Structural Characterization and Solid State Properties of Thermal Insulating Cellulose Materials of Different Size Classifications

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This study investigated two classifications of wood cellulose of particle sizes 300 µm to 424 µm and 600 µm to 849 µm. The cellulose samples were characterized using X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), and scanning electron microscopy (SEM). The cellulose crystal revealed a preferred orientation along the (200) plane for the most prominent peak. The XRD diffractogram revealed an orthorhombic structure obtained from the powder diffractogram file (PDF). Furthermore, the crystallinity index and crystalline size were calculated and the increase in crystalline size of the isolated cellulose indicated higher thermal stability. The EDX analysis showed chemical components of carbon (C), sodium (Na), chlorine (Cl), and oxygen (O) in the isolated cellulose. The morphology of the cellulose appeared as strings of fibres. The isolated cellulose has applications in the production of biomaterial, thermal insulating devices, and domestic applications.

Keywords: Celtis philippensis; Pulping; Bleaching; Cellulose; Instrumental Analysis

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INTRODUCTION

Wood is one of the most abundant natural materials on earth with a composition of cellulose, hemicellulose, and lignin. It has been widely used and found essential to human life for thousands of years as building materials and other applications (Edgar *et al*. 2001; Zhang 2001; Belgacem and Grandini 2005; Oluyamo and Adekoya 2015).

There has been concern in the environmental degeneration caused by residues and wastes from domestic and industrial activities all over the world. Therefore, the need to transform waste to wealth is vigorously being pursued by researchers to remove the constituent threats to the environment.

Sawdust, a by-product of wood, has been identified as a challenge and a waste to the environment as the material is usually disposed of in haphazard locations, which most often cause environmental pollution. Various studies have been conducted on this waste material. The results have shown that it can be used to improve insulation properties of device materials (Adekimi 2004; Oluyamo and Bello 2014).

Thermal insulation materials can prevent heat loss and provide thermal comfort. The main factor that determines an insulation material's effectiveness is its thermal conductivity. The lower the thermal conductivity of a material, the more effective it can

be as an insulator. One such material is cellulose isolated from wood, which is naturally eco-friendly and also has favourable thermal properties.

Cellulose, having the general formula $(C_6H_{10}O_5)_n$, can be isolated from other raw materials (cotton, sugarcane bagasse, rice straw, durra stalk, groundnut shell, *etc*.), but wood remains one of the main sources of cellulose isolation. It is a renewable resource with an exceptional strength, low density, and high durability (Draftz *et al*. 2015; Wei *et al*. 2015). Cellulose can be regarded as the major component of wood, a natural composite that has several components (Hon 1994). This natural polymer is close to one-third of plant tissue, which can be restocked by photosynthesis (Morán *et al.* 2008). Cellulose is one of the most widely used polymers in nature, mostly used by humans for thousands of years as building material, and also used by engineers due to its natural availability (Rong *et al.* 2001; Salajkova 2003; Vignon *et al.* 2004; Largerwall *et al.* 2014). It represents a naturally linear condensation polymer consisting of D-anhydroglucopyranose units joined together by β-1,4-glycosidic bonds (Klemm *et al.* 1998; Bledzki and Gassan 1999). The chemical, constitutional, and spatial confirmations are structural entities that aggregate the cellulose chain with a strong tendency (Sun *et al.* 2008). Van der Waals forces and stronger inter- and intra-molecular H-bonding are the tightly and compactly arranged chain (Abdullah *et al.* 2011). Various reagents can be used for the isolation of cellulose from wood, and acidified sodium chlorite ($NaClO_2$ + H_3O^+) has been a widely used standard reagent (Wise *et al*. 1946). The chlorine radical, Cl·, can react with the lignocellulosic material, transforming it into toxic organochlorine.

Cellulose is unique with respect to its versatility in usage, which can be affected by the method of its isolation, the number of inter- and intra-molecular hydrogen bonds, chain lengths, chain length distribution, crystallinity, and distribution of functional groups within the repeating units and along the polymer chains (Åkerholm *et al.* 2004; Klemm *et al.* 2005; Oh *et al.* 2005).

Celtis philippensis Blanco is a flowering plant that includes the elms (genus *Ulmus*) and the zelkovas (genus *Zelkova*). It is from the family Cannabaceae, which is common in the research area. The tree is harvested from the wild for local use as medicine, food, and as a source of wood (Denk and Grimm 2005). Relevant research has been conducted to determine its thermal properties and applications of the material.

The main objective of the present work is to produce thermal insulating cellulose materials from *Celtis philippensis* and characterize the structural and solid-state properties for domestic and industrial applications. The crystalline properties were studied by X-ray diffraction (XRD), the morphology was analyzed using scanning electron microscopy (SEM), and the elemental composition was analyzed using energy-dispersive X-ray spectroscopy (EDX).

EXPERIMENTAL

Materials

The *Celtis philippensis* samples were collected from a sawmill in Akure South Local Government Area of Ondo State, South Western Nigeria. All the samples were authenticated, processed into saw dust at the Department of Forestry and Wood Technology, and sieved into different particle sizes (300 µm to 424 µm and 600 µm to 849 µm) at the Department of Materials and Metallurgical Engineering of The Federal University of Technology, Akure Nigeria. Sodium chlorite ($NaClO_2$) (Sigma-Aldrich,

Steinheim, Germany), sodium hydroxide (NaOH) (British Drug House, Darmstadt, Germany), and acetic acid (Sigma-Aldrich, Steinheim, Germany) of analytical grades were the chemicals used in the analysis.

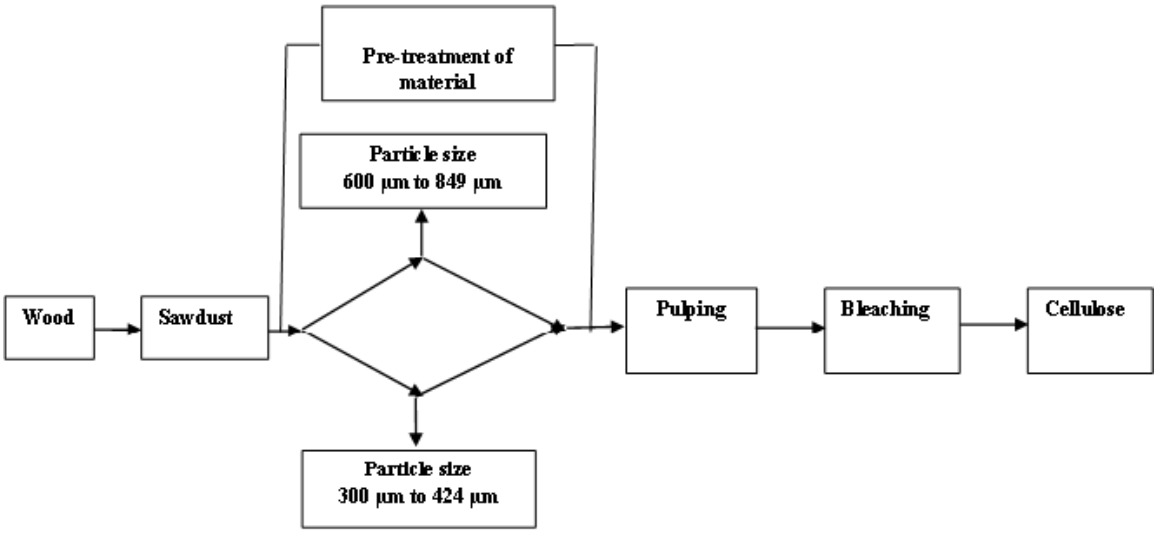

Fig.1. Schematic diagram of the isolation process

Pre-treatment of material

Prior to the pulping of the samples, the materials were sieved using a Wiley mechanical sieve shaker (Pascal Engineering, Sussex, England) and sawdust with two different particle sizes ranges (300 µm to 424 µm and 600 µm to 849 µm) were obtained.

Pulping procedure

The pulping method followed the procedure developed by Oluwasina *et al.* (2014) with a few modifications. Specifically, the wood particle was pulped under atmospheric pressure in a water bath at 90 °C with a wood to liquor ratio of 1:20, using 20 % NaOH for 90 min. After digestion, the pulp was obtained by filtration and washed thoroughly with water until it was free of residual alkali. The pulp yield was oven-dried at 105 °C to a constant weight.

Bleaching procedure

An amount of 1000 mL of hot distilled water, 10 g of $NaClO_2$, and 3 mL of acetic acid were added to approximately 20 g of oven-dried pulp sample in a 2-L Erlenmeyer flask. The flask was covered, and the mixture heated in a water bath at 70 °C for 30 min with intermittent stirring. After the first 30 min in the water bath, another 10 g of $NaClO_2$ and 3 mL of acetic acid was added with intermittent stirring and sustained for another 30 min before switching the bath off. The sample was allowed to settle down for 24 h in the water bath. After digestion, the bleach was obtained by filtration and washed thoroughly with water until it was free of residual alkali and chlorine. The obtained sample was dried at 80 °C to a constant weight.

Methods

Characterization

The crystallinity resulting from different processing procedures was determined using the XRD techniques, which enabled verification of the phases present in the samples. The XRD patterns were obtained using a Philips PW 3710 X'pert Pro diffractometer (Philips Analyical, Almelo, Netherlands) with a Cu-Kα monochromator of wavelength, λ =1.540598 Å, in the range of 5° to 50° (2θ) generated at 15 kV. The surface morphology and atomic composition of the cellulose were studied using SEM (FEI Company, Hillsboro Oregon, USA) with an accelerating voltage of up to 30 kV and a resolution of up to 1 nm. The elemental composition was determined with an energy-dispersive X-ray (EDX) using a FEI NOVA 200 NanoSEM equipment (FEI Company, Hillsboro Oregon, USA).

Theoretical considerations

The Interplanar spacing (*d*-spacing) was calculated from the Bragg equation (Wada and Okano 2001; Kim *et al.* 2010),

$$n\lambda = 2dsin\theta \quad (1)$$

where n is the order of reflection, λ is the wavelength of the incident X-rays (m), d is the interplanar spacing of the crystal, and θ is the Bragg's angle (°).

The orthorhombic lattice parameter ($a \neq b \neq c$) for the orthorhombic phase structure was calculated by Eq. 2 as,

$$d = \sqrt{\left(\frac{a}{h}\right)^2 + \left(\frac{b}{k}\right)^2 + \left(\frac{c}{l}\right)^2} \quad (2)$$

where d is the interplanar spacing(m), a, b, and c are lattice parameters, which are measure in (m),and h, k, and l are the miller indices.

The crystallinity index (CrI, %) was estimated from the XRD diffraction pattern. The patterns were engaged to determine the crystallinity parameters of cellulose derived from different particle sizes of the wood dust samples. The crystallinity index was calculated according to Segal *et al.* (1959), as follows in Eq. 3,

$$CrI = \frac{I_{200} - I_{am}}{I_{200}} \times 100 \quad (3)$$

where I_{200} is the maximum intensity of the lattice diffraction and I_{am} is the low intensity peak of the amorphous region of the baseline at 2θ, approximately 18°.

The crystalline size (L) was calculated using the Scherrer equation (Gümüskaya *et al.* 2003; Popescu *et al.* 2011), as

$$L = \frac{K \times \lambda}{H \times Cos\theta} \quad (4)$$

where K is a constant whose value is given as 0.91, θ is the Bragg's angle (°), and H is the intensity of the full width at half maximum (FWHM) (°) corresponding to a high intensity peak of the diffraction plane.

RESULTS AND DISCUSSION

To determine the crystallinity, the XRD patterns of the isolated cellulose were analyzed. Figures 2a and 2b show the XRD diffractogram pattern of cellulose with two ranges of particle sizes, 300 µm to 424 µm and 600 µm to 849 µm.

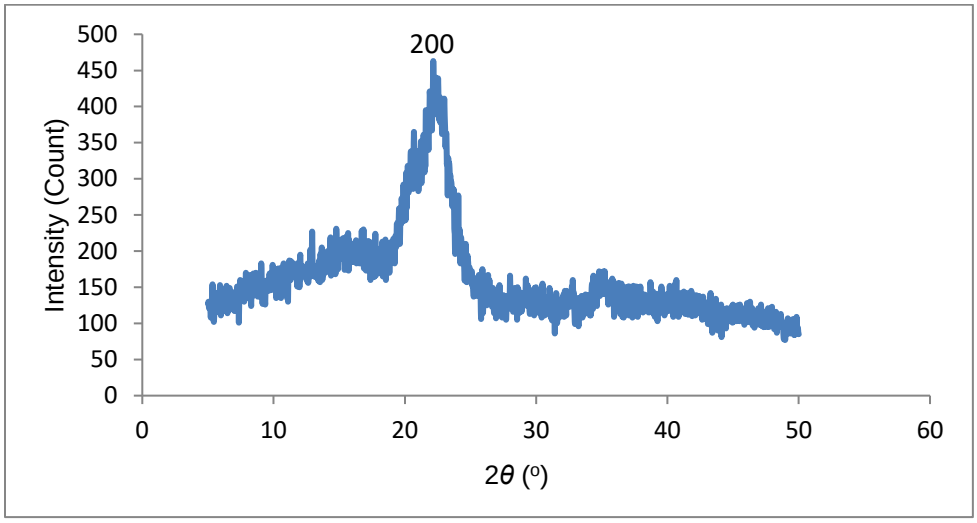

Fig. 2a. XRD pattern of cellulose with particle size ranging from 300 µm to 424 µm

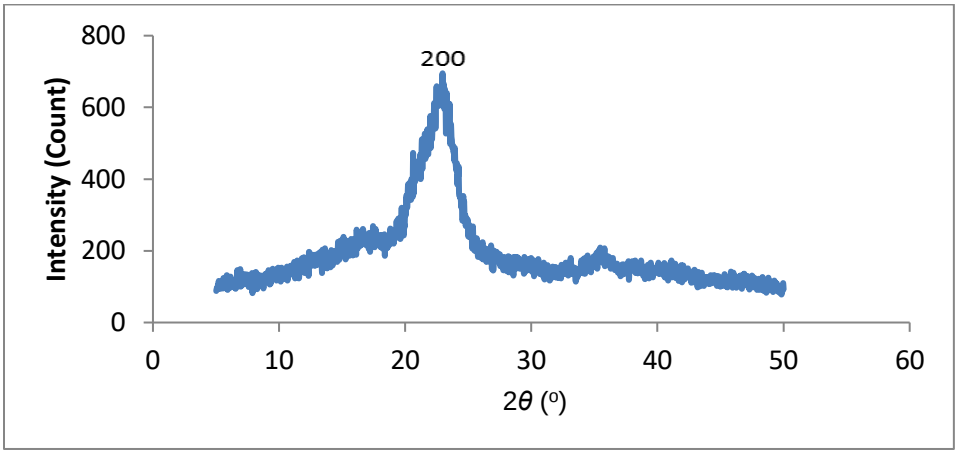

Fig. 2b. XRD pattern of cellulose with particle size ranging from 600 µm to 849 µm

The band positions of angle 2θ and the observed interplanar spacing (d-spacing) values of the isolated cellulose spectra closely matched the reported values in the powder diffractogram file (PDF) indicated in Table1. Other parameters obtained from XRD measurements, such as particle sizes, FWHM, plane of orientation, and isolated cellulose phase are also included in Table 1 for the particle sizes examined (300 µm to 424 µm and 600 µm to 849 µm). The Scherrer's equation was used to estimate the crystalline sizes for each sample.

It was observed that the isolated cellulose with the particle sizes considered had the same pattern. This was in agreement with Zugenmaier (2008) in the study of crystalline cellulose and derivatives.

Table 1. Summary of XRD Analysis on the Particle Size Range of Plane (200)

Particle Size (µm)	Angle (2θ)°	d - Spacing (Åm)	FWHM (°)	Crystalline Size (nm)	Crystalline Index (%)	Phase	Ref. Code Marching
300 to 424	22.289	3.985	0.6336	0.226	60.91	Orthorhombic	00-008-0109
600 to 849	22.860	3.889	1.1088	0.130	64.89	Orthorhombic	01-072-1026

The crystal plane of preferred orientation was along the (200) orthorhombic plane for the most prominent peak. These peaks were observed at 2θ = 22.289° for cellulose obtained from sawdust with particle size 300 µm to 424 µm and 2θ = 22.860° for cellulose with particle size 600 µm to 849 µm. The calculated orthorhombic lattice parameters ($a \neq b \neq c$) of the isolated cellulose were: a = 4.990Å, b = 10.990Å, and c =7.110Å for cellulose with particle size 300 µm to 424 µm, and a = 4.947Å, b =11.032Å, and c = 7.108Å for cellulose with particle size 600 µm to 849 µm.

The crystallinity index (CrI) calculated according to Segal *et al.* (1959) showed that cellulose with particle size 600 µm to 849 µm had a higher index than that obtained from that with particle sizes 300 µm to 424 µm. The CrI values were 60.91% and 64.89% for cellulose with particle size 300 µm to 424 µm and 600 µm to 849 µm, respectively. In a previous study, 60.4% and 62.6% were recorded for native celluloses of *Eucalyptus grandis* and *Pinus taeda* (Poletto *et al.* 2013). However, the particle sizes of the celluloses in the study were not specified.

This high percentage in crystallinity index might be associated with the reduction in the corresponding amorphous state of the material due to the probable dissociation of the bonds as a result of pulping.

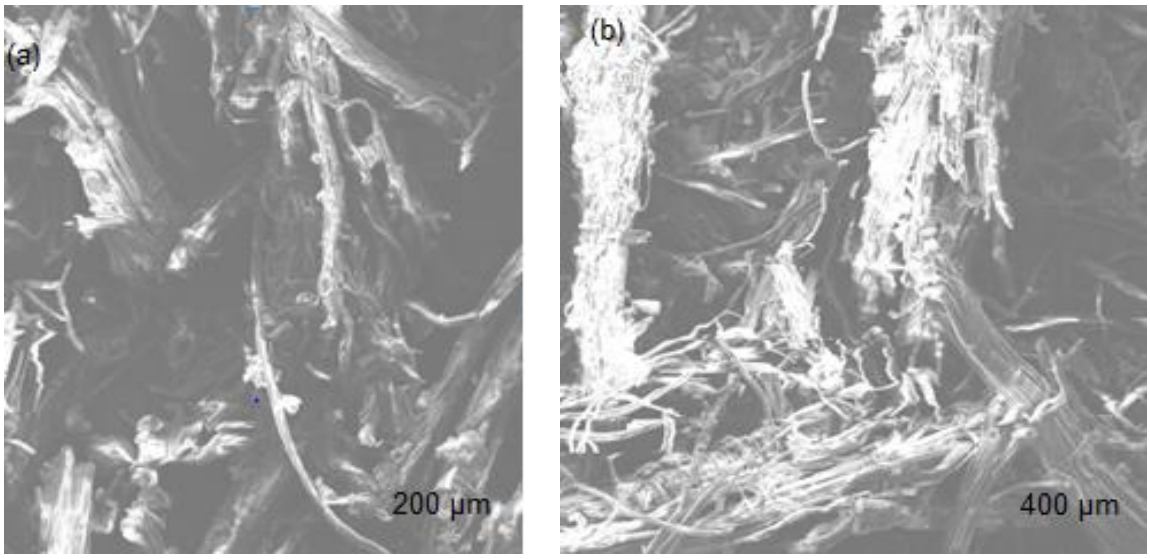

Fig. 3. SEM image of cellulose from sawdust with particle size (a) 300 µm to 424 µm and (b) 600 µm to 849 µm

As shown in Fig. 3, SEM images of the isolated cellulose revealed strings of fibres, which was in agreement with other studies (El-Sakhawy and Hassan 2007; Adel *et al.* 2010; Ibrahim *et al.* 2010; Morgado and Frollini 2011; Pereira *et al.* 2011; Oluwasina

et al. 2014). This property suggests the strong potential of the cellulose in thermal insulating devices and domestic applications.

Figures 4a and 4b show the EDX spectra of the isolated cellulose particle sizes (300 µm to 424 µm and 600 µm to 849 µm). The EDX spectra peaks correspond to the energy levels for which the carbon, oxygen, chlorine, calcium, and sodium were identified.

Carbon had the highest percentage among the elements observed in the spectra and sodium had the lowest.

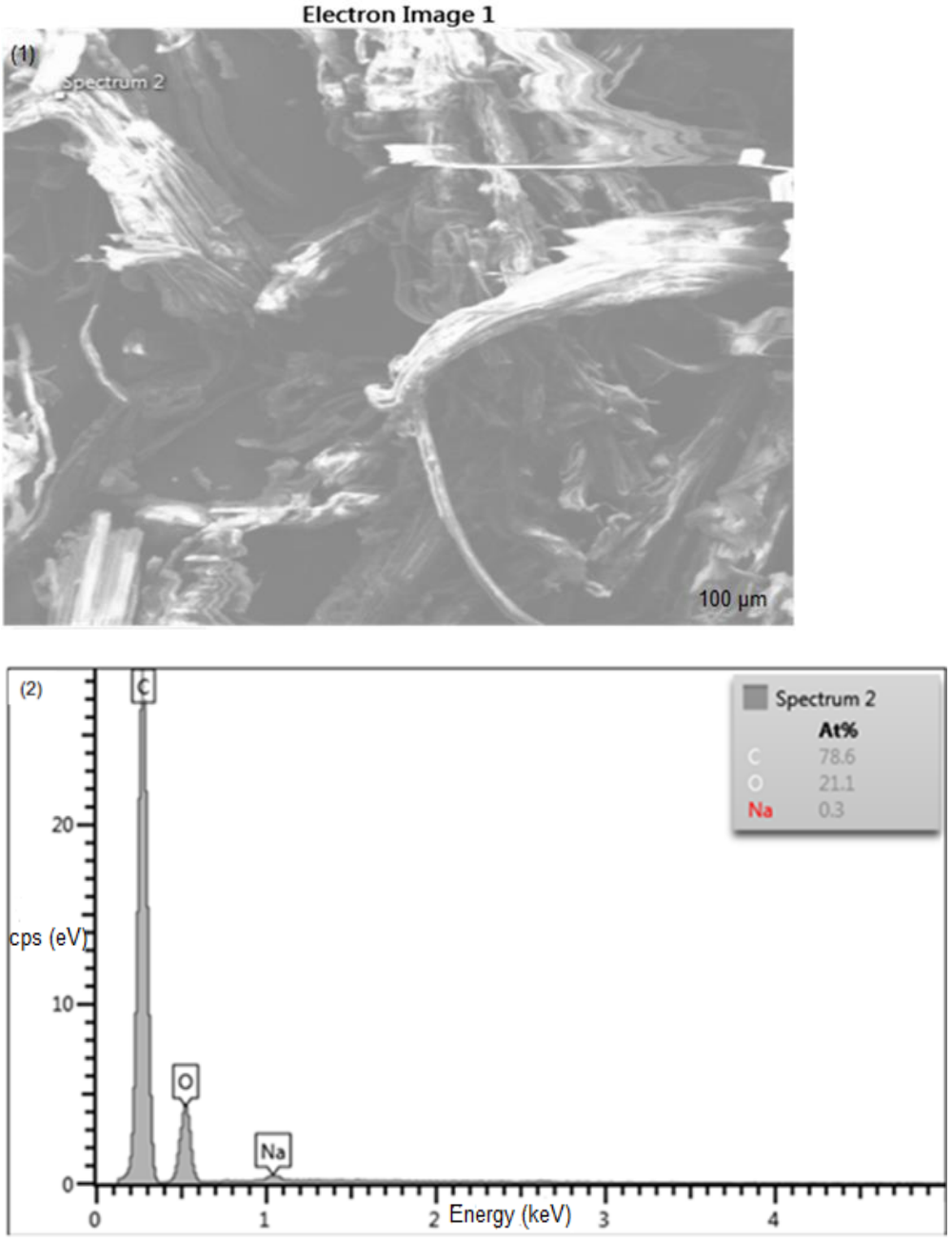

Fig. 4a.(1) SEM image of isolated cellulose with particle sizes 300 µm to 424 µm, and (2) EDX spectrum of isolated cellulose with particle sizes 300 µm to 424 µm

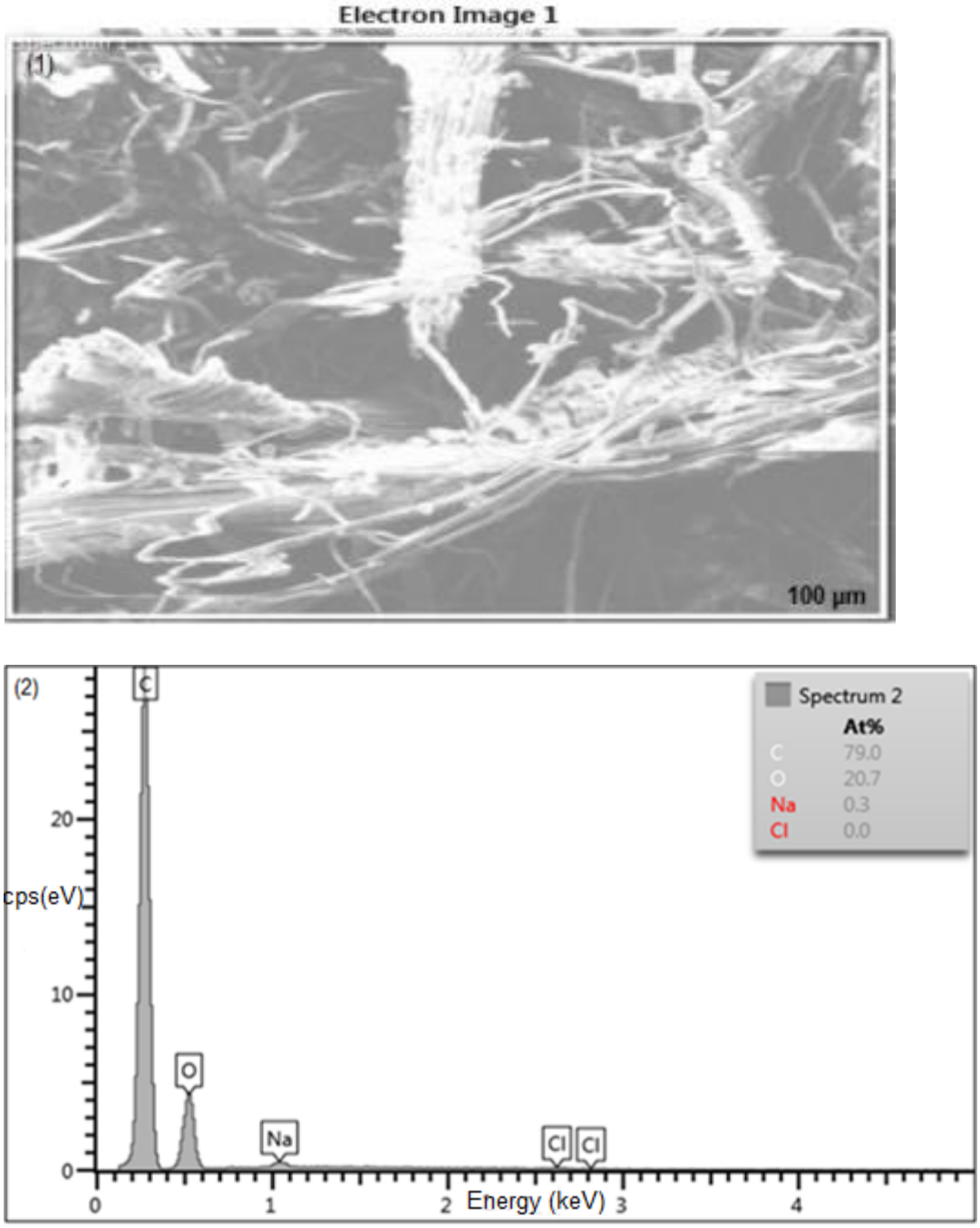

Fig. 4b. (1) SEM image of isolated cellulose with particle sizes 600 µm to 849 µm, and (2) EDX spectrum of isolated cellulose with particle sizes 600 µm to 849 µm

The elemental compositions for the sample with particle sizes 300 µm to 424 µm were 78.6% carbon, 21.1% oxygen, and 0.3% sodium. While, that obtained from the samples with a particle sizes 600 µm to 849 µm were 79.0% carbon, 20.7% oxygen, and 0.3% sodium.

CONCLUSIONS

The isolation and characterization of cellulose of *Celtis philippensis* of two different size classifications were studied using XRD, EDX, and SEM. The results of the study revealed that:

1. The elemental composition of the isolated cellulose consisted of C, O, Ca, and Na.
2. The CrI values were 60.91% and 64.89% for cellulose with particle sizes 300 µm to 424 µm and 600 µm to 849 µm, respectively.
3. The samples revealed a crystal plane of preferred orientation along the (200) plane for the most prominent peak.
4. The crystal structure observed was orthorhombic for both ranges of particle sizes.
5. The isolated cellulose can find useful applications in the production of biomaterials, thermal insulating devices, *etc*.

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REFERENCES CITED

Abdullah, M. A., Nazir, M. S., and Wahjoedi, B. A. (2011). "Development of value added biomaterials from oil palm agro-waste," in: *2nd International Conference on Biotechnology and Food Science (ICBFS)*, Bali, Indonesia.

Adekimi, E. (2004). "Potential uses of sawdust in energy and manufacturing industries B(Eng project report)," Department of Mechanical Engineering, Universityof Ado-Ekiti, Ado, Nigeria.

Adel, A. M., Abou-Youssef, H., El-Gendy, A. A., and Nada, A. M. (2010). "Carboxymethylated cellulose hydrogel; Sorption behavior and characterization," *Nat. Sci.* 8(8), 244-256.DOI:10.7537/marsnsj080810.29

Åkerholm, M., Hinterstoisser, B., and Salmén, L. (2004). "Characterization of the crystalline structure of cellulose using static and dynamic FT-IR spectroscopy," *Carbohyd. Res.* 339(3), 569-578.DOI: 10.1016/j.carres.2003.11.012

Belgacem, M. N., and Gandini, A. (2005). "The surface modification of cellulose fibres for use as reinforcing elements in composite materials," *Compos. Interface.* 12(1-2), 41-75. DOI: 10.1163/1568554053542188

Bledzki, A. K., and Gassan, J. (1999). "Composites reinforced with cellulose based fibres," *Prog. Polym. Sci*. 24(2) 221-274. DOI: 10.1016/S0079-6700(98)00018-5

Denk, T., and Grimm, G. W. (2005). "Phylogeny and biogeography of Zelkova (*Ulmaceae sensustricto*) as inferred from leaf morphology, ITS sequence data and the fossil record," *Bot. J. Linn. Soc.*147(2), 129-157. DOI: 10.1111/j.1095-8339.2005.00354.x

Draftz, M. H. H., Franz, A., Namyslo, J. C., and Kaufmann, D. E. (2015). "Chemistry and spectroscopy of renewable materials. Part 1: Imaging the penetration depth of covalent wood modification," *ACS Sustain. Chem. Eng.* 3(4), 566-568. DOI: 10.1021/sc5008048

Edgar, K. J., Buchanan, C. M., Debenham, J. S., Rundquist, P. A., Seiler, B. D., Shelton, M. C., and Tindall, D. (2001). "Advances in cellulose ester performance and application," *Prog. Polym. Sci.* 26(9), 1605-1688. DOI: 10.1016/S0079-6700(01)00027-2

El-Sakhawy, M., and Hassan, M. L. (2007). "Physical and mechanical properties of microcrystalline cellulose prepared from agricultural residues,"*Carbohyd. Polym.* 67(1), 1-10. DOI: 10.1016/j.carbpol.2006.04.009

Gümüskaya, E., Usta, M., and Kirci, H. (2003). "The effects of various pulping conditions on crystalline structure of cellulose in cotton linters," *Polym. Degrad. Stabil.* 81(3), 559-564. DOI: 10.1016/S0141-3910(03)00157-5

Hon, D. N. S. (1994). "Cellulose: A random walk along its historical path," *Cellulose* 1(1), 1-25. DOI: 10.1007/BF00818796

Ibrahim, M. M., Agblevor, A. F., and El-Zawawy, W. K. (2010). "Isolation and characterization of cellulose and lignin from steam-exploded lignocellulosic biomass," *BioResources* 5(1), 397-418. DOI:10.15376/biores.5.1.397-418

Kim, U. J., Eom, S. H., and Wada, M. (2010). "Thermal decomposition of native cellulose: Influence on crystallite size," *Polym. Degrad. Stabil.* 95(5), 778-781.DOI: 10.1016/j.polymdegradstab.2010.02.009

Klemm, D., Heublein, B., Fink, H. P., and Bohn, A. (2005). "Cellulose: Fascinating biopolymer and sustainable raw material," *Angew. Chem. Int. Edit.* 44(22), 3358-3393. DOI: 10.1002/anie.200460587

Klemm, D., Philipp, B., Heinze, T., Heinze, U., and Wagenknecht, W. (1998). *Comprehensive Cellulose Chemistry, Volume 1, Fundamentals and Analytical Methods*, Wiley-VCH, Weinheim, Germany.

Largerwall, J. P. F., Schütz, C., Salajkova, M., Noh, J., Park, J. H., Scalia, G., and Bergström, L. (2014). "Cellulose nanocrystal-based materials: From liquid crystal self-assembly and glass formation to multifunctional thin films," *NPG Asia Mater.* 6, 1-12. DOI: 10.1038/am.2013.69

Morán, J. I., Alvarez, V. A., Cyras, V. P., and Vázquez, A. (2008). "Extraction of cellulose and preparation of nanocellulose from sisal fibres," *Cellulose* 15(1), 149-159. DOI: 10.1007/s10570-007-9145-9

Morgado, D. L., and Frollini, E. (2011). "Thermal decomposition of mercerized linter cellulose and its acetates obtained from a homogeneous reaction," *Polímeros* 21(2), 111-117. DOI: 10.1590/S0104-14282011005000025

Oh, S.Y., Yoo, D. I., Shin, Y., Kim, H. C., Kim, H. Y., Chung, Y. S., Park, W. H., and Youk, J. H. (2005). "Crystalline structure analysis of cellulose treated with sodium hydroxide and carbon dioxide by means of X-ray diffraction and FTIR spectroscopy," *Carbohyd. Res.* 340(15), 2376-2391.DOI: 10.1016/j.carres.2005.08.007

Oluwasina, O., Lajide, L., and Owolabi, B. (2014). "Microcrystalline cellulose from plant waste through sodium hydroxide-anthraquinone-ethanol pulping," *BioResources* 9(4), 6166-6192. DOI:10.15376/biores.9.4.6166-6192

Oluyamo, S. S., and Adekoya, M. A. (2015). "Effect of dynamic compression on the thermal conductivities of selected wood products of different particle sizes," *International Research Journal of Pure and Applied Physics* 3(1), 22-29.

Oluyamo, S. S., and Bello, O. R. (2014). "Particle sizes and thermal insulation properties of some selected wood materials for solar device applications," *IOSR-JAP*. 6(2), 54-58. DOI: 10.9790/4861-0903011417

Pereira, P. H. P., Voorwald, H. C. J., Cioffi, M. O. H., Mulinari, D. R., da Luz, S. M., and da Silva, M. L. C. P. (2011). "Sugarcane bagasse pulping and bleaching: Thermal and chemical characterization," *BioResources* 6(3), 2471-2482. DOI:10.15376/biores.6.3.2471-2482

Poletto, M., Pistor, V., and Zattera, A. J. (2013). "Structural characteristics and thermal properties of native cellulose," in: *Cellulose-fundamental Aspects*, T. Van de Ven, and L. Gdbout (eds.), Intech Open Science, Rijeka, Croatia, pp. 45-68.

Popescu, M. C., Popescu, C. M., Lisa, G., and Sakata, Y. (2011). "Evaluation of morphological and chemical aspects of different wood species by spectroscopy and thermal methods," *J. Mol. Struct.* 988(1-3), 65-72. DOI: 10.1016/j.molstruc.2010.12.004

Rong, M. Z., Zhang, M. Q., Liu, Y., Yang, G. C., and Zeng, H. M (2001). "The effect of fiber treatment on the mechanical properties of unidirectional sisa-reinforced epoxi composite," *Compos. Sci. Technol.* 61(10), 1437-1447. DOI: 10.1016/S0266-3538(01)00046-X

Salajkova, M. (2003). *Wood Nanocellulose Materials and Effects from Surface Modification of Nanoparticles*, Ph.D. Dissertation, KTH Royal Institute of Technology, Stockholm, Sweden.

Segal, L., Creely, J. J., Martin, A. E., and Conrad, C. M. (1959). "An empirical method for estimating the degree of crystallinity of native cellulose using the X-ray diffractometer," *Text. Res. J.* 29(10), 786-794. DOI:10.1177/004051755902901003

Sun, Y., Lin, L., Deng, H., Li, J., He, B., Sun, R., and Ouyang, P. (2008). "Structure changes of bamboo cellulose in formic acid," *BioResources* 3(2), 297-315. DOI:10.15376/biores.3.2.297-315

Vignon, M. R., Heux, L., Malainine, M. E., and Mahrouz, M. (2004). "Arabinan-cellulose composite in *Opuntiaficus-indica* prickly pear spines," *Carbohyd. Res.* 339(1), 123-131. DOI: 10.1016/j.carres.2003.09.023

Wada, M., and Okano, T. (2001). "Localization of Iα and Iβ phases in algal cellulose revealed by acid treatments," *Cellulose* 8(3), 183-188. DOI: 10.1023/A:1013196220602

Wei, L., McDonald, A. G., and Stark, N. M. (2015). "Grating of bacteria polyhydroxybutyrate (PHB) onto cellulose *via in-situ* reactive extrusion with dicumylperoxide," *Biomacromolecules* 16(3), 1040-1049. DOI: 10.1021/acs.biomac.5b00049

Wise, L.E., Murphy, M., and D'Addieco, A. A. (1946). "Chlorite holocellulose: Its fractionation and bearing on summative wood analysis and on studies on the hemicelluloses," *Paper Trade J.* 122(2), 35-43.

Zhang, L. M. (2001). "New water-soluble cellulosic polymers: A review,"*Macromol. Mater. Eng.* 286(5), 267-275.DOI: 10.1002/1439-2054(20010501)286:5<267::AID-MAME267>3.0.CO;2-3

Zugenmaier, P. (2008). *Crystalline Cellulose and Derivatives: Characterization and Structures*, Springer, Heidelberg, Germany.

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