three main directions: longitudinal (L), radial (R), and transverse (T) of *P. halepensis* wood along time during water immersion.

Tab. 2 - Mean swelling (α), shrinkage (R), volumetric swelling and shrinkage (V), and Anisotropy (A) of *P. halepensis* wood in the three directions (L, R and T). (STD): standard deviation.

Values	Variable	Parameter	Mean ± STD
Experimental values	L (%)	α	0.29 ± 0.11
		R	1.14 ± 0.31
	R (%)	α	1.58 ± 0.53
		R	3.76 ± 1.04
	T (%)	α	5.00 ± 1.56
		R	4.76 ± 1.34
Calculated values	V (%)	α	6.87
		R	8.34
	A (%)	-	1.26

swelling values, respectively – Erten & Sözen 1996). This difference in swelling properties possibly arises from the differences in wood density and wood moisture content (Tsoumis 1991).

Drying properties

As in swelling, the moisture loss was significant in the first days of drying and reduced towards the end of the shrinkage test. The shrinkage of *P. halepensis* wood was not the same in all three directions with higher dimensional change in the tangential and radial directions than in the longitudinal direction.

The mean values of the radial, transverse,

Tab. 3 - Test results of 3-point bending of the *P. halepensis* wood. F is force (N), f is deflection (mm), f_1 and f_2 are deflections occurred at 10% (F_1) and 40% of maximum force (F_2), MOR is modulus of rupture (MPa) and MOE is elasticity modulus (Mpa).

Parameters	Units	Values
F_{max}	N	2070
f_{max}	mm	15.2
f_1	mm	0.55
f_2	mm	2.04
F_1	N	207
F_2	N	828
MOR	MPa	116.4 ± 8.5
MOE	MPa	17520 ± 1500

and longitudinal shrinkage of *P. halepensis* wood are summarized in Tab. 2. The radial and tangential shrinkage values of Algerian *P. halepensis* wood was 3.76% and 4.76%, respectively (Tab. 2). These results are similar but lower than the Tunisian *P. halepensis* wood values with a radial shrinkage from 4.4% to 6.0% and a tangential shrinkage from 6.9% to 7.5% (Elaieb et al. 2017). The Algerian *P. halepensis* wood also shrinks less than French and Turkish *P. halepensis* woods in terms of radial, tangential, and volumetric shrinkage values (4.5%, 7.4%, 11.8% and 4.8%, 7.2%, 12.5%, respectively – Thibaut et al. 1992, Erten & Sözen 1997). The shrinkage properties of Algerian Aleppo pine were also better than black pine (*P. nigra*) and Italian stone pine (*P. pinea*) which had radial, tangential, and volumetric shrinkage values of 5.0%, 7.2%, 12.5% and 3.1%, 5.7%, and 8.8%, respectively (As et al. 2001).

Shrinkage is affected by factors such as density, moisture content, anatomical structure, mechanical stress and chemical composition of wood (Tsoumis 1991). When wood dries, the free water is removed first; it moves to the surface of wood and evaporates, usually without causing detrimental effect to the wood. When cells do not contain free water, the wood reaches the fiber saturation point (FSP) and if the drying process continues beyond this point, wood starts to shrink. Shrinkage shows a similar anisotropy as that of swelling (Thibaut et al. 1992). The anisotropy (A) of the shrinkage indicates

the dimensional stability of the wood and is calculated by the ratio between the tangential and radial shrinkage values. The wood anisotropy of *P. halepensis* shrinkage (1.26) is lower than that of other coniferous species such as *Pinus pinea* (1.53), *Pinus pinaster* (2), *Pinus sylvestris* (1.7) or *Pseudotsuga menziesii* (1.7 – Elaieb et al. 2015). The low T/R shrinkage ratio indicates that the Algerian *P. halepensis* wood has a good dimensional stability.

Mechanical properties

The results of the 3-point bending tests on the *P. halepensis* wood are shown in Tab. 3. The Young's modulus (MOE) found in this study (17241 MPa) is considerably higher than the other reported MOE values (between 8300 and 13500 Mpa, respectively – Langbour et al. 2008). The bending strength (MOR) of the Algerian *P. halepensis* wood (116 MPa) was also higher than other values reported for the same species (Tab. 3). Different authors found bending strength values between 43 MPa and 138 MPa for *P. halepensis* wood (Thibaut et al. 1992, As et al. 2001, Langbour et al. 2008, Elaieb et al. 2017). On the other hand, lower MOR values were reported for other pine species such as 82 MPa for Turkish pine (*P. brutia*) and 100 MPa for Scots pine (As et al. 2001). Only the MOR values of black pine (*P. nigra*: 96-120 MPa) exceeds the bending strength of Algerian Aleppo pine wood (As et al. 2001).

According to these results, it seems that the Algerian *P. halepensis* has superior mechanical properties (bending strength and Young's module, respectively) to those of other conifers such as maritime pine (*P. pinaster*: 80, 8800 MPa), Scots pine (*P. sylvestris*: 90, 11900 MPa), Douglas pine (*Pseudotsuga menziesii*: 85, 12100 MPa), silver fir (*Abies alba*: 68, 12200 MPa) and Norway spruce (*Picea abies*: 71, 11000 Mpa – Benoit 2007). It is important to note that these results were obtained on wood samples that did not present defects such as knots or resins pockets that could decrease the wood mechanical strength (Tsoumis 1991). For instance, the presence of knots or resins reduced the modulus of elasticity by 15% and the stress at break in bending by 11% compared to the average values recorded on specimens without defects (Langbour et al. 2008).

The findings of the physical and mechanical properties of *P. halepensis* wood need to be interpreted with caution because they are limited with a small number of tests, in this study. However, these results provide a basis for the development of future applications along with the results of thermal behavior.

Thermal behavior

Low-temperature thermal degradation

The low-temperature thermal degradation of Algerian *P. halepensis* wood was investigated between 120 and 250 °C. The

Tab. 4 - Thermal conductivity and thermal resistance of *P. halepensis* wood veneer in different directions (λ// is the thermal conductivity in longest direction; $\lambda\perp$ is the thermal conductivity in smallest direction; R// is the thermal resistance in longest direction; R$\perp$ is the thermal resistance in smallest direction.

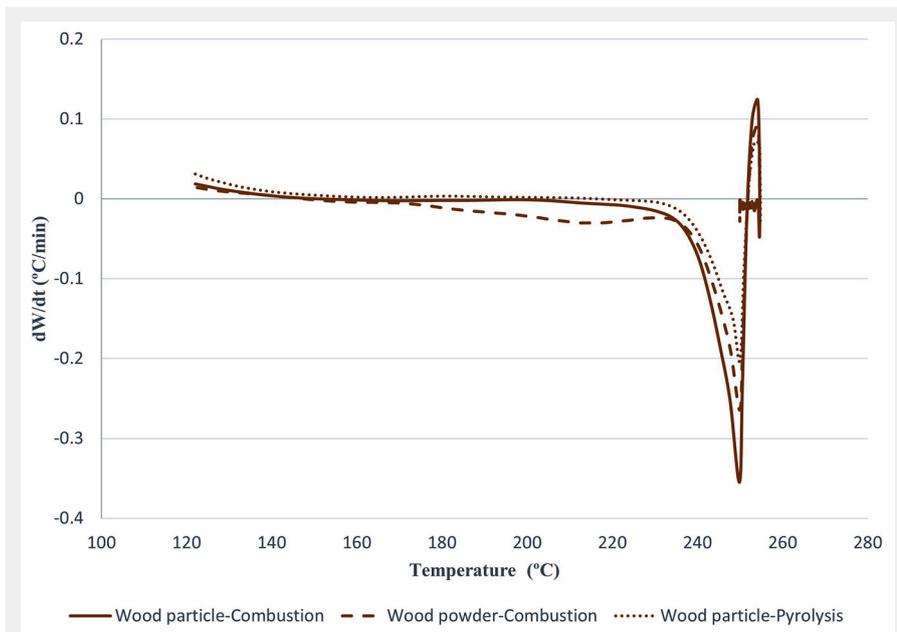| Parameter	Direction (Units)	Value
Thermal conductivity	λ// (W m^{-1} K^{-1})	0.17 ± 0.10
	$\lambda\perp$ (W m^{-1} K^{-1})	0.25 ± 0.11
Thermal resistance	R// (m^2 K W^{-1})	0.12 ± 0.09
	R$\perp$ (m^2 K W^{-1})	0.07 ± 0.10
Average thermal diffusivity	a (m^2 s^{-1})*	0.25 ± 0.06 · 10^{-6}

Fig. 4 - Comparative low-temperature thermal degradations of *P. halepensis* wood particle and wood powder.

mass loss values in combustion were higher in the powder sample than in the particle sample (62.7% and 18.1%, respectively), indicating the occurrence of mass and heat transfer limitations on the latter.

The powder sample started degradation at lower temperatures than the particle sample under pyrolysis conditions (Fig. 4). The thermal degradation rate remained constant after reaching the peak temperature. Pyrolysis of the Algerian *P. halepensis* wood resulted in 9.4% mass loss under the similar experimental conditions as used for combustion. The mass loss rate was smaller than that of combustion and shifted to the higher temperatures (Fig. 4). The low mass loss values in combustion and pyrolysis imply that Algerian *P. halepensis* timber structures are likely to be resistant to thermal degradation at low temperatures.

Fig. 4 shows low-temperature thermal degradations of *P. halepensis* wood particle and wood powder.

Thermal conductivity

Thermal conductivity is an important property particularly for thermal insulation applications. Tab. 4 summarizes the average values of thermal conductivity of the samples of *P. halepensis* wood veneer. The average thermal conductivity was 0.21 W m^{-1} K^{-1}. The higher thermal conductivity of *P. halepensis* wood veneer in the smallest direction compared to longest direction was an interesting result, although the difference was not high (0.08 W m^{-1} K^{-1}). The thermal conductivity results of this study are in agreement with a previous study (Limam et al. 2016) reporting thermal conductivity values of Algerian *P. halepensis* wood of 0.18 W m^{-1} K^{-1} and 0.28 W m^{-1} K^{-1} for parallel and perpendicular directions, respectively. Because of the anisotropy of wood,

the thermal conductivity in the perpendicular direction to the fibres is generally smaller than in the parallel direction, while radial and tangential directions show similar thermal conductivities (Kollmann & Coté 1968, Suleiman et al. 1999, Ross 2010). The thermal diffusivity of Algerian *P. halepensis* wood was 0.25 × 10^{-6} m^2 s^{-1} considering the reported heat capacity of the species (Limam et al. 2016 – Tab. 4). The thermal diffusivity of Algerian *P. halepensis* wood is slightly higher than the average value of wood species (0.16 × 10^{-6} m^2 s^{-1}) but lower than mineral wool (1 × 10^{-6} m^2 s^{-1} – Ross 2010).

The thermal conductivity values of *P. halepensis* wood veneer found in this study are in the upper range of values reported for wood as shown for example in the Wood Handbook (Ross 2010), which indicates that the thermal conductivity ranges between 0.10 and 0.21 W m^{-1} K^{-1} in several wood species. Therefore, the thermal conductivity and thermal diffusivity results indicate that *P. halepensis* wood veneers should be used with insulating core materials such as cork for thermal insulation applications of sandwich panels, where core layer acts as the greatest thermal resistance.

Conclusions

The physicomechanical and thermal properties of Algerian *P. halepensis* wood were investigated aiming at its use as a component of cork sandwich structures for construction applications. The Algerian *P. halepensis* wood has a medium density (540 kg m^{-3}), good dimensional stability in swelling and shrinkage, favorable bending properties (116 MPa bending strength and of 17520 MPa modulus of elasticity) and a good resistance to thermal degradation at

low temperatures. The Algerian *P. halepensis* wood veneer has an average thermal conductivity of 0.21 W m^{-1} K^{-1}.

The overall results of the study suggest that Algerian *P. halepensis* wood has a promising potential in the use of face layers in sandwich panel formulations with insulating core layers for the production of structural members and thermal insulation.

Conflict of Interest

The authors of the article certify that they have no involvement in any organization or entity with any financial interest.

References

As N, Koç H, Dogu D, Atik C, Aksu B, Erdinler S (2001). Türkiye'de yetisen endüstriyel öneme sahip agaçlarin anatomik, fiziksel, mekanik ve kimyasal özellikleri [The anatomical, physical, mechanical, and chemical properties of trees of industrial importance grown in Turkey]. Istanbul Üniversitesi Orman Fakültesi Dergisi 51: 71-88. [in Turkish]

B51-003 (1985). Wood - General test conditions - Physical and mechanical tests. AFNOR-French Standardization Association, Paris, France, pp. 1-4.

B51-004 (1985). Wood - Determination of moisture. AFNOR-French Standardization Association, Paris, France, pp. 1-3.

B51-005 (1985). Wood - Determination of density. AFNOR-French Standardization Association, Paris, France, pp. 1-7.

B51-006 (1985). Wood - Determination of shrinkage. AFNOR-French Standardization Association, Paris, France, pp. 1-10.

B51-009 (1985). Wood - Dynamic bending test. AFNOR-French Standardization Association, Paris, France, pp. 1-3.

Benoit Y (2007). Le guide des essences de bois: 74 essences, les choisir, les reconnaitre, les utiliser [The Guide to Wood Species: 74 species, selection, identification, usage]. Editions Eyrolles, Paris, France, pp. 13-87. [in French]

Benouadah N, Aliouche D, Pranovich A, Willför S (2019). Chemical characterization of *Pinus halepensis* sapwood and heartwood. Wood Material Science and Engineering 14: 157-164. - doi: 10.1080/17480272.2018.1448436

Daoui A, Douzet J, Marchal R, Zerizer A (2007). Valorisation du bois de pin d'Alep par déroulage: optimisation de son étuvage [Optimization of steaming prior to rotary peeling of Aleppo pine]. Bois et Forets des Tropiques 294: 51-64. [in French]

DIN-52186 (1978). Testing of wood, bending test. German Institute for Standardization, Berlin, Germany, pp. 1-4.

Elaieb MT, Khaldi A, Candelier K (2015). Impact of location and forestry conditions on some physical and mechanical properties of Northern Tunisian *Pinus pinea* L. wood. Bois et Forêts des

iForest – Biogeosciences and Forestry

Tropiques 324: 65-74. [in French] - doi: 10.19182/bft2015.324.a31267

Elaieb MTE, Shel F, Elouellani S, Janah T, Rahouti M, Thévenon MF, Candelier K (2017). Physical, mechanical and natural durability properties of wood from reforestation *Pinus halepensis* Mill. in the Mediterranean Basin. Bois et Forêts des Tropiques 331: 19-31. - doi: 10.19182/bft2017.331.a31323

El Haouazali H (2009). Deroulage du peuplier: effets cultivars et stations sur la qualité des produits dérivés [Peeling of Poplar: cultivar and forest station effects on veneer-based products quality]. Paris Institute of Technology, Paris, France, pp. 72-74 [in French]

EN-310 (1993). Wood-based panels; determination of modulus of elasticity in bending and of bending. European Committee for Standardization, Brussels, Belgium, pp. 1-6.

Erten AP, Sözen MR (1996). Halep çami odununun fiziksel ve mekaniksel özelliklerinin belirlenmesi [Studies on the determination of physical and mechanical properties of Aleppo pine]. Central Anatolian Forest Research Institute, Ankara, Turkey, vol. 268, pp. 1-40. [in Turkish]

Fekih N, Allali H, Merghache S, Chaïb F, Merghache D, El Amine M, Djabou N, Muselli A, Tabti B, Costa J (2014). Chemical composition and antibacterial activity of *Pinus halepensis* Miller growing in West Northern of Algeria. Asian Pacific Journal of Tropical Disease 4 (2): 97-103. - doi: 10.1016/S2222-1808(14)60323-6

Gibson L, Ashby M (1999). Cellular solids: structure and properties. Cambridge University, Cambridge, UK, pp. 345-386. - doi: 10.1017/CBO9781139878326

Gryc V, Vavrčík H, Gomola S (2008). Selected properties of European beech (*Fagus sylvatica* L.). Journal of Forest Science 54 (9): 418-425. - doi: 10.17221/59/2008-JFS

ISO-3129 (2019). Wood - Sampling methods and general requirements for physical and mechanical tests. International Organization for Standardization, Geneva, Switzerland, pp. 1-8.

ISO-8894-1 (2010). Refractory materials-determination of thermal conductivity - Part 1: hot wire methods. International Organization for Standardization, Geneva, Switzerland, pp. 1-19.

Kollmann FFP, Coté W (1968). Principles of wood science and technology. I: Solid wood. Springer-Verlag, Berlin, Germany, pp. 246-247.

Lakreb N (2015). Elaboration, caractérisation thermomécanique et hygrothermique d'un composite sandwiche multicouches à base de liège et bois de déro [Elaboration, thermome-

chanical and hygrothermal characterization of a multilayer sandwich composite based on cork and wood]. M'hamed Bougara University, Boumerdes, Algeria, pp. 43-44. [in French]

Lakreb N, Bezzazi B, Pereira H (2015a). Mechanical behavior of multilayered sandwich panels of wood veneer and a core of cork agglomerates. Materials and Design 65: 627-636. - doi: 10.1016/j.matdes.2014.09.059

Lakreb N, Bezzazi B, Pereira H (2015b). Mechanical strength properties of innovative sandwich panels with expanded cork agglomerates. European Journal of Wood and Wood Products 73: 465-473. - doi: 10.1007/s00107-015-0908-y

Langbour P, Gérard J, Guibal D, Mahlani K (2008). Caractérisation technologique et valorisation en bois d'oeuvre du pin l'Alep (*Pinus halepensis*) de la région Provence-Alpes-Côte d'Azur [Technological characterization and valorization in timber of Aleppo pine (*Pinus halepensis*) from the Provence-Alpes-Côte d'Azur region]. Forêt Méditerranéenne 32 (3): 263-270. [in French]

Limam A, Zerizer A, Quenard D, Sallee H, Chenak A (2016). Experimental thermal characterization of bio-based materials (Aleppo Pine wood, cork and their composites) for building insulation. Energy and Buildings 116: 89-95. - doi: 10.1016/j.enbuild.2016.01.007

Liphschitz N, Biger G (2001). Past distribution of Aleppo pine (*Pinus halepensis*) in the mountains of Israel (Palestine). Holocene 11: 427-436. - doi: 10.1191/095968301678302869

Maestre FT, Cortina J (2004). Are *Pinus halepensis* plantations useful as a restoration tool in semiarid Mediterranean areas? Forest Ecology and Management 198: 303-317. - doi: 10.1016/j.foreco.2004.05.040

Mauri A, Di Leo M, De Rigo D, Caudullo G (2016). *Pinus halepensis* and *Pinus brutia* in Europe: distribution, habitat, usage and threats. In: "European Atlas of Forest Tree Species" (San-Miguel-Ayanz J, De Rigo D, Caudullo G, Houston Durrant T, Mauri A eds). Publ. Off. EU, Luxembourg, pp. 122-123. [online] URL: http://forest.jrc.ec.europa.eu/media/atlas/Pinus_halepensis_brutia.pdf

Mitsopoulos ID, Dimitrakopoulos AP (2007). Canopy fuel characteristics and potential crown fire behavior in Aleppo pine (*Pinus halepensis* Mill.) forests. Annals of Forest Science 64: 287-299. - doi: 10.1051/forest:2007006

Montero G, Cañellas I, Ruíz-Peinado R (2001). Growth and yield models for *Pinus halepensis* Mill. Investigación agraria - Sistemas y Recursos

Forestales 10 (1): 179-201. [online] URL: http://sia.revistas.inia.es/index.php/fs/article/view/720

Nahal I (1962). Le pin d'Alep (*Pinus halepensis* Mill). Etude taxonomique, phytogéographique, écologique et sylvicole [Aleppo pine (*Pinus halepensis* Mill). Taxonomic, phytogeographic, ecological and silvicultural study]. Annales de l'Ecole Nationale des Eaux et Forêts et de la Station de Recherches et Expériences, Nancy, France, vol. 19, pp. 475-686 [in French] [online] URL: http://hal.archives-ouvertes.fr/hal-03483847/

Quiquandon B (1966). Etude des bois de pin d'Alep en Tunisie [Study of Aleppo pine wood in Tunisia]. Centre Technique du Bois, Paris, France, pp. 1-19. [in French]

Ricard C, Oliva T (1995). Valorisation du bois de pin d'Alep - Étude Bibliographique [Valorization of Aleppo pine wood - Bibliographic study]. École Nationale des Arts et Métiers, Centre de Paris, France, pp. 9-10. [in French]

Ross RJ (2010). Wood handbook: wood as an engineering material. General Technical Report FPL-GTR-190, USDA Forest Service, Madison, WI, USA, pp. 80-146. [online] URL: http://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr190.pdf

Sghaier T, Ammari Y (2012). Croissance et production du pin d'Alep (*Pinus halepensis* Mill.) en Tunisie [Growth and production of Aleppo pine (*Pinus halepensis* Mill.) in Tunisia]. Ecologia Mediterranea 38: 39-57. [in French] - doi: 10.3406/ecmed.2012.1325

Siegel C, Buchelt B, Wagenführ A (2020). Application of the three-point bending test for small-sized wood and veneer samples. Wood Material Science & Engineering 11 (3): 1-6. - doi: 10.1080/17480272.2020.1814410

Suleiman BM, Larfeldt J, Leckner B, Gustavsson M (1999). Thermal conductivity and diffusivity of wood. Wood Science and Technology 33: 465-473. - doi: 10.1007/s002260050130

Thibaut B, Loup C, Chanson B, Dilem A (1992). La valorisation du pin d'Alep en zone méditerranéenne française [The valorization of Aleppo pine in French Mediterranean area]. Forêt Méditerranéenne 13: 226-233. [in French]

Tsoumis G (1991). Science and technology of wood: structure, properties, utilization. Van Nostrand Reinhold, New York, USA, pp. 113-202. [online] URL: http://www.trae.dk/wp-content/uploads/2001/10/science-and-technology-of-wood.pdf