Original Article

JOURNAL OF REINFORCED PLASTICS & COMPOSITES

Journal of Reinforced Plastics and Composites
0(0) 1–10

DOI: 10.1177/0731684415588356
jrp.sagepub.com
SAGE

Potential utilization of date palm wood as composite reinforcement

Kenza Almi[1], Adel Benchabane[1], Said Lakel[2] and Abdelouahed Kriker[3]

Abstract

This research reports the results of an experimental study on the physical, chemical, and mechanical properties as well as the thermal behavior of eight varieties of date palm residues coming from the same environment. The aim is to evaluate each variety of this natural material to be used thereafter, individually or as a mixture, in the manufacturing of composite materials. The results show that Rachis variety exhibits relatively high values of tensile strength and Young's modulus; they attained 213 MPa and 8.5 GPa, respectively. In contrast, Petiole variety exhibits relatively high values of specific mechanical properties. This is due to its low value of bulk density, which is 0.160 g/cm^3. Besides that, Petiole variety is also characterized by relatively high porosity and high rate of water absorption; they reached 81.52 and 140%, respectively. Results of thermal analysis show that Leaflets variety provides the highest resistance to thermal degradation; its main degradation occurred at 360°C.

Keywords

Composite materials, natural reinforcement, date palm fibers

Introduction

With growing concern about depletion of fossil resources and environmental risks caused by their overusing, it is expected that the world is heading for renewable natural resources such as biomass resources. Natural fibers as reinforcement have a great interest in new technologies dealing with environmental aspect.[1–4]

Date palm tree residues are one of the interesting sources of the natural fibers since they are renewable and abundantly available. Palm tree provides eight kinds of residues (Petiole, Rachis, Leaflets, Fibrillium, Bunch, Pedicels, Spathe, and Thorns) collected from the seasonal pruning process as an essential agricultural practice (Figure 1). A survey carried out among farmers and agricultural organizations in the region of Biskra has estimated that approximately 47.57 kg of palm residues is obtained per tree annually. This quantity of residues is made up of 28.7% Leaflets, 27% Rachis, 23.9% Petioles, 6.3% Fibrillium, 5% Spathes, 4.9% Bunches, 3.3% Pedicels, and 0.8% Thorns. According to the direction of the agricultural services of Biskra region (Algeria), the number of palm trees exceeds 15 million in Algeria, last decade. This number is in increase every year and sheds huge quantity of biomass which is also in increase annually (Figure 2). In fact, this natural resource is not enough exploited as much as many other natural fibers such as jute, flax, ramie, hemp, and fleece fibers which their use as reinforcement is taking place in several industrial applications.[5,7] Despite the multiple studies on its use as composite reinforcement, date palm wood is not yet used adequately in industry. One of the reasons is the lack of information about the material properties

[1]Laboratoire de Génie Energétique et Matériaux, LGEM, Université Mohamed KHider, BISKRA: BP 145 RP, 07000 Biskra, Algérie
[2]Laboratoire de Matériaux Semi Conducteurs et Métalliques, LMSM, Université Mohamed KHider, BISKRA: BP 145 RP, 07000 Biskra, Algérie
[3]Laboratoire EVRNZA, université, Kasdi Merbah, OUARGLA: Route de Ghardaia 30000 Ouargla, Algérie

Corresponding author:
Kenza Almi, Laboratoire de Génie Energétique et Matériaux, LGEM, Université Mohamed KHider, BISKRA: BP 145 RP, 07000 Biskra, Algérie.
Email: almi.kenza@yahoo.fr

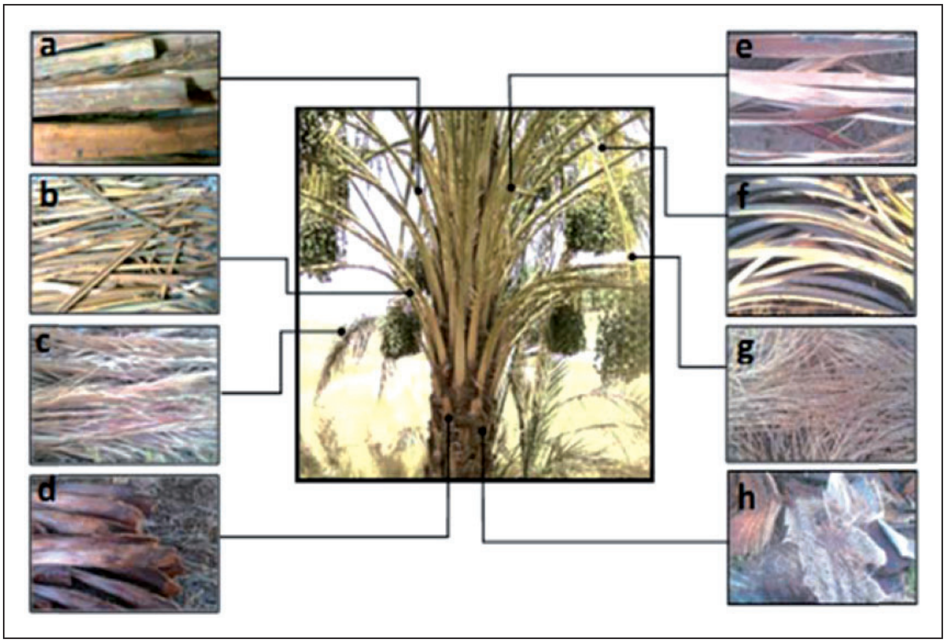

Figure 1. Different parts of date palm wood: (a) Rachis, (b) Thorns, (c) Leaflets, (d) Petiole, (e) Spathe, (f) Bunch, (g) Pedicels, (h) Fibrillium.

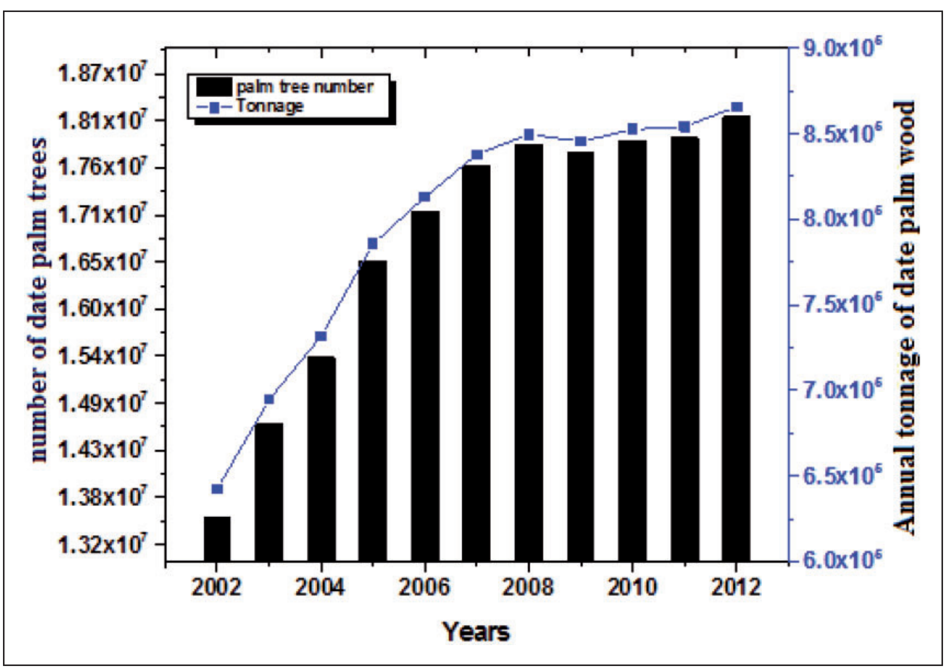

Figure 2. Estimation of annual number of date palm trees and annual tonnage of date palm wood in Algeria.

especially about its behavior after its insertion in various industrial matrices. Most of the work carried out on this subject reported some properties of some kinds of date palm wood,[8–12] that represent a small percentage of the entire biomass offered by the date palm tree. No reference is found in literature concerning the properties of all kinds of date palm tree residues. Knowledge of these properties is required to optimize the industrial process and materials especially when they are used as a mixture.

This research is a preliminary study to a global study about the potential utilization of all kinds of date palm residues as a mixture in manufacturing new biomaterials. To attain this objective, there is a need to a global characterization of each part of palm tree residues which are Petiole, Rachis, Leaflets, Fibrillium, Bunch, Spathe, Pedicels, and Thorns. Thus, this paper aims to offer significant basic data for the mentioned varieties through the evaluation of their chemical, physical, and mechanical properties in addition to their thermal stability and comparing them with other commonly used natural fibers.

Experimental part

Raw materials

Materials used in this research have more than one year since they have been collected. They were obtained from trees of 40 years old from Borj-Rose Oasis in Biskra region situated at south east of Algeria. According to the direction of agricultural services in the same region, there are more than four million of palm trees, 61.45% of them are Deglet-Noor palm trees. For that reason, we have chosen the samples from this variety of palm tree.

Preparation of samples

Eight varieties of date palm wood (Petiole, Rachis, Leaflets, Thorns, Spathe, Bunch, Pedicels, and Fibrillium) were investigated (Figure 1). Samples chosen from each variety were hewed to get rid of degraded parts and then they were cleaned with water to remove dust and impurities. Fibrillium meshes were separated in water into individual fibers. Petiole, Rachis, Spathe, Bunch, and Pedicels were cut into two or three pieces and all the eight varieties of date palm wood were oven dried. Afterward the samples were prepared according to the characterization experiment: as fibers cut to the desired length, small pieces, or powders.

Methods of characterization

Chemical analysis. Ash content of samples was determined after the ignition of the samples in a muffle furnace at 550°C during 5 h until all the carbon is eliminated. Ash content was calculated as a percentage of residues based on the oven-dry samples weight. Contents of celluloses, hemicelluloses, lignin, and products solubilized in hot water were determined using the procedures described in the literature.[13,14] The content of extractive in samples was determined using Soxhlet extraction apparatus with ethanol–toluene mixture for 4 h. The contents of cellulose brute, which is the organic matter remaining insoluble after the acid and alkaline treatment, were calculated according to the Weende method.[15]

Physical analysis. Bulk density of samples was determined by the gravimetric method based on the Archimedean principle,[16] on a balance with a precision of ±0.1%. Ten portions of different volumes taken from each sample were tested, under the following climatic conditions, $T = 30 \pm 2°C$ and $RH = 65 \pm 2\%$.

Absolute density was determined by measuring the real volume of the samples. For that, samples were ground into meal and were compressed to 70 MPa for eliminating air volume. The absolute density is the ratio of the compressed mass to its volume. Water absorption of the samples was measured according to standard ASTM C127/88.[17] The mean porosity (P) of the samples was calculated by the following equation[8]

$$p = 1 - \left(\frac{Bulk\ density}{Absolute\ density}\right)$$

Mechanical analysis. The mechanical properties (tensile strength, elongation, and modulus of elasticity) of the eight parts of date palm residues were determined in accordance with standards NF EN ISO 5079,[18] under the following climatic conditions, $T = 28 \pm 2°C$ and $RH = 65 \pm 2\%$, using an electromechanical universal testing machine WDW. To avoid the slipping or breaking of the fiber's extremities, two plywood (4 cm × 4 cm) scratched in the middle are inserted between the two grips of the tensile testing machine to maintain the two fiber extremities. Five fibers of each sample were tested. The tensile test lengths were chosen to be 100 mm for all the samples and the crosshead speed employed was 0.5 mm/min.

Thermal analysis. The thermal behavior of the samples was studied under inert atmosphere using a LINSEIS 2400 (Thermal analysis TGA and DTA Instrument) at a heating rate of 5°C/min from 25°C temperature to 700°C.

Results and discussion

Chemical properties

Table 1 summarizes the chemical composition of the eight kinds of date palm wood. The results show that there is no significant difference between the samples on the contents of cellulose, hemicellulose, and lignin. Nevertheless, it can be noted that lignin content in Rachis is relatively high compared to the lignin contents in the other samples. The high content of lignin in Rachis is also observed in the results reported by

Table 1. Chemical composition of date palm wood.

Samples	Extractives wt %	Hot water solubility wt%	Ash wt %	Cellulose Brute wt %	Lignin wt %	Hemi-cellulose wt %	Cellulose wt %
Petiole	13.86	27.00	3.70	23.97	26.03	20.44	33.79
Rachis	7.68	17.67	4.00	54.02	33.00	19.35	41.42
Thorns	7.55	14.00	5.52	56.29	30.10	21.17	35.05
Leaflets	9.56	22.64	2.62	49.00	28.57	20.05	38.58
Bunch	10.27	11.45	5.14	59.77	29.97	20.68	39.82
Pedicels	5.89	12.26	3.05	68.29	27.64	21.15	33.29
Spathe	5.38	29.42	5.10	43.27	28.27	19.10	42.48
Fibrillium	4.32	3.37	1.55	82.28	27.80	21.68	43.94

other work,[12,19,20] but in this work it was higher. This may be related to the climate conditions and to the soil chemical composition in which the plants are growing.

It can be observed also that Petiole, Bunch, and Leaflets are characterized by high amounts of ethanol–toluene extractives while Fibrillium, Leaflets, and Pedicels are characterized by low ash contents which are very close to those known for nonwoody biomass.[12]

The high ethanol–toluene extractives in Petiole, Bunch, and Leaflets varieties could be an advantage for decay resistance when they are used as compressed wood[21] and the low ash contents in Fibrillium, Leaflets, and Pedicels can positively affect the processing machinery.[22] Furthermore, the high content of cellulose brute in Fibrillium and Pedicels indicates that these varieties are more resistant in acid and alkaline environment which makes them more suitable to reinforce alkaline matrix.

Compared to the chemical composition contents of natural fibers reported in literature[14,23] (Figure 3), date palm wood contains lower amount of cellulose. Nevertheless, the cellulose content in Leaflets, Bunch, Rachis, Spathe, and Fibrillium is close to that of coconut and bamboo, and it belongs to the range of 38–45% which is compatible to the reported cellulose content of softwoods (40–52%) and hardwoods (38–56%). Cellulose contents in this range make these parts of palm tree a suitable raw material for the paper and pulp industry.[22] It can be noted also from Figure 3, that date palm wood is rich in lignin and it is close to lignin content of coconut. Like in coconut wood, the higher lignin content makes palm wood very tough and stiffer compared to the other natural fibers and contributes to its flexibility and its hydrolysis rate. The structural rigidity of the palm wood makes it a valuable building material.[24]

Physical proprieties

Table 2 presents the physical properties of the eight varieties of date palm wood. It could be noted that Rachis and Bunch wood had higher values of density in relation to the other kinds examined in this work. According to the wood classification reported in the literature,[25] Rachis and Bunch wood are considered as light wood 500–650 kg/m^3. While Petiole, Fibrillium, Spathe, Leaflets, Pedicels, and Thorns wood are classified as very light wood ($<500\,kg/m^3$), which makes them soft and easy to handle according to the same reference.

The lightness of palm tree wood is remarkable compared to the other reinforcement fibers.[23] On the one hand, it is an advantage for reducing industrial consumption. On the other hand, it influences other properties and consequently influences its processing and utilization.

Concerning the rate of water absorbed after 24 h by mass, the results show that Petiole, Spathe, and Fibrillium have relatively high values compared to other parts. Petiole's rate reached 140%, is lower than mean rate of absorption of sisal 230%, and higher than that of coconut[3] which was 100%. The mean rate of absorption of Rachis, Thorns, Pedicels, Bunch, Leaflets was lower than that of coconut, and this could have a beneficial effect on the chemical treatment consumption to reduce the moisture absorption of the fibers especially of the Rachis 36.88%.

Globally, the rate of water absorption of the eight samples varies in direct ratio to the mean porosity value shown in Table 2. Petiole, Fibrillium, and Spathe are noted to have high values of porosity; it attains 81.52% in the case of Petiole which is less than straw porosity 96%[26] and more than that of many other natural fibers. Indeed, this latter property contributes mainly in the absorption process that is why Petiole has the ability to absorb a great quantity of water compared to the other parts. However, on the other hand, porosity is responsible for the excellent properties of thermal and acoustic insulation of the material. Thus, the use of Petiole, Fibrillium, and Spathe varieties by reason of these properties will be advantageous.[10]

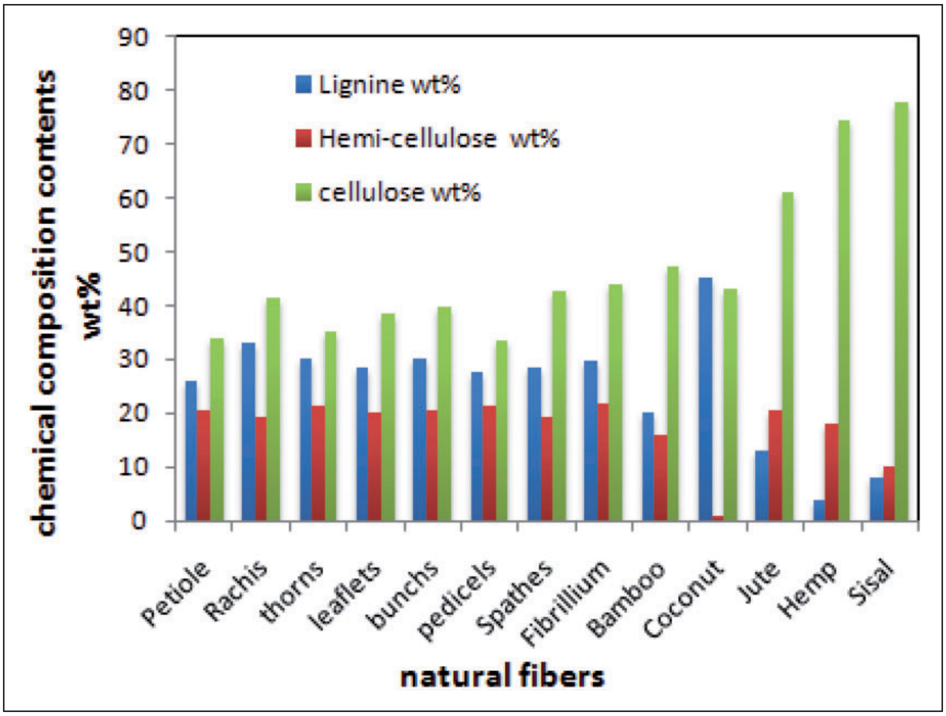

Figure 3. Chemical composition of date palm wood compared to other natural fibers.

Table 2. Physical properties of date palm wood.

Property	Petiole	Rachis	Thorns	Leaflets	Bunch	Pedicels	Spathe	Fibrillium
Bulk density (kg/m^3)	160 ± 54	635 ± 22.8	431 ± 39.8	411 ± 41.4	555 ± 11.8	425 ± 23.6	328 ± 42.4	209 ± 31.7
Absolute density (kg/m^3)	866 ± 20.5	751 ± 10.2	716 ± 22.2	830 ± 23.6	826 ± 13.7	749 ± 25.6	897 ± 10.4	786 ± 23.6
Water absorption (% by mass)	146.32 ± 21	36.88 ± 10	83.85 ± 3.1	96.6 ± 1.4	63.2 ± 5	73.78 ± 3	130.83 ± 2	115.11 ± 15.7
Porosity (%)	81.52	15.44	39.80	50.6	32.8	43.25	63.43	73.41

Table 3. Mechanical properties of date palm fibers.

Property	Petiole	Rachis	Thorns	Leaflets	Bunch	Pedicels	Spathe	Fibrillium
Diameter (mm)	0.40–1.00	0.60–0.75	0.70–0.73	0.35–0.90	0.30–0.50	0.63–0.77	0.43–0.51	0.50–0.80
Tensile strength (MPa)	90 ± 8.87	213 ± 58	95.35 ± 48	100.12 ± 43.87	113.95 ± 54	86 ± 5.00	120.5 ± 12.5	90 ± 30,70
Elongation (%)	0.95 ± 0.42	4.38 ± 1.96	3.67 ± 1.14	2.68 ± 0.49	3.37 ± 1.39	2.37 ± 0.15	2.41 ± 0.05	4.59 ± 0.90
Young's modulus (GPa)	7.00 ± 2.00	8.50 ± 2.33	3.87 ± 2.13	4.00 ± 1.33	4.33 ± 2.67	3.00 ± 1.00	5.00 ± 1.00	3.66 ± 2.33

Mechanical proprieties

The average value of the tensile strength, elongation at break, and the modulus of elasticity of each sample are summarized in Table 3. The results show that the mechanical properties of the eight date palm tree residues differed slightly. The highest value of tensile strength and of Young's modulus is that of Rachis and this may be due to its chemical and physical properties (relatively high content of cellulose and less rate of porosity as shown in Tables 1 and 2).

Tensile strength and Young's modulus values of Fibrillium fibers obtained in this work are comparable to those reported in the literature,[8,27] but those of

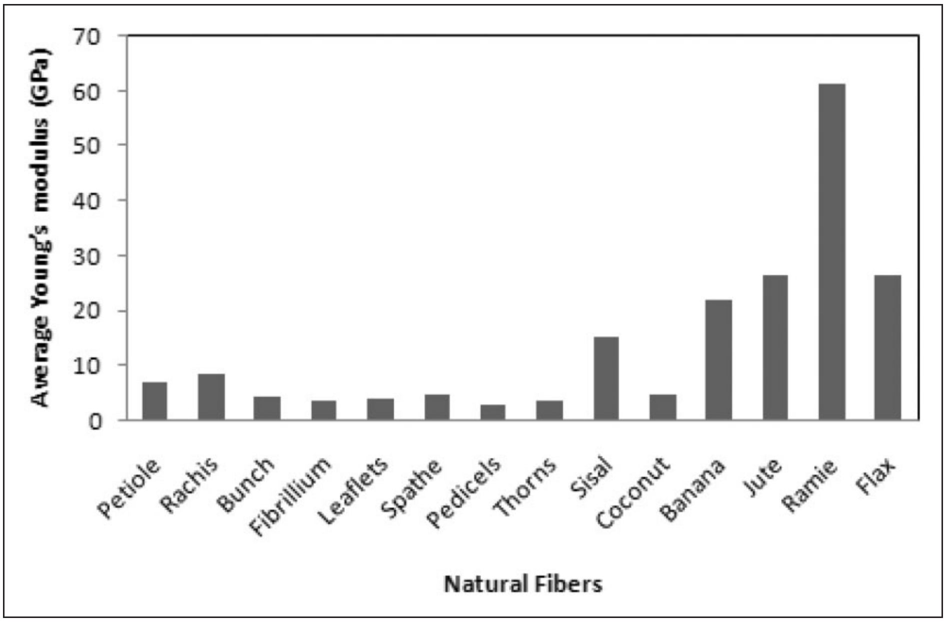

Figure 4. Average Young's modulus of date palm fibers compared to other natural fibers.

Petiole obtained in this work are significantly higher than those of literature.[28] This difference can be attributed to several factors such as the different sources of fibers, the different conditions of test, the defects (cracks) of cellulose fiber, and the breaking mechanism of fiber.[29] Those could be also the reason for the great dispersion of the mechanical testing results even under carefully controlled conditions of laboratory. It can be noted also that all samples except Petiole have a significant elongation at break. This could have a relation to the high content of lignin which characterizes date palm wood, as it is known; the lignin was the chemical component responsible on the tenacious and elastic behavior of the fiber;[24,29] nevertheless, date palm wood fibers range among the natural fibers which have weak mechanical properties.

Figure 4 shows that Young's modulus values of date palm fibers are close to that of coconut fibers and are considerably lower than those of most vegetable fibers.[30] This can be explained by the physical structure of the natural fibers such as the crystal structure, the degree of crystallinity, the spiral angle of the fibrils, the degree of polymerization, the porosity content, and the size of the lumen in addition to the chemical composition.[6] However, when the specific modulus (Young's modulus/bulk density) is considered, date palm tree fibers indicate values which are comparable or better than those of other natural fibers[30] as is shown in Figure 5. These higher specific properties constitute one of the principal advantages of the use of composites with date palm fibers in the applications which require at the same time a high strength and a light weight.

Thermal behavior

The thermal analysis TGA and DTA of each sample, under inert atmosphere, are shown in Figure 6. The results indicated slight differences between the evolution profiles of the thermal degradation TGA and DTA of the eight samples. All present the same tendencies of mass loss according to the increase in the temperature. The TGA curves show three principal phases in the evolution of pyrolysis.

The first phase corresponds to a mass loss of 14.80, 9.47, and 6.81% for the Petiole, Spathe and Fibrillium observed, respectively, in the intervals 75–200, 110–220, and 110–250°C. For the other samples, this phase is characterized by an endothermic phase until 230°C. Loss mass in this phase is attributed primarily to the dehydration[31] and elimination from volatile compounds,[4] in addition to the degradation of part of lignin.[32] The relatively earlier loss mass observed from Petiole, Spathe, and Fibrillium pyrolysis could be due to simultaneous moisture and low temperature volatiles release of these varieties compared to the others.

The second phase started approximately at 200, 220, 240, and 250°C for Petiole, Spathe, Thorns, and Fibrillium, respectively, and at 230°C for Bunch and Rachis and at 260°C for Pedicels and Leaflets. It ended at 460, 420, 420, 410, 450, 470, 400, and 450°C, for the same order of pyrolysis. The curves of TGA in the second phase are characterized by very strong slopes corresponding to significant losses of mass 66.3, 65.79, 63.15, 69.45, 61.5, 63, 69.66, and 56.66% of the same samples sequence. This second weight loss corresponds to the decomposition and the oxidation

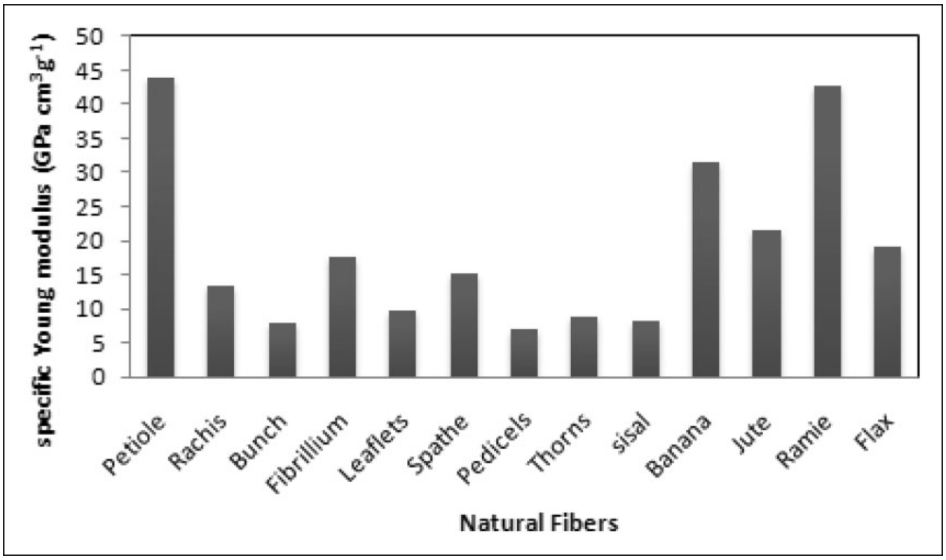

Figure 5. Specific Young's modulus of date palm fibers compared to other natural fibers.

pyrolytic of the dry vegetable material. According to the literature,[4,32] the temperature interval of this phase corresponds to the destruction temperatures of hemicellulose, cellulose, pectin, and part of lignin.

The third phase started from the ends of the second phase and continues beyond 600°C for all samples. This phase is characterized by a reduction of the speed of mass loss. It corresponds to the pyrolytic destruction of the remainder of the organic matter (lignin) transformed for the majority into products carbonized during the second phase. According to the literature,[32] lignin degrades on a wide range of temperature which goes from 160 to 900°C.

It is clearly observed from Figure 7 that Leaflets exhibited more resistance to thermal degradation than other samples. This can be related to the elemental and chemical compositions of the samples.[33]

The DTA curves of the eight palm tree residues indicate two exothermic peaks. The first peak located at 320°C for Petiole, Spathe, and Fibrillium, at 350°C for Bunch and Rachis, at 340°C for Thorns, at 330°C for Pedicels, and at 360°C for Leaflets. It is attributed to the thermal depolymerization of hemicellulose and pectin. The second peak located around 400°C for all the samples. It is related to the decomposition of cellulose. This peak is not easily observable except on the Petiole curve (Figure 6(a)) where it is localized at 440°C. Thus, the main degradations of date palm wood occurred at temperature beyond 320°C.

Compared to other natural fibers, the first peak of date palm fibers notably that of Leaflets is located at a higher temperature than that of sisal, coconut, and bamboo[15,33] and it is close to that of hemp.[34]

Conclusion

The present study investigated the chemical, physical, and mechanical properties in addition to the thermal behavior of date palm wood from Biskra region. Eight kinds of palm wood obtained from date palm tree residues are investigated.

The results show that the eight parts of date palm wood consist mainly of cellulose, hemicellulose, and lignin with an average of 40, 20, and 28 wt%, respectively. They are characterized by low value of density which is generally less than 600 kg/m^3 and low rate of water absorption (under 100% except for Petiole, Spathe, and Fibrillium). Date palm wood ranges among the materials which have weak mechanical properties (the tensile strength ranged from 86 to 213 MPa, Yong modulus ranged from 3 to 8.5 GPa, and elongation at break close to 3%); however, it is characterized by high specific properties which constitute one of the principal advantages of use it to develop lightweight and high strength materials.

Thermogravimetric analysis of date palm tree fibers indicated that date palm fibers are suitable as reinforcement for making composites even with thermoplastic matrix materials whose processing temperature is less than 320°C.

Based on the results presented in this paper, further research should be developed to study the possibility of using all kind of date palm wood as a mixture in manufacturing new materials. The results of this further research will be published in a forthcoming paper.

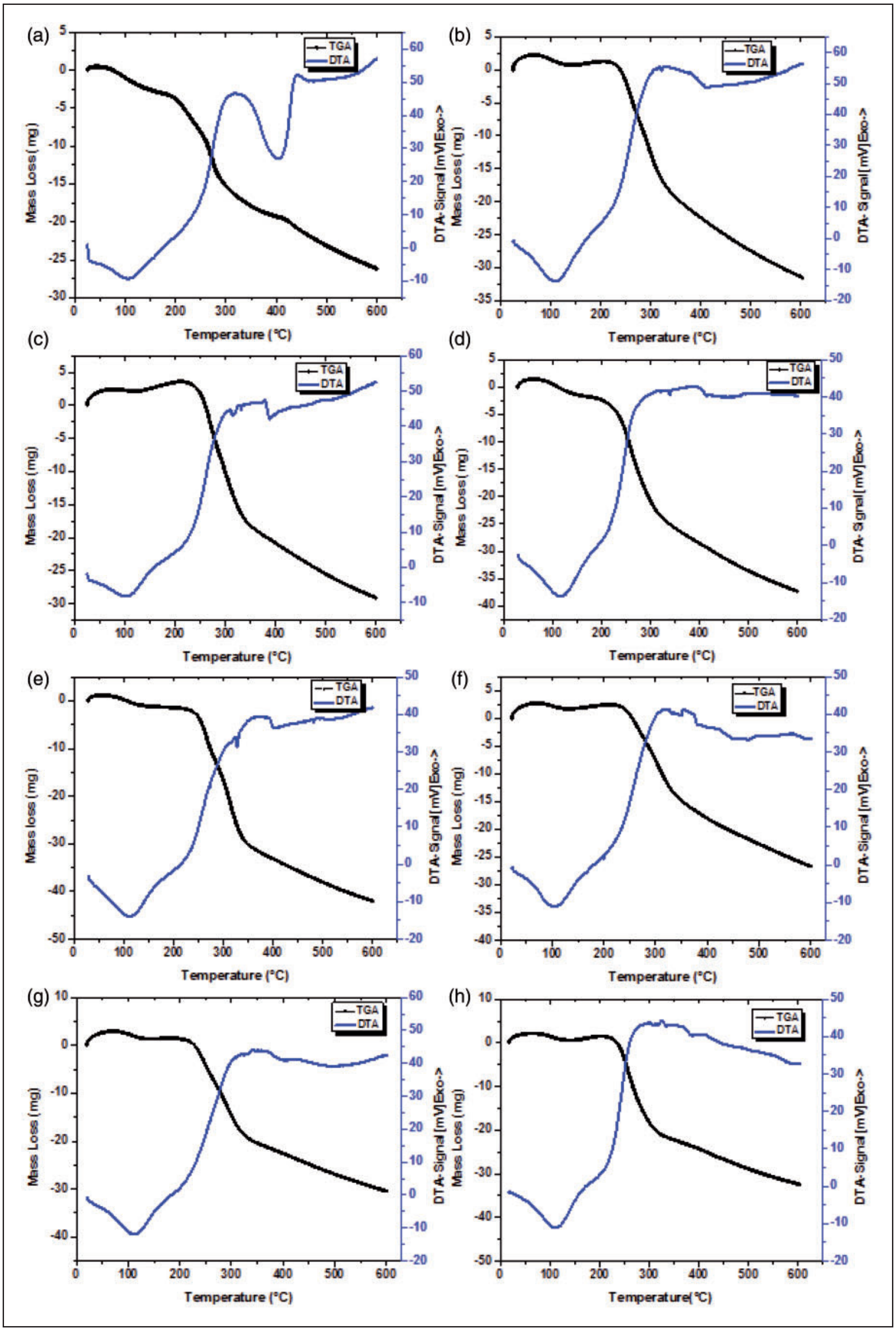

Figure 6. Thermal analysis of date palm wood: (a) Petiole, (b) Thorns, (c) Pedicels, (d) Spathe, (e) Fibrillium, (f) Leaflets, (g) Rachis, (h) Bunch.

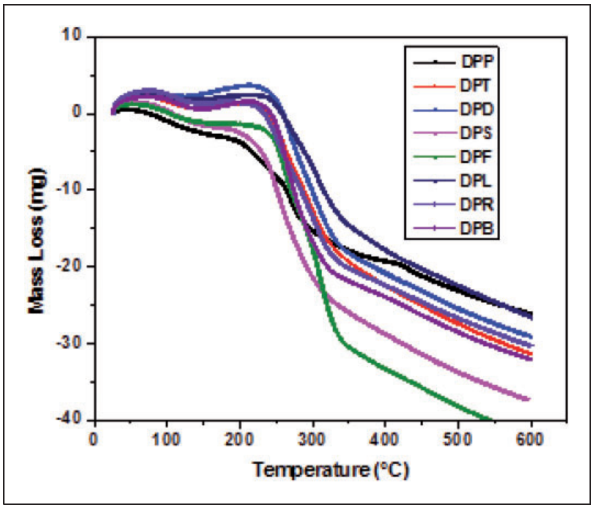

Figure 7. Thermogravimetric curves of date palm wood: (DPP)Petiole, (DPT)Thorns, (DPD)Pedicels, (DPS)Spathe, (DPF)Fibrillium, (DPL)Leaflets, (DPR)Rachis, (DPB)Bunch.

Acknowledgment

The authors are grateful for the assistance of Mrs Sakina Bencharef teacher at the University of Biskra.

Conflict of Interest

None declared.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

References

1. Sbiai A, Kaddami H, Fleury E, et al. Effect of the fiber size on the physicochemical and mechanical properties of composites of epoxy and date palm tree fibers. *Macromol Mater Eng* 2008; 293: 684–691.
2. Taj S, Munawar AM and Shafiullah K. Natural fiber reinforced polymer composites. *Proc Pakistan Acad Sci* 2007; 44: 129–144.
3. Tolêdo Filho RD, Scrivener K, England GL, et al. Durability of alkali-sensitive sisal and coconut fibers in cement. *J Cem Concr Compos* 2000; 22: 127–143.
4. Nenonene AY. *Elaboration et caractérisation mécanique de panneaux de particules de tige de kénaf et de bioadhésifs à base de colle d'os, de tannin ou de mucilage*. Thèse doctorat, 2009, Université de Toulouse.
5. Bledzki AK, Izbicka J and Gassan J. *Kunststoffe-Umwelt-recycling*. Stettin, Poland, 1995, pp.27–29.
6. Bledzki AK and Gassan J. Composites reinforced with cellulose based fibers. *Prog Polym Sci* 1999; 24: 221–274.
7. Wittig W. *Kunststoffe im Automobilbau*. Dusseldorf: VDI-Verlag, 1994.
8. Kriker A, Debicki G, Bali A, et al. Mechanical properties of date palm fibers and concrete reinforced with date palm fibers in hot-dry climate. *Cem Concrete Comp* 2005; 27: 554–564.
9. Sihama IS. Acoustic and mechanical properties of polymer composites reinforced by pre-deformed palm fiber. *J Eng Tech* 2013; 31: 484–499.
10. Agoudjil B, Benchabaneb A, Boudennec A, et al. Renewable materials to reduce building heat loss: characterization of date palm wood. *Energy Build* 2011; 43: 491.
11. Al-Khanbashi A, Al-Kaabi K and Hammami A. Date palm fibers as polymeric matrix reinforcement: fiber characterization. *Polym Compos* 2005; 26: 486–497.
12. Ammar H, Abid M and Abid S. Cellulose fibers obtained by organosolv process from date palm rachis (Phoenix dactylifera L.). *Mater Sci Eng* 2012; 11: 012002.
13. Nasser RA and Al-Mefarrej HA. Midribs of date palm as a raw material for wood-cement composite industry in Saudi Arabia. *World Appl Sci J* 2011; 15: 1651–1658.
14. Do Thi VV. *Matériaux composites fibres naturelles/polymère biodégradables ou non*. Thèse de PhD, Université de Grenable, 2011.
15. AFNOR. Produits agricoles et alimentaires. Détermination de la cellulose brute. NF V 03-040, 1993, 12pp.
16. Manual of Weighing Applications, Marketing, Weighing Technology 1999 BK - 07.07.99 - VORWOR_E.DOC.
17. ASTM C-127-88. Standard test method for specific gravity and absorption of coarse aggregate, 1988.
18. Norme Européenne NF EN ISO 5079 Fibres. AFNOR, France, 1996, p.20.
19. Khiari R, Mhenni MF, Belgacem MN, et al. Chemical composition and pulping of date palm rachis and Posidonia oceanica – a comparison with other wood and non-wood fibre sources. *Bioresour Technol* 2010; 101: 775–780.
20. Khristova P, Kordsachia O and Khider T. Alkaline pulping with additives *of* date palm rachis and leaves from Sudan. *Bioresour Technol* 2005; 96: 79–85.
21. Feng WY, Wang Z and Guo WJ. *A study on chemical composition and fiber characteristics of two sympodial Bamboos*. Research Report. Beijing: Research Institute of Wood Industry, CAF, 2002.
22. Xiaobo L. *Physical, chemical, and mechanical properties of bamboo and its utilization potential for fiberboard manufacturing*. Thesis of Master of science, Baton Rouge, Louisiana, US: School of Renewable Natural Resources, 2004.
23. Bledzki AK, Reihmane S and Gassan J. Properties and modification methods for vegetable fibers for natural fiber composites. *J Appl Polym Sci* 1996; 59: 1329–1336.
24. Rajan A, Senan CR, Pavithran C, et al. Biosoftening of coir fiber using selected microorganisms. *Bioprocess Biosyst Eng* 2005; 28: 165–173.
25. Besset J. Bois Et Matériaux Dérivés. Direction Du Centre Technique Du Bois Et De L'ameublement.
26. Bouasker M, Belayachi N, Dashnor H, et al. Physical characterization of natural straw fibers as aggregates for construction materials applications. *Materials* 2014; 7: 3034–3048.
27. Alawar A, Hamed AM and Al-Kaabi K. Characterization of treated date palm tree fiber as composite reinforcement. *Compos Part B* 2009; 40: 601–606.

28. Tlijania M, Gouadriab A, Benyounesc A, et al. Study and optimization of palm wood mechanical properties by alkalization of the natural fiber. *Int J Sci Basic Appl Res* 2013; 11: 30–38.
29. Thi H and Nga T. *Étude de L'influence de La Température et de L'humidité sur les Propriétés Mécaniques en Traction des Fibres de Chanvre et de Coco*, PhD Thesis, Ecole De Technologie Supérieure, Université Du Québec, 2008.
30. Maya JJ and Sabu T. *Natural polymers: Composites*. Cambridge: Royal Society of Chemistry, 2012, p.40.
31. Budrugeac P, Trandafir V and Albu MG. The effect of the hydration degree on the hydrothermal and thermo-oxidative stability of some collageneous matrices. *J Therm Anal Calorimetry* 2003; 72: 581–585.
32. Yang H, Yan R, Chen H, et al. Characteristics of hemicellulose, cellulose and lignin pyrolysis. *Fuel* 2007; 86: 1781–1788.
33. Mansaray KG and Ghaly AE. Thermal degradation of rice husks in nitrogen. *Bioresour Technol* 1998; 65: 13–20.
34. Sedan D. *Etude des interactions physico-chimiques aux interfaces fibres de chanvre/ciment*. *Influence sur les propriétés mécaniques du composite*. Thèse doctorat, Université De Limoges, 2007.