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Natural thermal-insulation materials composed of renewable resources: characterization of local date palm fibers (LDPF)

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Abstract
This research work is focused on analyzing the potential application of local date palm waste (LDPW) as an alternative sources of plant-based energy-conserving materials for uses either singly or as a composite material to prevent heat conduction through walls into or out of interior spaces in the vessel of refrigerator, cooler and food flask. First, physical and mechanical properties of seven varieties of local date palm waste from Errachidia oasis in Morocco namely *Khalt, Boufeggous, Bu-Slikhen, Mejhoul, Admou*, *Khalt Zhar* and *Tazaout* were measured and analyzed. The result showed that Boufeggous varieties were found to have the most important physico-chemical and mechanical properties compared with other varieties. Hence scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis of the date palm fibers of Boufeggous varieties were investigated to characterize the microstructure and the chemical composition of the sample. It was found that carbon and oxygen were the only consistent compounds in these palm fibers varieties. It can be also noted that the surface of fibers is irregular and rough with many impurities, cells and pores. A simultaneous determination of the thermal conductivity was achieved using a periodic method. The thermal conductivity measured in atmospheric pressure showed that the material remains with good properties compared with other natural and synthetic insulating materials with a thermal conductivity value of 0.041 W/m.K, which suggest that the date palm wood of the *Boufeggous* varieties is useful for further development and design of natural efficient and safe thermal insulating materials for people's daily life.

Keywords; Date palm waste; physical and mechanical properties; microstructures; thermal insulation.

Introduction
The world's cooling demand has increased considerably during the last decades as a result of increased population and industrialization in combination with increased comfort demand, electronic equipment usage, and new building technologies. One of the problems people face is how to maintain the temperature of their foodstuff, water, research samples, vegetable and others at the required temperature for a required length of time. One of the factors causing change in the temperature of food or sample is the heat transmitted in or out through the walls of the containing vessel by the process of conduction and radiation. The heat gain or loss can be minimized if good insulating material is used to finish the walls of the container [1-6]. Thermal insulation materials are chosen for their physical properties such as low thermal conductivity, moisture protection, and mould and fire resistance. At present, the most insulating materials used for refrigerator, cooler and food flask, are manufactured from fiberglass, mineral wool, polystyrene (expanded), or polyurethane (rigid foam). Although these materials have good physical prosperities, e.g. low thermal conductivity, good moisture protection and fire resistance, they are very expensive to acquire and they can be hazardous to human health and to the environment [7-9]. For example, exposure to the small particles from fiberglass and glass wool insulation can cause health hazard and respiratory or skin irritation [8]. The toxic nature and high cost of these materials have necessitated research activity in recent time toward finding alternative thermal insulation products. The interest in naturally

occurring substances stems from the fact that they are non-toxic, biodegradable, cheap and readily available in plenty. The performance of thermal insulation materials made of plant-based products such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, palm etc., as well as wood for the construction materials applications in building sector have already been examined [9-11]. The thermal performance of these insulation materials is comparable to that of conventional, mineral and glass fiber based products.The aim of this research is to evaluate the possibility of using the date palm waste (*Phoenix Dactylifera L.*), including dried leaflets, midribs, spikelets, spathes, sheaths, and petioles as a potential component of an insulating material to reduce the heat loss in the refrigeration and air conditioning sectors. The physical, morphological, and mechanical performance of this plant-based material was also analyzed. Besides fruit, the date palm over the centuries has also provided a large number of other products which have been extensively used by man in all aspects of daily life. Practically all parts of the date palm are used for a purpose best suited to them [12]. Date palm (*Phoenix Dactylifera L.*) is a tropical tree found primarily in the Middle East. According to the UN Food & Agriculture Organization (FAO), the Persian Gulf countries account for approximately 50 percent of the global date production [13]. In Morocco, there are about 4.45 million palm trees [14] which make the use of the date palm by-products as raw material source for industrial purposes a promising project. A mature tree has approximately 30-140 leaves with spines on the petiole and renews 10-30 leaves each year [12]. The same amount of leaves dries out annually and must be removed. This dried organ is not consumed by animals and has traditionally been used in shading, house construction, and crates, ropes, baskets, and other handicrafts [15]. However, aside from a few modern applications, e.g., as soil amendments and in panel boards, date palm waste is now most often burned. To the best of knowledge, to date, no study has been conducted in the field of thermal protection in refrigerated equipment using waste date palm. This work presents the first investigation in the literature which aimed to develop alternative sources of plant-based energy-conserving materials for uses either singly or as a composite material to prevent heat conduction through walls into or out of interior spaces in the vessel of refrigerator, cooler and food flask.

2. Methods and materials

2.1. Preparation of materials

The natural fibers used in this study are local date palm fibers (LDPF) were collected from the region of Errachidia in Morocco. Seven varieties namely, *Khalt, Boufeggous, Bu-Slikhen, Mejhoul, Admou, Khalt Zhar* and *Tazaout* (local names) were studied. The LDPF are manually separated to single fibers and are washed in water and then dried in an oven at 60 °C.

2.2. Determination of mass loss

The mass loss was determinate by drying process in an electric oven at the following temperatures: 30 °C, 40 °C, 50 °C, 60 °C, 70 °C, 80 °C, 90 °C, 110 °C and 130 °C. The drying time for each test is 24 hours. Monitoring the mass is performed by weighing on an electronic balance with an error of 10^{-4} g. The mass loss (ML) was calculated using formula (1) shown below:

$$ML\ (\%) = \frac{M_O - M}{M_O} \quad \text{Eq (1)}$$

Where: ML = masse loss (%),
M_0 = weight of air dried sample (g),
M = weight of oven dried sample (g).

2.3. Water uptake

The water uptake measurements were conducted using NF EN 382 standards; the samples were cut into small pieces and then emerged in distilled water, the water absorption behavior was studied by following the samples density versus immersion time.

2.4. Density measurement

The density of fibers from different date palm varieties was determined by measuring the mass and volume of each sample. Each sample was weighed to an accuracy of 0.01 g by using an analytical balance. The dimensions of each sample were measured using a sliding caliper, in accordance with BS EN 325:1993. The volume of the fiber was obtained by multiplying the length and cross sectional area of the samples. Three replicate specimens were tested, and the results were presented as average of the tested specimens. Determination of density was done in accordance with BS EN 323:1993 using Eq. (2):

$$D = \frac{m}{v} \quad \text{Eq (2)}$$

Where m is the masse and v is the volume of date palm sample.

2.5. Tensile test

The uniaxial tensile tests of different date palm varieties were conducted at room temperature using an MPZ3k universal testing machine at constant cross-head speed of 2 $mm.mn^{-1}$. A 50 mm gauge length extensometer was attached to the samples during tensile test to record the strain data in each case five samples were tested and average value was reported.

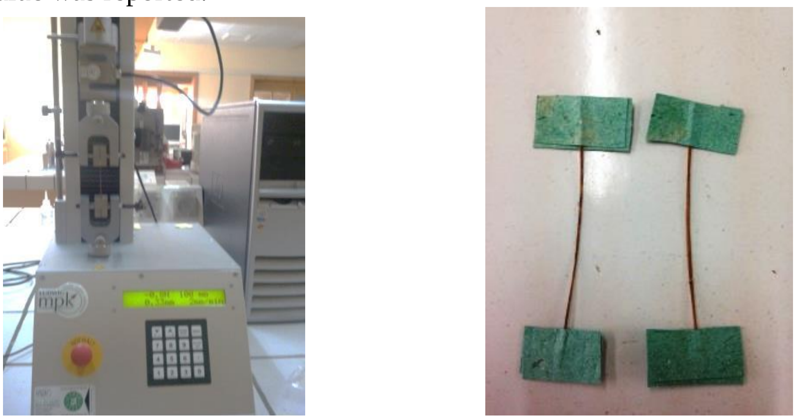

Fig. 1: Tensile test measurements

2.6. Scanning electron microscopy (SEM)

A Hitachi S-3400N scanning electron microscopy with operating voltage of 0.3-30 Kv was used to observe the surface structure of date palm fibers of *Boufeggous* varieties in order to evaluate the pores structure and their distribution. Prior to the observation, small portion of fibers was prepared and mounted on an aluminum stub and sputter coated with a thin layer of gold to avoid electrostatic charging during SEM examination.

2.7. Thermal conductivity testing

The thermal conductivity of the different date palm samples at room temperature are achieved according to NF ISO 88941 2nd edition 15/05/2010 using the CT meter device [16].The measurement technique is based on the hot wire method and allows the estimation of the thermal conductivity of a material from the variation of the temperature measured by a thermocouple placed near a resistive wire. The probe is constituted with resistive wire and thermocouple in an insulating support of kapton that is placed between two samples of the material to be characterized. The heating period is chosen by the user depending on the material to be tested and the type of sensor used. The results are displayed directly on the device screen. The accuracy of this setup is 5 %, the temperature range of measurement test is from 20 °C to 30 °C for thermal conductivity materials from 0.01 to 10 $W.m^{-1}K^{-1}$.

3. Results and discussion

3.1. Moisture content

Fig. 2 shows the drying of various date palm fibers starting from 30 °C to 130 °C. The data are plotted as density and as mass loss versus temperature. These show an initial rapid drying, following Fickian behavior but then a certain amount of water remains in the sample even after long drying times. The first stage of drying was the evaporation of moisture where the temperature ranged from 30 °C to 85 °C. As the fibers were heated, the weight of material decreased via a release of the bound water and volatile extractives. This phenomenon is common for plant fibers and makes the fiber more flexible and easy to collapse, as well as improving the heat transfer heat [17]. However, the structurally bound water molecules are resistant to complete water removal during drying process due to the hydrophilic nature of plant fibers. The mass loss varied within the range 3 % to 5 % for all the fibers. These results are lowers than previous observations done by *White et al.* [18] who found high mass loss between 5 % and 10 % during evaporation of moisture when they studied different agricultural plant fibers. This may be due to many factors which may influence these values, like the atmospheric conditions, type of fibers, age of plants, soil condition in which the plant was grown and the method and duration of preservation.

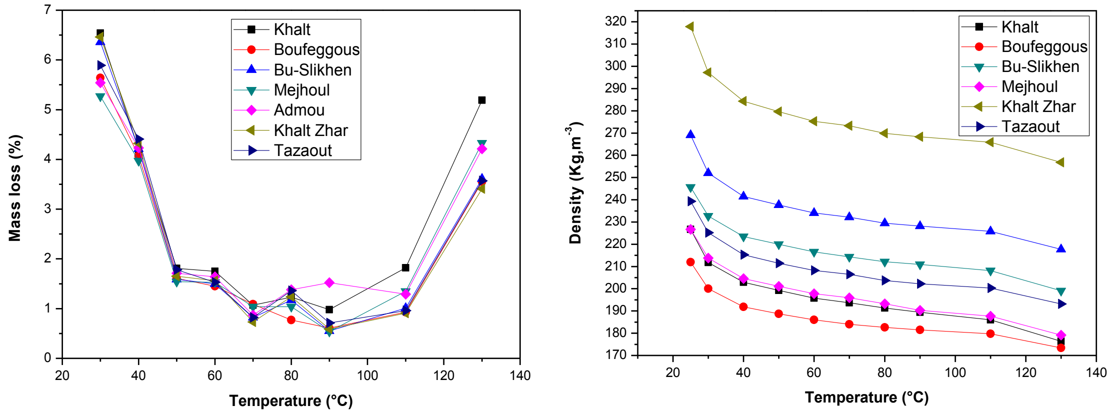

Fig. 2: Drying behavior of all the various date palm fibers: Density and Mass loss versus temperature.

3.2. Water up-take behavior

The water-absorption patterns of the seven varieties of LDPF are presented in Fig.3. The samples presented the characteristic moisture absorption behaviour. The wood samples exhibited an initial high rate of moisture sorption followed by slower absorption in the later stages (Kumar and Flynn, 2006) which can be explained by the hydrophilic nature of this type of wood and the reactivity of its chemical components consisting essentially of cellulose and hemicelluloses (Fig.3).

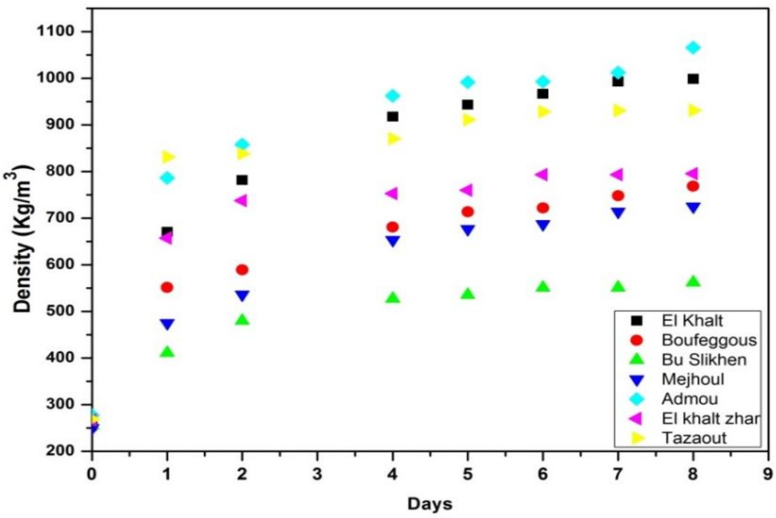

Fig. 3: Water uptake behavior of different varieties of LDPF

3.3. Tensile test of single fibers

Tensile strength and tensile modulus are the most important properties of natural fibers which were determined in this paper. The results of the measurements of the different varieties of local date palm fibers are shown in Fig.4. It is observed that the tensile strength varies between 86.98 MPa for the variety of *Khalt Zhar* and 253.48 MPa for the variety of *Boufeggous* with an average of tensile modulus of about 4.41 GPa.

Indeed, the mechanical performances of the different varieties of date palm fibers are influenced by complex interactions between numerous external variables and inherent structural characteristics at molecular, macromolecular, and microscopic levels. Similar effects from other factors can be noted such as cellulose, lignin, and hemicelluloses content, degree of polymerization, or crystallinity, microscopic and molecular defects of fiber's wall, and the presence of moisture or other introduced chemicals, for mechanical performance reasons, the rest of this study will be conducted using the variety of *Boufeggous*.

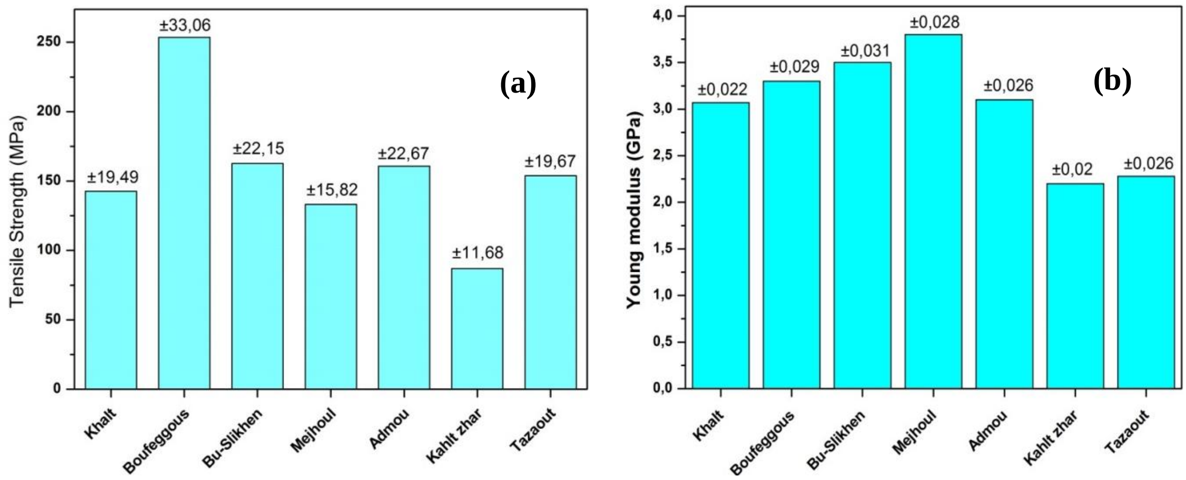

Fig. 4: Mechanical properties of different varieties of LDPF: (a) Tensile strength and (b) Young modulus

3.4. Scanning electron microscopy (SEM)

Scanning electron microscopy analysis of the date palm fibers of *Boufeggous* variety was investigated to characterize the microstructure of the sample. The results show that the date palm fiber has a cylindrical form and consists of a parallel assembly of microfibrils (Fig.5d), it can be also noted that the surface of fibers is irregular and rough with the existence of many impurities and salt coming essentially from the Saharan nature of the source of this kind of palm (Figs 5a and 5b).

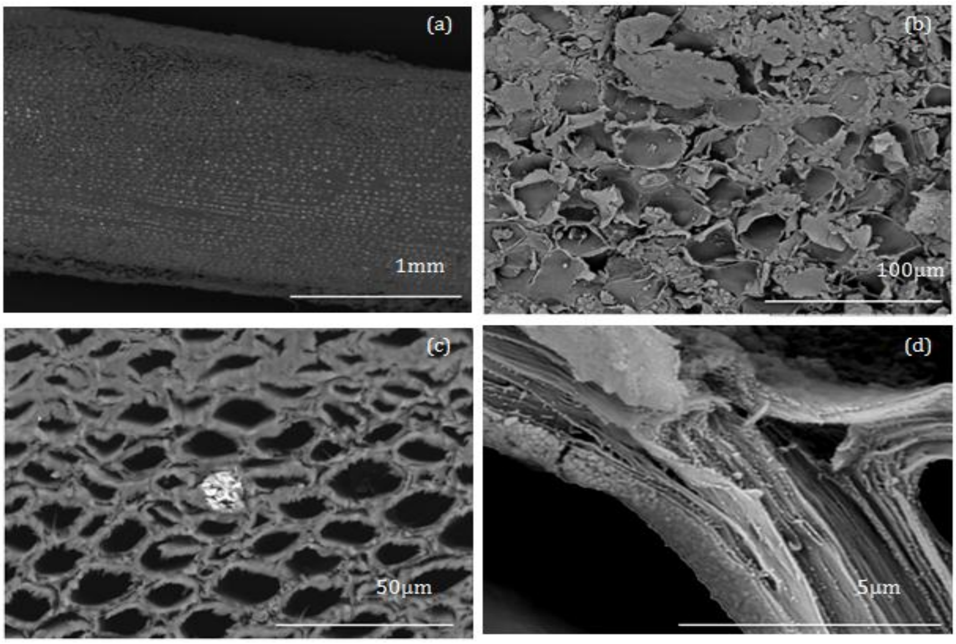

Fig. 5: SEM images of a LDPF of *Boufeggous* variety: scale (a) 1 mm (b) 100 µm (c) 50 µm and (d) 5 µm

These observations are similar to those reported in the literature on the fibers extracted from the date palm tree [19-21], indeed the structure and the shape of fibers of date palms are similar to those of coir fibers [22, 23], All these kinds of fibers are cylindrical in shape and each fiber consists of multicellular fibers each containing a central void (lumen).

3.5. Energy dispersive spectroscopy analysis (EDS)

In order to investigate on the chemical composition of date palm fibers, energy dispersive spectroscopy analysis (EDS) was used. Two different points from the fiber were analyzed:

The first point was focused on the external part of the fiber; it was found that carbon and oxygen were the major consistent compounds in these LDPF varieties with atomic percentages of about 47.50 % and 41.84 % respectively (Fig.6, table 1). The second point has shown that the impurity is composed essentially of different oxides such as iron oxide, chromium oxide, nickel oxide and silicon oxide (Fig.7, table 2).

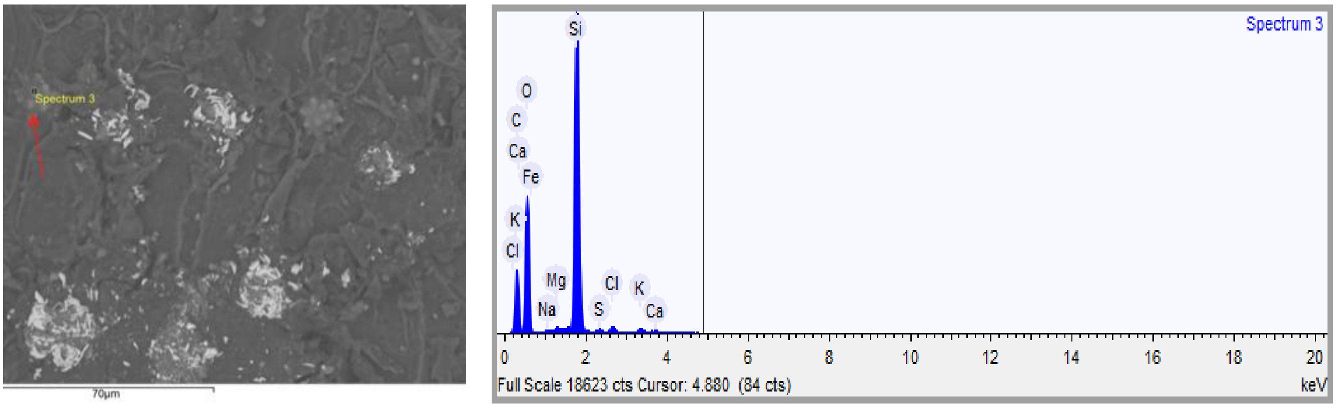

Fig. 6: EDS analysis of the 1st analyzed point

Table 1: Chemical composition of the 1st analyzed point

Elements	% weight	% weight σ	% atomic
Oxygen	43.359	0.602	41.843
Carbon	36.954	0.848	47.501
Silicon	18.015	0.252	9.903
Chlorine	0.506	0.023	0.220
Potassium	0.326	0.022	0.129
Sulfur	0.205	0.019	0.099
Magnesium	0.185	0.018	0.117
Iron	0.181	0.041	0.050
Calcium	0.151	0.021	0.058
Sodium	0.119	0.021	0.080

Table 2: Chemical composition of the 2nd analyzed point

Elements	% weight	% weight σ	% atomic
Iron	60.239	0.327	46.533
Chromium	16.121	0.169	13.375
Oxygen	9.763	0.316	26.326
Nickel	7.509	0.220	5.517
Silicon	2.680	0.073	4.117
Manganese	1.486	0.133	1.167
Chlorine	0.909	0.060	1.106
Potassium	0.649	0.054	0.716
Magnesium	0.644	0.080	1.142

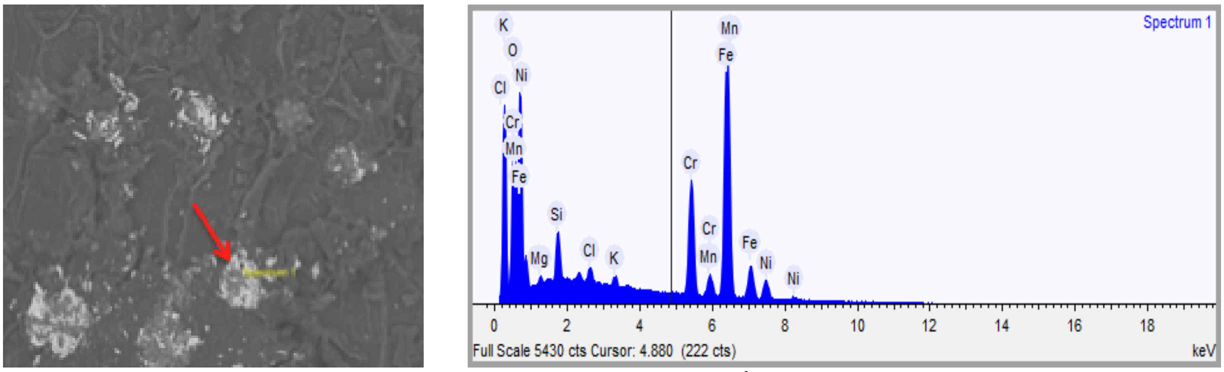

Fig. 7: EDS analysis of the 2nd analyzed point

3.6. Thermal conductivity

The thermal conductivity of wood of date palm was determined at 25 °C. The sample effusivity is about the 163.36 W.s$^{1/2}$/m^2.K while the thermal conductivity is about 0.041 W/m.K. These values are comparable to those found for other products (Cotton, kenaf, cattail fiber…) [24] and it turned out that the date palm has a thermal insulation capacity rather interesting.

Conclusion

This paper reports the results of an experimental investigation on the physical and mechanical properties of seven varieties of Moroccan date palm fibers (*Phoenix Dactylifera L.*), as well as the thermal conductivity, microstructure and chemical composition of the species which was found to have the most important mechanical properties compared with other varieties. The goal, as mentioned above, was to use this natural material for further development and design of natural efficient and safe thermal insulating. As results, *Boufeggous* date palm specie showed higher tensile strength and tensile modulus than the other species. It can be also noted from the microstructure and the chemical composition analysis that carbon and oxygen were the only consistent compounds in this variety and the surface of fibers is irregular and rough with many impurities, cells and pores. When compared with other natural and synthetic insulating materials, the thermal conductivity of *Boufeggous* date palm specie did not exceed the maximum value (0.041 W.m^{-1}.K^{-1}), therefore, it can be concluded that the date palm wood of the *Boufeggous* varieties can be used as thermal insulating material because of its low thermal conductivity, resulting in high thermal resistivity and high resistance to heat flow.

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References

1. Agency of Toxic Substances and Disease Registry (ATSDR), Toxicological profile for synthetic VitreousFibers, Department of Health and Human Services, Atlanta, U.S., 2004.
2. Infante P.F., Schuman L., Dement J., Huff J., *Am.J. Ind. Med.* 26 (1994) 559-584.
3. U.S. Environmental Protection Agency, Health and Environmental Effect Profile for Formaldehyde, Cincinnati: Environmental Criteria and Assessment Office, Office of Health an Environment Assessment, Office of Research and Development, 1988.
4. Akpabio G. T., *Global J. Pure Appl. Sci.* 5 (1) (1999) 139-141.
5. Al-Homoud M.S., *Build. Environ.* 40 (2005) 353-366.
6. Collieu A.M. B., Powney D.J., *London: Edward Arnold* (1977) 64-73.
7. Occupational Safety and Health Administration, (2003). Synthetic Mineral Fibers: Health Hazards. United State Department of Labor.
8. Chikhi M., Agoudjil B., Boudenne A., Gherabli A., *Energ. Buildings* 66 (2013) 267-273.
9. Liu K., Takagi H., Osugi R., Yang Z., *Composite: Part A* 43 (2012) 1234-1241.

10. Kauriinvaha E., Viljanen M., Pasila A., Kymäläinen H-R., Pehkonen A., (2001). *Helsinki University ofTechnology*,Publications TKK-TRT-117.
11. Barreveld W. H., *Date palm products. Rome: Food and Agriculture Organization of the United Nations*; ISBN 92-5-103251-3; 1993.
12. Food and Agriculture Organization of the United Nations. FAOSTAT 2010 food and agricultural commodities production; 2012.
13. Zouine J., Embryogenèse somatique chez Phoenix dactyliferaL.: amélioration des conditions de culture et étude de paramètres biochimiques impliqués dans la multiplication, la maturation et la germination des embryons somatiques. *Thesis, Université Cadi Ayyad de Marrakech, Maroc*; 2007.
14. Chao C.C.T., Krueger R.R., *Hort. Science* 42 (2007) 1077-82.
15. Ndazi B., Tesha J., Bianda E., *J. Mater. Sci.* 41 (2006) 6984.
16. Sallée H.,CT.Meter Manual Users', CSTB Grenoble, FT131099-A.
17. Kriker A., Bali A., Debicki G., Bouziane M., Chabannet M., *Cement Concrete Comp.* 30 (2008) 639–648.
18. White J. E., Catallo W.J., LegendreB.L., *J. Appl. Pyrol.* 91 (2011) 1-3.
19. Al-Khanbashi A., Al-Kaabi K., Hammami A., *Polym Composite* 26 (2005) 486–497.
20. Kriker A., Debicki G., Bali A., Khenfer M., Chabannet M., *Cement Concrete Comp.* 27 (2005) 554–564.
21. John M.J., Anandjiwala R.D., *Polym. Composite* 29 (2008) 187–207.
22. Rout J., Misra M., Tripathy S., Nayak S., Mohanty A., *J. Appl. Polym. Sci.* 84 (2002) 75–82.
23. Kumar A., Flynn P.C., *Fuel Process Technol.*87 (2006) 605–608.
24. Luamkanchanaphan T., Chotikaprakhan S., Jarusombati S., *APCBEE Procedia* 1 (2012) 46–52.

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