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Influence of Size Classifications on the Structural and Solid-State Characterization of Cellulose Materials

Oluyamo Sunday Samuel and Adekoya Mathew Adefusika

Abstract

Influence of size classification on the properties of cellulose materials has been a subject of neglect over the years. Researchers had the opinion that there exist no significant difference between the characteristics of bulk particulate materials and sizes of their constituents. However, it has been affirmed that increase in crystallinity index, increases the strength properties of cellulose materials. Therefore, there is need to establish the influence of size classification as it affects the properties of cellulose materials. This study focused on the influence of size classifications on the structural and solid State characterization of cellulose obtained from wood dust. The structure of the cellulose composed principally of crystalline cellulose (I and II) and amorphous cellulose. The crystallinity and the inter-planar spacing revealed different structural properties for the two size classifications. The elemental composition consists of Carbon (C), Oxygen (O), Sodium (Na) and Chlorine (Cl) with Carbon having the highest percentage. The surface morphology of the isolated cellulose appears fiber -like for the size classifications examined. The isolated cellulose exhibits good mechanical and solid state properties with promising applications in device utilization. Within the limit of the research, size classification is noted to influence the characteristics of the cellulose materials.

Keywords: cellulose, size classification, crystallinity, structural characterization, solid state properties

1. Introduction

Wood is one of the hard fibrous structural tissue and abundant natural materials on earth. It is an organic material with a composition of cellulose, hemicellulose, and lignin which has been used for many years as a basic need in construction materials and other purposes [1–3]. The effect of particle sizes on the thermal and mechanical properties of wood had gained popularity in recent years due to its importance in improving the insulation properties of materials [4].

The environmental degeneration caused by solid waste from different activities had been a challenge to the waste management throughout the world. Nigeria, with a population over 180 million as at 2018, has the largest producer of residue and solid waste in Africa.

One important waste from wood is the wood dust. This by-product usually constitutes menace to man and his environment as the material is usually disposed of sometimes indiscriminately in different locations which most often constitute environmental pollution [3]. Studied had shown that if well harness, wood dust may attract economic values to the country rather than the usual pollution.

Cellulose is a formation of the composite, a versatile and widely natural-based material in nature that consists of glucose molecules which has various uses to man and used by man for thousands of years as building material, or energy source. It is a polymer that contains crystallites and displayed para-crystalline morphology [5]. The linear molecules are linked laterally by hydrogen bonds to form linear bundles which give rise to the crystalline structure. It has become one of the material's serving mankind for centuries and major subject in the history of polymer science in developing nation's economic and determination of polymeric crystal structures. Today, it is an important material which is widely used in industries (paper, pharm, food, etc.) and it has also served as an economic output in many countries of the world.

It has a general formula $(C_6H_{10}O_5)_n$, found in plants as microfibril and isolated from wide range of species from higher plants such as wood to green algae [6, 7]. It is a polymer that composed of amorphous and crystalline regions which varies depending on the plant species. Cellulose can be isolated from plants and non-plant sources. Isolation can be from a variety of sources such as (cotton, hemp, jute, sugarcane bagasse, rice straw, durra stalk, groundnut shell, etc.). The composition of chemical and cell dimensions depend on plants, origin and isolation method.

Cellulose can exist in its derivative forms namely rayon, cellulose acetate, cellulose nitrate, and ethyl cellulose. It is the main component of about half to one-third of plant tissues and categorized into three namely, α-cellulose, β-cellulose and γ-cellulose [8]. Solubility and precipitation nature are the major category upon which cellulose is based. In plants, it composed of a linear homopolymer of 1,4-β-glucopyranose units associated with hydrogen bonding and as a semicrystalline structure that is found and circulated from highly developed trees to primitive organisms [9, 10]. The chemical repeating unit is the β-1,4-linked glucose and structural repeat is β-cellobiose [11]. The repeating unit in cellulose is the anhydrocellulobiose and half a degree of polymerization (DP) gives rise to the number of repeating per molecule. It is higher in native cellulose than other group of cellulose which is usually due to the purification procedures. Van der Waals forces and hydrogen bonds tightly bound the glucose to each other to form crystalline structures called Elementary fibril. This consists of around 40 glucan chains, 40 Å widths, 30 Å tick and 100 Å long [12].

There are two main regions found in cellulose fibers. These are crystalline and amorphous. Crystalline are regions with a high order of microfibrils while less order of microfibrils is called amorphous. Amorphous material are materials that lack definite shape or formless. These regions vary proportions among the plants species. For this reason, the properties of cellulose materials depend largely on the material. The versatility of cellulose makes it important in it usage. The method of isolation or treatment, sources of cellulose give rise to different polymorphs with only a few exceptions. This may be due to molecular orientation and hydrogen bonding [3]. The polymorphic forms can be grouped into four: I, II, III, and IV which can be determined by XRD pattern. The first model of the crystalline structure of native cellulose of a monoclinic unit cell was developed by Mayer and Mish [13]. All native cellulose crystalline consists of CI with only a few exceptions and exhibits the same crystalline structure. It composed of two distinct allomorphs Iα(triclinic) and Iβ(monoclinic) depending on the biological origins. Iαstructure is metastable and dominated polymorph for most algae and bacteria, whereas Iβis dominant for

higher plant cell wall cellulose and in tunicates. Iα can be converted to Iβ in alkaline solution by hydrothermal treatments at a temperature of 260°C. Native cellulose is organized in fibrils, which are represented by the association of cellulose molecules. The native cellulose of higher plants possesses a high degree of polymerization (DP) of up to 10.000 β- anhydroglucose residues [14]. This indicates that the molecular weight is above 1.5 million (g/mol). The increase in crystalline regions increases the rigidity and decreases the elasticity of the polymeric substance. The accessibility of cellulose molecules affects the ratio of the crystalline region and the amorphous region in the cellulose structure [15–18].

Modification of cellulose is identified by addition of crystalline allomorphs, II, III, and IV. Mercerization (Alkali treatment) and regeneration (solubilization and subsequent recrystallization) are the two main methods of preparing celluloses II.

However, when the time and the amount of chemical introduced in the treatment of native cellulose are not restricted to a predetermined pattern, it results to the production of cellulose (I and II).

Treatments with liquid ammonia with celluloses I and II produces celluloses III_I and III_{II}. In addition, heating of III_I and III_{III} produces celluloses IV_I and IV_{II} [19, 20].

Structure and morphology of cellulose give a clearer picture of understanding the behavior of cellulose during chemical modification. It also gives understanding on the morphological changing of materials after hydrolysis. There are three structural levels that describe the complex structure of cellulose. These are molecular level (molecular mass, potential intramolecular and chemical constitution), supramolecular levels (crystal structure and intermolecular hydrogen-bonding system) and morphological levels (organization of crystals into microfibrils, the existence of different cell wall layers in the fibers, and other cellulose morphologies). These levels determine both chemical and mechanical properties of cellulose.

One of the parameters used to study the total cellulose present in cellulosic materials is the crystallinity Index [21–25]. In addition, the presence of crystallinity in cellulose contributes greatly to its physical, chemical and mechanical properties [22, 26, 27]. The crystallinity index of cellulosic material has an influence on the stiffness, rigidity and the strength of the material. The increase in the crystallinity index (CI) is associated with high potential mechanical property and increase reinforcing capability of a cellulose material. Several techniques have been used to measure the crystallinity index. These techniques include; XRD, solid-state ^{13}C NMR, infrared (IR) spectroscopy and Raman spectroscopy. The crystallinity index has been used for years in interpreting cellulose changes after treatment (physicochemical and biological). It has been reported that crystallinity index varies significantly depending on the measurement method. Among these methods, XRD is the mostly employed. Three different methods are commonly employed in calculating the CI from the raw spectrographic data on the XRD [23, 28–32]. The first method was established by [33], proposed for cellulose I. In this method, consideration was based on the ratio of the peak height between the intensity of the crystalline and the total intensity after subtraction of background signal at 18° (2θ) degrees. The idea behind the Segal equation is that there are no crystalline peaks near 18° for cellulose I, therefore any observed intensity would be due to amorphism region. [33] found a maximum at 18° but other authors have found maxima at values even higher, such as 20–22° [34]. Thus, [30] showed that a perfectly crystalline cellulose would still only give a Segal CrI value of 92% when the crystal is approximately the size of a good cotton crystal (FWHM = 1.7°). Furthermore, for a 100% amorphism, a pattern would have to be completely flat; something that never happens. Because there is no fundamentally sound method that is well proven for crystallinity determination, Segal method results remain fairly simple to obtain and give helpful information. Segal with other methods (peak de-convolution method, and amorphous subtraction) all has fundamental flaws.

Available researches into isolation of cellulose focused mostly on thermal and mechanical properties. Hitherto, there is no available information about the influence of size classifications on the structural and solid state characterization of cellulose materials. Although, some school of thought have the notion that size classification has no significant influence on the properties of cellulose materials.

This effect is however well established for wood bulk and particle materials [2, 35, 36]. It is important to note that cellulose particles are presented in differing sizes in material processes and applications.

Guarea thompsonii is a species of plant from the family of *Meliaceae*. It is a hard wood that is naturally durable, resistant to impregnation, medium shrinkage and has a desired compressive advantage for concrete as a structural material.

Therefore in the present research, cellulose particles isolated from *Guarea thompsonii* are classified into two categories while the structural and solid state characterizations are determined.

2. Method

2.1 Material

Wood specie (*Guarea thompsonii*) was selected from a sawmill in the area of research and authenticated at the Department of Forestry and Wood Technology, Federal University of Technology, Akure (FUTA), Nigeria. The sample was processed into wood dust and sieved into two size classifications (424–599 μm and 600–849 μm) at the Department of Materials and Metallurgical Engineering (FUTA). Analytical grades chemical used were Sodium chlorite ($NaClO_2$) (Sigma-Aldrich, Steinheim, Germany), sodium hydroxide (NaOH) (British Drug House, Darmstadt, Germany), and acetic acid (Sigma-Aldrich, Steinheim, Germany).

2.2 Pre-treatment of material

The obtained sample after processed to wood dust were sieved using a Wiley mechanical sieve shaker (Pascal Engineering, Sussex, England) and the wood dust with two size classifications (425–599 μm and 600–849 μm) were obtained.

2.3 Pulping procedure

The two classifications of the wood dust were pulped in a water bath at 90°C under atmospheric pressure with the ratio of wood to liquor of 1:20, using 20% NaOH for 90 minutes. The pulped was obtained by filtration after digestion 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 and stored for further processing.

2.4 Bleaching procedure

1000 mL of hot distilled water, 12 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 minutes with intermittent stirring. After the first 30 minutes in the water bath, another 12 g of $NaClO_2$ and 3 mL of acetic acid was added with intermittent stirring and sustained for another 30 minutes before switching the bath off. The sample was allowed to settle down for 24 hours 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 105°C to a constant weight.

3. Theoretical consideration

3.1 X-ray diffraction method

One of the reliable techniques to determine the crystal structure of any material is the X-ray diffraction (XRD). The crystalline phase of the material can be obtained by examine the diffraction patterns.

The XRD patterns of the two size classifications 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 Åm, in the range of 10–50° (2θ) generated at 15 kV. All experiments were repeated twice and duplicate X-ray analyses were performed.

The Interplanar spacing (*d*-spacing) was calculated from the Bragg equation using [37, 38].

$$n\lambda = 2d \sin\theta \tag{1}$$

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 crystallinity index (*CrI*, %) was obtained from the XRD diffraction pattern. The patterns where engaged to determine the crystallinity parameters of cellulose derived from different size classifications of the wood dust samples. The crystallinity index was calculated according to [33], as followed Eq. (2),

$$CrI = \frac{I_{020} - I_{am}}{I_{020}} \times 100 \tag{2}$$

where I_{020} is the maximum intensity of the lattice diffraction and I_{am} is the low intensity peak at the amorphous region of the baseline at 2θ, approximately 18°.

The average crystallite sizes (*L*) in the isolated cellulose samples were calculated from the XRD line broadening using the Scherrer's equation

$$L = \frac{K \times \lambda}{H \times Cos\theta} \tag{3}$$

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.

The Surface chain W occupying a layer that is approximately 0.57 nm thick is given as

$$W = \frac{(L - 2h)^2}{L^2} \tag{4}$$

The determination of the monoclinic and triclinic structure for the two size classifications was calculated from the method developed by [37]. The isolated cellulose was categorized into Iα or Iβ predominant form by employing discriminant analysis. The function which discriminates between them (the monoclinic and triclinic structure) is given as:

$$Z = 1693d_1 - 902d_2 - 549 \tag{5}$$

where $d_1 (nm)$ is the d-spacing of the Iβ $(1\bar{1}0)$ peak and $d_2 (nm)$ is the d-spacing of the Iβ (110) peak. Z > 0 indicates that cellulose is rich in the Iα form and Z < 0 indicates that Iβ is the predominant form.

3.2 FTIR spectroscopy measurement

Fourier transform infrared (FTIR) spectroscopy is a mature analytical technique employed to examine the microscopic area of a materials. FTIR spectra of powder samples of cellulose were obtained using a Thermo Nicolet 5700 FTIR spectrometer (Nicolet, Madison, WI, USA). The Spectra were acquired over the range 500–4000 cm^{-1} at a resolution of 2 cm^{-1} for samples in pellet form prepared by mixing 1.0 mg of powder samples with 200.0 mg KBr spectroscopic grade. The spectra obtained were used for rapid information about the chemical structure of the cellulose samples.

3.3 Scanning Electron MicroscopeMeasurement

The morphological characterization of composite materials can be investigated by the Scanning Electron Microscopy (SEM). It is a popular and powerful technique for imaging the surface of a material (surface topology, morphology and chemical composition) [39]. The image resolution depends on the property of the electron and the electron probe interaction with the specimen. SEM analysis was performed on the isolated cellulose obtained of the two size classifications using FEI NOVA 200 NanoSEM equipment (FEI Company, Hillsboro Oregon, USA) with an accelerating voltage of up to 30 kV and a resolution of up to 1 nm to observe the morphology of the cellulose obtained.

4. Results

4.1 X-ray diffraction (XRD) of cellulose

X-ray diffraction (XRD) is a method generally used to determine the crystallinity of materials, interplanar distances etc. The free hydroxyl groups present in the cellulose macromolecules are likely to be involved in a number of intramolecular and intermolecular hydrogen bonds, which may give rise to various ordered crystalline arrangements [40, 41].

In order to evaluate and determine the intensities of the diffraction bands, establish the crystalline and amorphous areas and determine the crystallite sizes of the cellulose, the X-ray diffractogram (**Figure 1**) was adopted. The crystallographic planes from the diffractogram are labeled according to the cellulose structure.

The diffractograms showed that 12.414–14.755°C (2θ), 16.910–17.127°C (2θ), 18.01°C (2θ), 22.107–22.591°C (2θ) and 34.908–35.075°C (2θ) reflections were assigned to reflection assigned to the (1̄10) crystallographic plane, (110) crystallographic plane, amorphous phase, (020) crystallographic plane and (004) crystallographic [37].

The X-ray diffraction pattern generated to evaluate the crystallinity of the cellulose samples in **Figure 1** showed a peak at 2θ = 22.591 and 22.308°C for *Guarea thompsonii of* 425–599 μm and 600–849 μm of size classifications. These distinct peaks obtained for the XRD of the samples is an indication that the cellulose are crystalline in nature.

The diffraction peak of cellulose shown around 2θ = 12.414–14.755°C was assigned to the crystalline plane of (1̄10) for cellulose type I and II. Moreover, it is interesting that cellulose showed the doublet in the intensity of the main peaks (2θ = 20.2–20.4°C) which were also assigned to the crystalline planes of (110) for cellulose type I and II. This shows that mixture of cellulose I and II has been the most stable structure of technical relevance and can be produced by two processes:
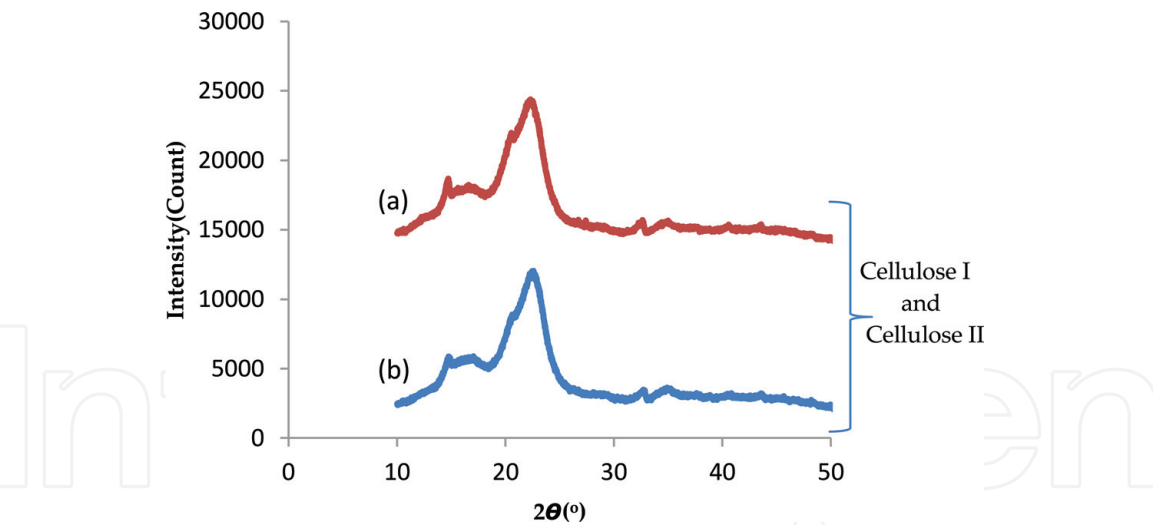
Figure 1.
XRD of isolated cellulose obtained for different size classifications for Guarea thompsonii *(a) 425–599 μm*
(b) 600–849 μm.

regeneration (solubilization and recrystallization) and mercerization (aqueous sodium hydroxide treatments) [27].

From this result, it can be concluded that alkali treatment in pretreatment process led to the change of cellulose allomorph from type I; the native cellulose found in nature, to type I and II; the regenerated cellulose which is the most stable crystalline form. Moreover, the acid hydrolysis which removed the amorphous region out from the cellulose led to re-crystallization was the main cause to obtain the obvious peaks of doublet intensity at 2θ = 20.2–20.4°C.

4.1.1 Investigation of the crystallites structure of cellulose by XRD

The average dimensions of the elementary crystallites perpendicular to the $(1\bar{1}0)$, (110) and (020) crystallographic planes of the mixture of cellulose I and cellulose II with amorphous can be calculated using the Scherrer's equation, by measuring the full widths at half maximum (FWHM) of the different diffraction peaks, assuming that the finite size of crystallites dominate the broadening of the X-ray reflections. These values have to be considered as a lower bound since instrumental broadening and possible imperfections of the crystal lattice are neglected by the method.

The results obtained from the XRD profiles of samples in **Figure 1** are presented in **Tables 1** and **2**. In this, only the length perpendicular to the (020) plane could be calculated since the $(1\bar{1}0)$ and (110) reflections in the XRD profile overlapped each other. An average crystallite length of about 1.742 nm and 1.748 nm were obtained *Guarea thompsonii* of 425 μm −599 μm and 600 μm −800 μm size classifications.

The inter-planar spacing (d-spacing) values of the cellulose spectra for most prominent peak with crystal plane of preferred orientation along the (020) were 3.933 Å m and 3.982 Å m for *Guarea thompsonii of* 425–599 μm and 600–849 μm

Classification (μm)	$(1\bar{1}0)$		(110)		(004)		(020)	
	2θ	d (Å)	2θ	d (Å)	2θ	d (Å)	2θ	d (Å)
425–599	14.754	5.999	17.044	5.198	34.908	2.568	22.591	3.933
600–849	14.721	6.013	16.726	5.293	34.992	2.562	22.308	3.982

Table 1.
Band position (2θ) and d-spacing of crystalline cellulose of Guarea thompsonii.

Classification (µm)	L(020) (nm)	Cr.I	W	Z-Values
425–599	1.750	56.89	0.12	−2.229
600–849	1.749	54.09	0.12	−8.428

Table 2.
Parameters obtained from the XRD analysis of the cellulose samples of Guarea thompsonii.

respectively. Other values of inter planar spacing for the remaining crystallographic planes were depicted in **Table 1**.

The crystalline interior chains W for the isolated samples were calculated by the fraction of cellulose chains contained in the interior of the crystallites. It was estimated as 0.12 for the two samples isolated in **Table 2**. This indicated that the proportion of crystallite interior chains, W, is similar for both samples examined.

Table 2 showed the calculated Z- values for the two size classifications (*Guarea thompsonii*). The values of the estimated isolated cellulose obtained wereless than zero (Z < 0). This shows that the cellulose samples belong to Iβ (monoclinic) dominant.

The degree of cellulose crystallinity is one of the most important crystalline structure parameters. The crystallinity index (CrI) calculated according to [33] showed that the crystallinity of cellulose obtained for 425–599 µm size classification was higher than that obtained for 600 µm to 849 µm size classification. The CrI value are 56.89 and 54.09% for *Guarea thompsonii* cellulose obtained from different size classifications of 425–599 µm and 600–849 µm, respectively. In contrast, 60.4% for *Eucalpyptus grandis* and 62.6% for *Pinus taeda* were also recorded in a study of structural characteristics and thermal properties of native cellulose [41]. 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. This can also due to significant increase in surface area-to-volume ratio of the molecules, and with the crystalline size of the samples reducing to nanoscale. The difference in the values obtained may be due to the chemical treatments for purification and crystalline or amorphous standard [42]. Moreover, high crystallinity index is associated to increase stiffness, rigidity and strength of the isolated cellulose obtained. As a result, sample with 425–599 µm size classifications has high potential mechanical property and reinforcing capability than sample with 600–849 µm size classifications [43].

4.2 Fourier infra-red spectroscopy (FTIR) of cellulose

Figure 2 shows the functional groups and the band positions for the isolated cellulose prepared by Fourier Infra-red Spectroscopy (FTIR).

Two main absorbance regions were pronounced by the samples considered. The absorbance regions were in the range of approximately 1110–870 cm^{-1} and 3630–2960 cm^{-1} wave number. The intensies regions were high in 425–599 µm size classifications than 600–849 µm due to the surface to volume ratio of the atom exposed to the FTIR machine.

The strong dominant broad peaks in the region are obtained from 3630 to 2960 cm^{-1} which is commonly observed for hydrogen. The absorption around 3320 cm^{-1} corresponds to the vibration of H- bonded OH groups while a peak near 2890 cm^{-1} is assigned to C-H stretching vibration. These inter- and intra- molecular hydrogen bonds in the cellulose has a strong influence on the physical and mechanical properties of the cellulose. The band near 1160 cm^{-1} is representative of the anti-symmetric bridge stretching of C—O—C groups. The band near 1300 cm^{-1}
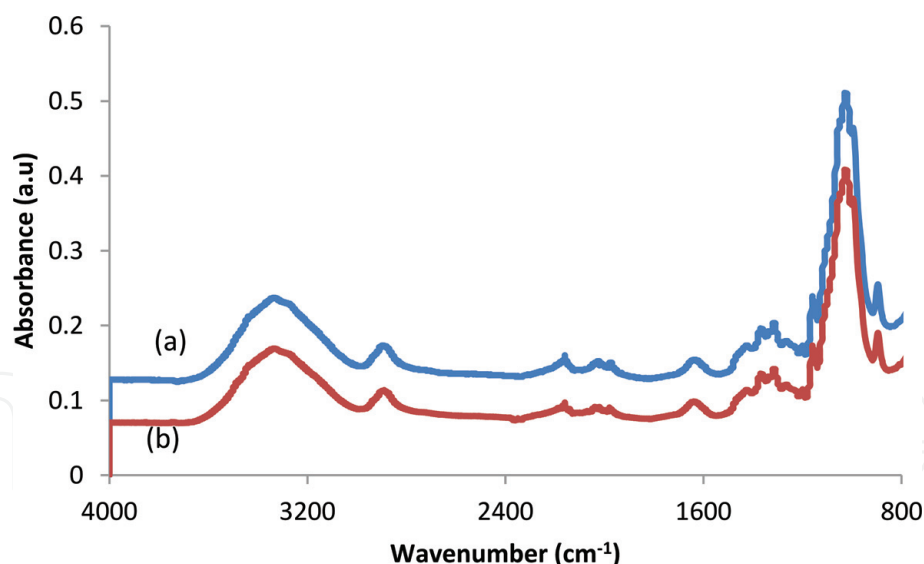
Figure 2.
FTIR spectra of isolated cellulose of different size classifications for Guarea thompsonii *(a) 425–599 μm (b) 600–849 μm.*

could be ascribed to CH_2 wagging vibrations in the cellulose while the absorption at 1200 cm^{-1} belongs to the C—O—H in-plane bending at C-6 [44, 45]. The band peak at 1610 cm^{-1} can be assigned as OH bending due to absorbed water because the OH bending mode is strongly perturbed by bound water [46]. Strong peaks at 1020 and 1090 $cm^{-1}$are indicative of C—O stretching at C-3, C—C stretching and C—O stretching at C–6 [45]. Finally, the absorbance peak observed at 899 cm^{-1} was assigned to the symmetric C—O—C stretching of β (1⟶4)-glycosidic linkage.

4.3 Scanning Electron Microscopy (SEM)

The Scanning Electron Microscopy (SEM) was an effective method for investigating the morphological characteristics of the composites. **Figures 3** and **4** show the SEM image of *Guarea thompsonii* of isolated cellulose obtained.

As shown in **Figures 3** and **4**, SEM images of the isolated cellulose of two samples depicted strings of fibers. This was in agreement with other authors' findings, although the length of the fiber may differ [47–52].
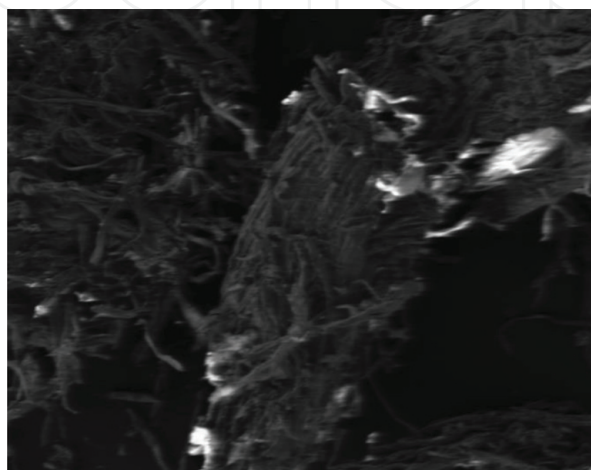

Figure 3.
SEM image of isolated cellulose for Guarea thompsonii *of 425–599 μm size classifications.*
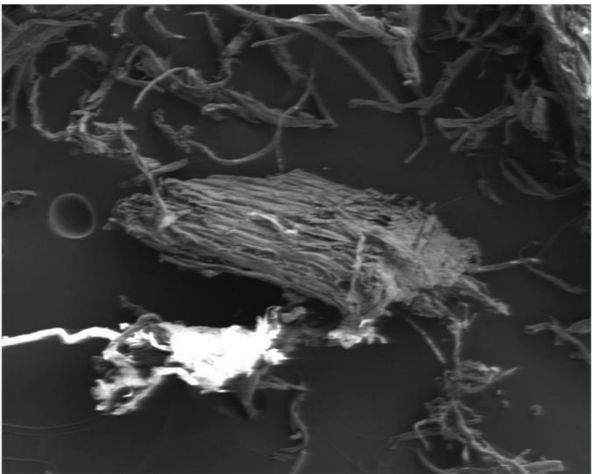
Figure 4.
SEM image of isolated cellulose for Guarea thompsonii *of 600–899 μm size classifications.*

4.4 Energy dispersive X-ray diffraction (EDX)

Energy dispersive X-ray diffraction (EDX) attached with SEM was used for elemental analysis of isolated cellulose. The EDX spectra (as shown in **Figures 5** and **6**) peaks correspond to the energy levels for which the carbon (C), oxygen (O),
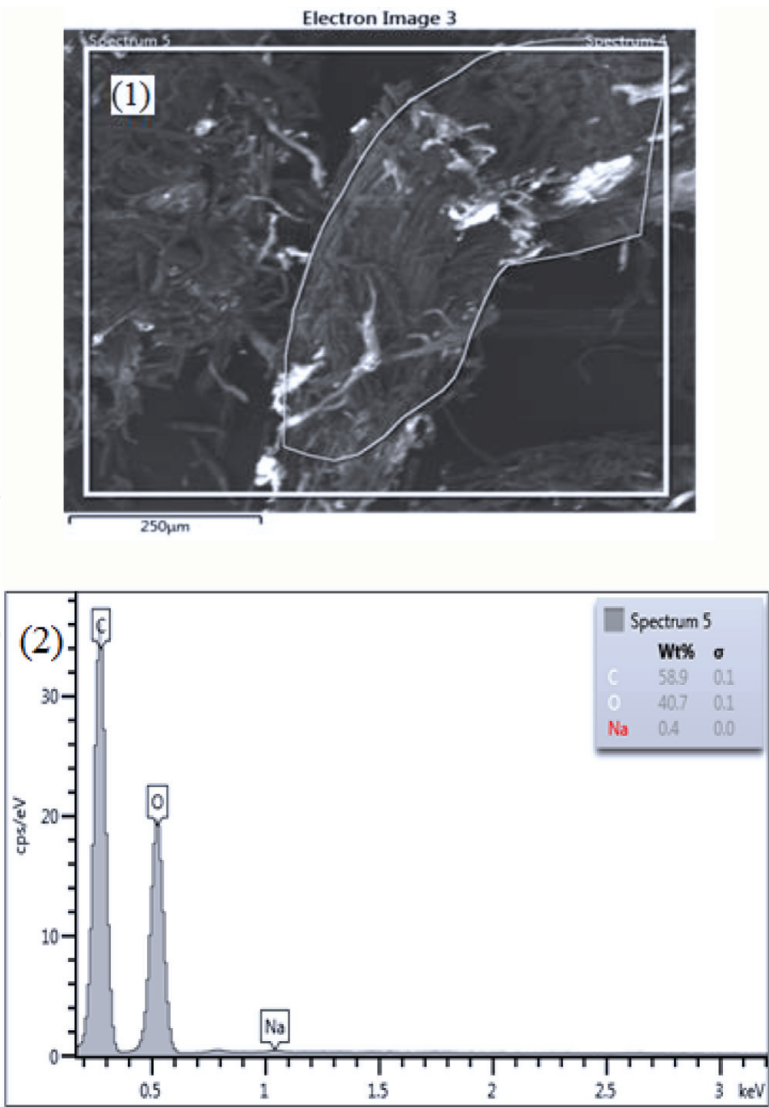

Figure 5.
(1) SEM image of isolated cellulose for Guarea thompsonii *of 425–599 μm size classifications; and (2) EDX spectrum of isolated cellulose for* Guarea thompsoniiof *425–599 μm size classifications.*
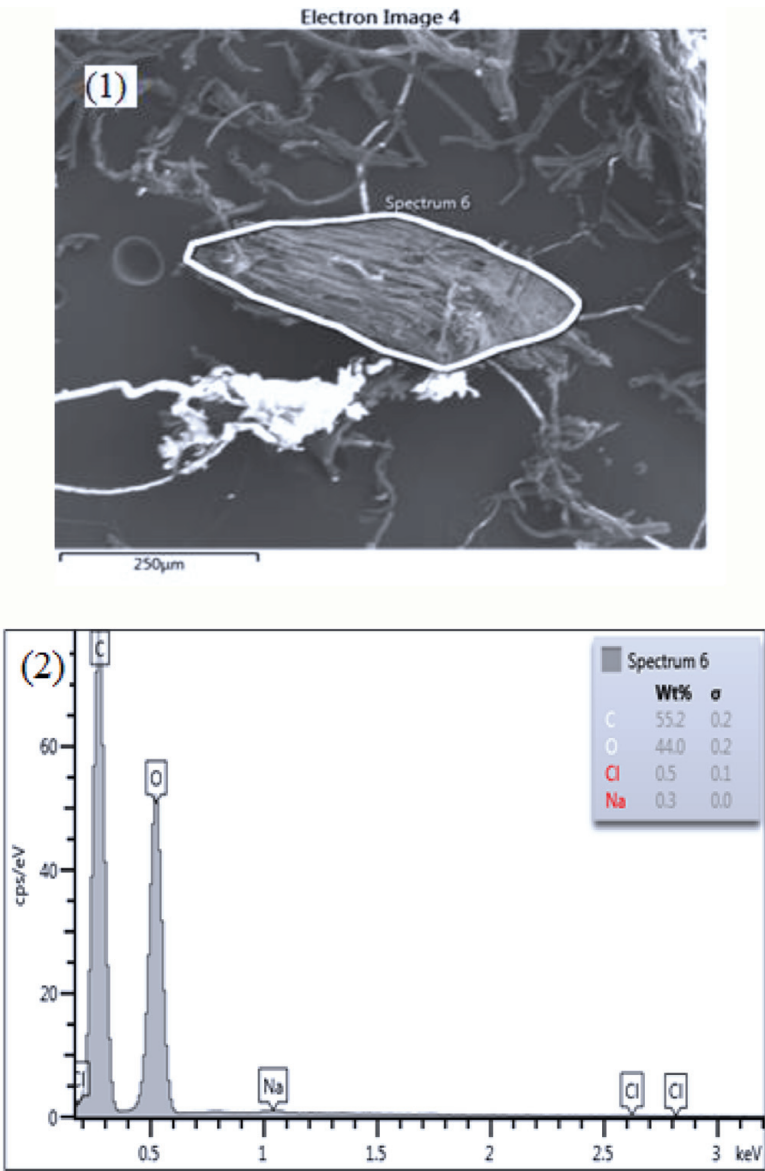
Figure 6.
(1) SEM image of isolated cellulose for Guarea thompsonii *of 600–899 μm size classifications; and (2) EDX spectrum of isolated cellulose for* Guarea thompsoniiof 600–899 μmsize classifications.

chlorine (Cl), and Sodium (Na) were identified with carbon having the highest percentage among the elements observed in the spectra. The elemental compositions for the samples with size classifications 425–599 μm were 58.9 wt % carbon, 40.7 wt % oxygen and 0.4 wt % sodium and 55.2 wt % carbon, 44.0 wt % oxygen, 0.5 wt % chlorine and 0.3 wt % sodium for 600–899 μm. The impurities present could have been due to the $NaClO_2$ that was used in the bleaching process.

5. Conclusion

Wood dusts from two size classifications were isolated from XRD, FTIR, SEM and EDX. The isolated cellulose obtained is the mixture of cellulose I and II and amorphous with fiber-like shape. The two celluloses examined has a preferred orientations along the (020) plane for the most prominent peaks with a crystallinity index of 56.89% for size range 425–599 μm and 54.09% for size range 600–849 μm. The crystallinity index is high in 425–599 μm size classifications compare to 600–849 μm. This indicates that the strength properties is higher in 425–599 μm size classification and have reinforcement ability than 600–849 μm. It is important to

note that size classifications played a major role on the crystallinity index on the sample examined which is a basic factor that determine how high the mechanical properties is in a material.

Acknowledgements

Conflict of interest

No conflict of interest.

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