

Synthesis of Nanocellulose as a Sustainable Construction Material from Waste Paper Using the Alkaline Method at Low Temperature

Pengki Suanto¹, Saloma², Siti Aisyah Nurjannah^{2,*}, Shek Poi Ngian³

¹Postgraduate Program, Department of Civil Engineering, Faculty of Engineering, Universitas Sriwijaya, Indonesia

²Department of Civil Engineering, Faculty of Engineering, Universitas Sriwijaya, Indonesia

³Construction Research Centre (CRC-UTM), Universiti Teknologi Malaysia, Malaysia

Received August 8, 2024; Revised October 16, 2024; Accepted November 13, 2024

Cite This Paper in the Following Citation Styles

(a): [1] Pengki Suanto, Saloma, Siti Aisyah Nurjannah, Shek Poi Ngian, "Synthesis of Nanocellulose as a Sustainable Construction Material from Waste Paper Using the Alkaline Method at Low Temperature," *Civil Engineering and Architecture*, Vol. 13, No. 1, pp. 175 - 192, 2025. DOI: 10.13189/cea.2025.130110.

(b): Pengki Suanto, Saloma, Siti Aisyah Nurjannah, Shek Poi Ngian (2025). *Synthesis of Nanocellulose as a Sustainable Construction Material from Waste Paper Using the Alkaline Method at Low Temperature*. *Civil Engineering and Architecture*, 13(1), 175 - 192. DOI: 10.13189/cea.2025.130110.

Copyright©2025 by authors, all rights reserved. Authors agree that this article remains permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

Abstract The development of the construction industry impacts the need for sustainable materials and efforts to utilize paper waste. Synthesis of nanocellulose from waste paper uses the alkaline method at low temperatures as an environmentally friendly alternative construction material. The central concept of the research involves the transformation of waste paper into nanocellulose using alkali at low temperatures, which aims to explore waste paper as the primary material for nanocellulose that can be used in concrete mixtures. The alkalization process uses NaOH and NaClO at low temperatures. The research results show the successful synthesis of nanocellulose with promising characteristics for application in construction materials. PSA results confirmed the achievement of the nano size, showing that the distribution of particles on the nanometer scale between 100-500nm has an impact on the material properties. FTIR spectroscopy verified the chemical structure of nanocellulose, identifying the characteristic functional groups of cellulose. XRD revealed an increased amorphous structure after alkali processing on nanocellulose, which correlated with its mechanical strength. SEM observations visualize the morphology of nanocellulose, displaying the structure of the nanofibrils formed. EDX results in unsynthesized fibres were dominated by carbon and impurities; after synthesis, the carbon content disappeared, and the silica increased. The overall results show the

potential of nanocellulose from waste paper as a sustainable construction material, offering an innovative solution for reducing waste and developing eco-friendly building materials. This research opens up new opportunities to utilize waste paper and develop nanomaterials for a more sustainable construction industry.

Keywords Composite Construction Materials, Low-Temperature Alkali Method, Material Characterization, Nanocellulose, Waste Paper

1. Introduction

Technological developments in the industrial world are so rapid that they can bring various innovations, one of which is in the construction industry. One of the promising innovations in the construction industry is the use of sustainable materials such as nanocellulose, which is helpful as a mixture in concrete which is part of sustainable construction materials. Nanocellulose obtained from renewable natural resources such as plants and agricultural waste has attracted the attention of researchers and practitioners in the construction industry for experimentation because of its unique properties and the potential to overcome various challenges in creating

material products used in sustainable development. In this context, research on synthesizing nanocellulose from waste paper using the alkaline method at low temperatures becomes very relevant. Waste paper is an abundant source of cellulose and is often wasted, so its use can provide added value while reducing waste. Nanocellulose is a solid, light, and environmentally friendly material that can be used as an alternative concrete mixture for sustainable construction. This research aims to develop sustainable construction materials from paper waste using nanocellulose. Using paper waste as the main material for making nanocellulose is considered capable of creating new materials and being an environmentally friendly solution, because it reduces waste, develops alternative building materials with better mechanical properties, and has the potential to replace conventional construction materials that have a negative impact on the environment. This research concept focuses on making nano cellulose from paper waste using the alkaline method at low temperatures and high temperatures and cellulose fibres without synthesis as a comparison. This synthesis process uses an alkaline method to separate cellulose fibres from paper waste, such as traces and stains. The alkalization process uses NaOH and NaClO at low temperatures: high-temperature, high-temperature combustion, and no synthesis. The low-temperature alkaline method was chosen because of its energy efficiency and potential to produce nanocellulose with desirable characteristics for construction applications. The advantages of choosing paper waste as the primary material for making nanocellulose include reducing the impact of paper waste because paper waste contains solid substances, alcohol, lignin, metal compounds, cholate and chlorine. Apart from reducing the availability of paper waste, it is also beneficial to develop sustainable construction materials. The resulting nanocellulose has highly reactive properties, allowing the formation of stronger bonds in the concrete mixture, reducing the carbon content, and increasing the silica content, which will positively impact the concrete mix. Concrete that uses nanocellulose has low permeability, so it can increase the concrete's resistance to chemical attacks such as chloride and sulfate, which is very important for the long-term durability of concrete.

The construction industry is a sector that significantly impacts the environment, both in terms of consumption of natural resources and greenhouse gas emissions. This industry also consumes around 3 billion tonnes of raw materials annually, equivalent to 40% of global consumption [1]. Developing sustainable construction materials is a top priority in mitigating climate change and conserving natural resources.

Nanocellulose has emerged as a promising material for sustainable construction applications. High mechanical strength, low density, biodegradable properties, and ability to be chemically modified make nano cellulose an ideal candidate for various applications in the construction industry. Nanocellulose has a tensile strength that can

reach 7.5 GPa, much higher than steel (0.2-0.6 GPa) or glass fiber (2.5 GPa). In addition, its low density (around 1.6 g/cm³) allows the development of lighter but still more robust construction materials [2].

One potential source for nanocellulose production is waste paper. Utilizing waste paper as raw material for nanocellulose provides a solution for waste management and creates a circular economic cycle in the paper and construction industries. Converting waste into nano cellulose using enzymatic-assisted processing has been carried out as an alternative with excellent potential to be explored [3].

Low-temperature alkaline methods for synthesizing nanocellulose have attracted attention due to several advantages. This process requires lower energy input than conventional methods that use high temperatures, making it more environmentally friendly. Alkaline treatment can effectively remove lignin and hemicellulose, producing nitrocellulose with a high degree of purity. Alkaline treatment at low temperatures (60 °C) can produce nanocellulose with an exemplary aspect ratio and is essential for material reinforcement applications [4].

The use of nanocellulose in construction has a wide range of potential applications. One of them is as an additive in concrete to increase strength and durability. The study conducted by Cao et al. [5] showed that adding nanocellulose as much as 0.5% by weight of cement can increase the compressive strength of concrete by up to 30%. In addition, nanocellulose can also be used as a reinforcement in polymer composites for lightweight structural applications. Research by Xu et al. [6] demonstrated an increase in elastic modulus of up to 40% in nanocellulose-reinforced epoxy composites. The sustainability aspect of nanocellulose is not only limited to renewable raw material sources but also includes its biodegradable properties. This means that nanocellulose-based construction materials have the potential to biodegrade at the end of their life, reducing the long-term environmental burden. A previous study conducted by Saba et al. [7] showed that nanocellulose composites could degrade up to 90% in compost conditions for 180 days, much faster than conventional construction materials. However, the main challenges in developing nanocellulose for construction applications are production scale and cost. The extraction and purification process of nanocellulose often requires complicated and energy-intensive steps, which can limit its commercial applications. Therefore, developing efficient and cost-effective synthesis methods, such as low-temperature alkaline methods, is very important. Nanocellulose synthesis uses waste paper, processed using alkali with the chemicals NaOH and NaClO, and can produce new construction materials that are good for the environment [8]. Additional test methods must be developed to complement the various chemical concentration and temperature variants. The results of this research can function as a concrete or mortar mixture. These tests

include tensile strength, compressive strength, density, resistance to the environment and chemicals, and water absorption permeability.

In addition, integrating nanocellulose into existing construction materials also requires further research. The interaction between nanocellulose and the cement or polymer matrix and its effect on the long-term properties of the material still needs to be studied in depth. The study conducted by Chen et al. [9] showed that surface modification of nanocellulose can increase compatibility with the matrix and optimize the mechanical properties of the composite. Another aspect that needs to be considered is standardization and regulations regarding using nanocellulose in construction. Given its tiny size, there needs to be a comprehensive understanding of the potential health and environmental risks of nanocellulose. Research by Endes et al. [10] highlighted the importance of toxicological and ecotoxicological evaluation of nanocellulose to ensure its safe use on a large scale.

Based on the background described, this research has several objectives:

1. Develop an efficient and environmentally friendly method for synthesizing nanocellulose from waste paper using alkaline treatment at low temperatures.
2. Optimize synthesis process parameters, including alkali concentration, temperature, and reaction time, to produce nanocellulose with optimal characteristics for construction applications.
3. Characterize the physical, chemical, and mechanical properties of the resulting nanocellulose, including morphology, amorphousness, and crystallinity.

This research is expected to provide various benefits, both from a scientific, technological, and socio-economic perspective:

1. This research will enrich our understanding of the process of nanocellulose synthesis from waste materials, especially waste paper. The research results may provide new insights into the mechanism of nanocellulose formation at low-temperature conditions and the role of alkali treatment in this process. In addition, thorough characterization of the resulting nanocellulose will contribute to the knowledge based on the relationship between process parameters, structure, and properties of nanocellulose.
2. Developing efficient and environmentally friendly nanocellulose synthesis methods can encourage innovation in the advanced materials industry. This method can overcome some main challenges in large-scale nanocellulose production, such as high energy consumption and hazardous chemicals. In addition, optimizing the process to produce nanocellulose with characteristics suitable for construction applications could pave the way for developing a new generation of construction materials that are stronger, lighter, and more sustainable.

3. Utilizing waste paper as raw material for nanocellulose synthesis can provide a solution for effective waste management. This aligns with circular economy principles and can contribute to reducing waste paper in landfills. In addition, synthesis methods at low temperatures can reduce energy consumption and green house gas emissions associated with nanocellulose production.
4. Developing an efficient nanocellulose production method based on cheap raw materials (used paper) can significantly reduce production costs. This has the potential to expand the application of nanocellulose in various industrial sectors, including construction, which has been limited due to high production costs. In addition, utilizing waste paper to produce high-value materials can create new economic opportunities and encourage the growth of a more sophisticated recycling industry.
5. Developing more sustainable nanocellulose production technologies can contribute to creating new jobs in the advanced materials and recycling industries. In addition, applying nanocellulose in construction can produce safer, more durable, and energy-efficient buildings, improving people's quality of life.

The synthesis of nanocellulose as a sustainable construction material based on waste paper using alkaline methods at low temperatures is a promising research area with potential broad impacts. This research aims to find a nanocellulose synthesis method that is more efficient and better for the environment and explore and develop it for application in the sustainable construction industry. By optimizing the synthesis process, comprehensive characterization of the resulting material, and evaluating its application potential, this research is expected to significantly contribute to developing a new generation of construction materials. Furthermore, the approach used in this research, namely utilizing waste as a high-value resource, reflects a paradigm shift towards a more sustainable circular economy. This includes further optimization of the synthesis process, the development of more sophisticated characterization methods, and in-depth studies of the interactions of nanocellulose with various construction material matrices. In addition, comprehensive sustainability analyses and economic evaluations will be required to ensure that the technologies developed are technically feasible, economically viable, and sustainable in the long term. Considering the potential and existing challenges, this research can be essential in developing innovative material solutions for a more sustainable construction industry. The results of this research will contribute to the progress of science and technology and potentially positively impact the environment, society, and economy.

2. Materials and Methods

2.1. Materials

This research used 70/80gsm HVS waste paper material collected from campuses and others. To neutralize the fiber, the solvent uses 99% solid sodium hydroxide (NaOH), liquid sodium hypochlorite (NaClO), and distilled water. Waste paper is cut into ± 1 cm pieces.

2.2. Methods

The flow of this methodology can be seen in Figure 1. The paper is cut to an average size of 1 cm to 10 grams and then cleaned from various impurities, such as staples and clips, to not affect the chemical composition during treatment. Then, soak for approximately 30 minutes at room temperature so the paper quickly turns into pulp. Then, grind for 5 minutes using a grinding machine. After grinding, the paper pulp is treated using an alkaline solution of 6% NaOH and 2% NaClO mixed in 800 ml of distilled water. The next stage is heated for 30 minutes at 50 °C (for low temperature) and stirred continuously using a

hot plate. After the synthesis process with alkaline material is completed, the rinsing process continues with distilled water to neutralize the pH. The next stage is the filtering process using a 1 μ filter and a 0.1 μ filter. The weight taken passes through a 1 μ sieve and is retained on a 0.1 μ sieve so that the particles obtained have a diameter of $<1 \mu$. Continue drying using an oven at 150 °C for 2 hours until the fiber dries into a membrane. After the sample is dry, grinding is carried out until reactive fiber granules are obtained. As a comparison of the processing results of waste paper burned at high temperatures and waste paper without processing, the results of the three processing methods can be compared with the physical, chemical properties and microstructural.

2.3. Characterization of Nanocellulose

Nanocellulose characterization includes testing for Particle Size Analyzers (PSA), Fourier Transform Infrared Spectroscopy (FTIR), X-ray diffraction (XRD), Scanning Electron Microscope (SEM), and Energy Dispersive X-ray (EDX).

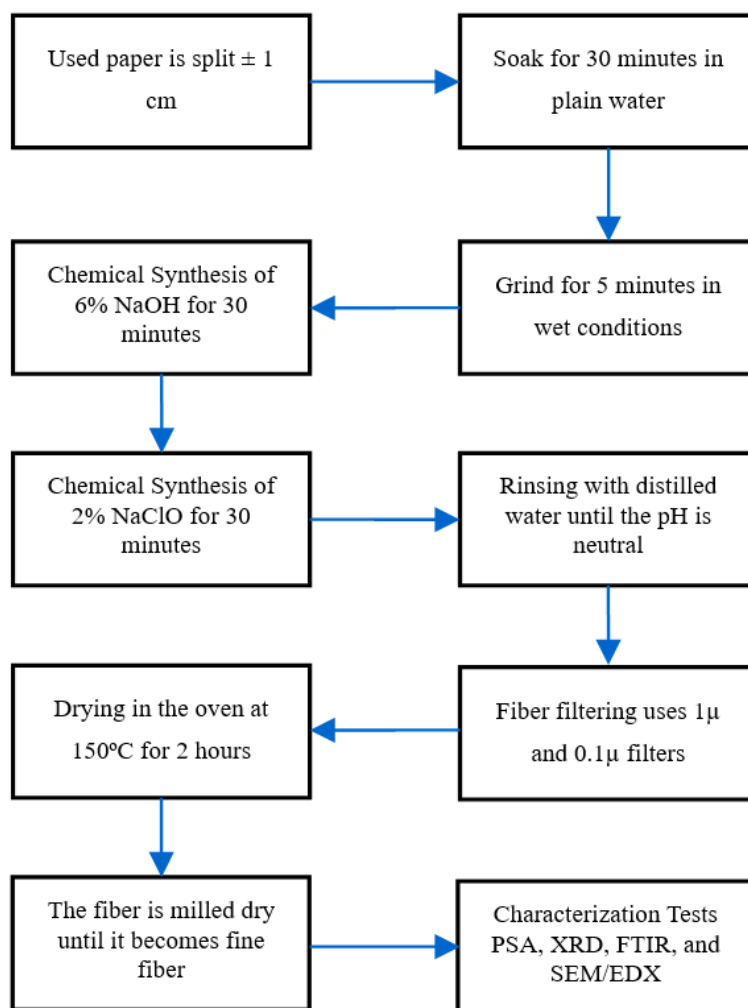


Figure 1. Research Flow Chart

3. Results and Discussion

3.1. PSA Results

Particle size analysis (PSA) testing aims to determine a material's particle diameter size distribution. Smaller particle diameters can change the characteristics of the resulting structure so that it becomes denser and has higher mechanical properties. This is because the tiny size of the nanoparticles fills the cavities on the surface of concrete or mortar to improve the material's physical and mechanical properties. PSA testing uses the Dynamic Light Scattering (DLS) method with the HORIBA SZ-100 to measure the intensity of light scattered by suspended particles. These fluctuations are described to obtain the particle size distribution. DLS is very effective for measuring small particles, usually in the nanometer range. Particle size

analysis (PSA) is an essential method in characterizing nanocellulose, which will be used as a concrete mixture in construction materials. The results of the PSA test with the distribution of nanocellulose particle diameters made from waste paper using the alkaline method at low temperatures are in Figure 2. The distribution of particles at a distance of 171.25 - 500.15 nm is explained in Table 1. The most dominant distribution is at a size of 300 - 400 nm, meanwhile, in Figure 3. The results of the synthesis of cellulose fibres at high temperatures show a more extensive distribution of fibre particles between 454.69 - 945.74 nm, where fibres are more dominant between 500 - 800 nm, as seen in Table 2. Meanwhile, Figure 4 explains the distribution of cellulose fibre particles without synthesis, only grinding, so that a particle distribution of around 246.98 - 2222.51 nm is obtained, as shown in Table 3.

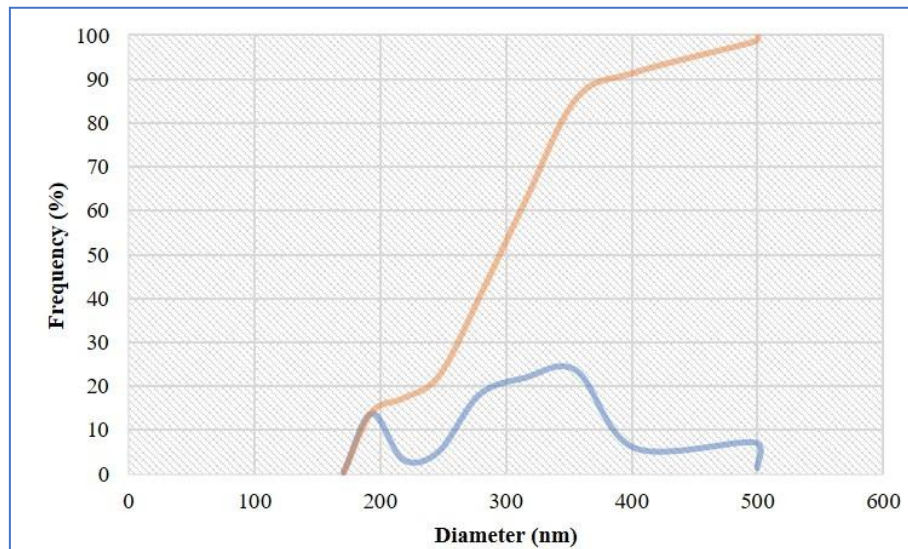


Figure 2. Distribution of cellulose fiber particle diameter sizes low temperature synthesis

Table 1. Distribution of cellulose fiber particles with low temperature synthesis

Diameter (nm)	Frequency	Cumulation
171.25	0.27	0.27
193.48	13.74	14.01
218.60	3.22	17.23
246.98	5.07	22.30
279.04	17.98	40.28
315.27	21.83	62.11
356.20	23.54	85.65
402.44	5.89	91.54
498.22	7.12	98.66
500.17	1.34	100.00

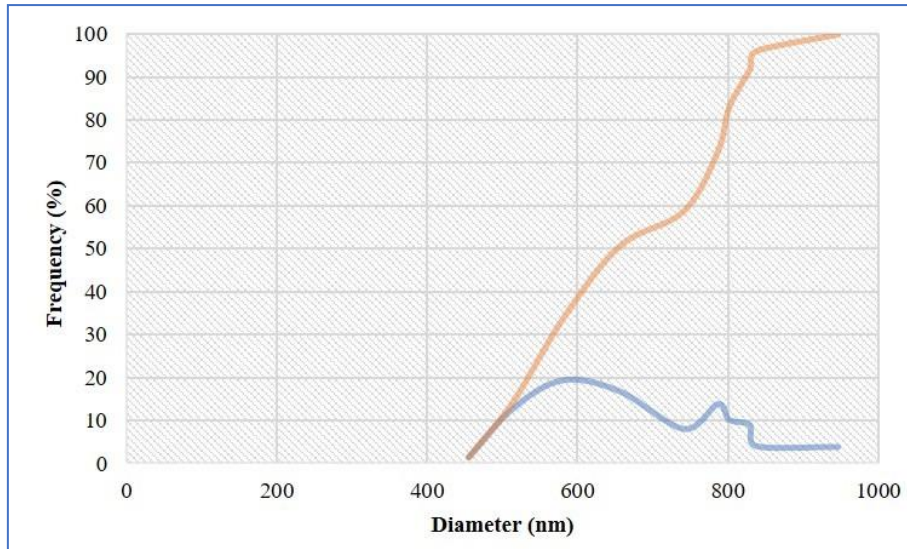


Figure 3. Distribution of cellulose fiber particle diameter sizes high temperature synthesis

Table 2. Distribution of cellulose fiber particles with high-temperature synthesis

Diameter (nm)	Frequency	Cumulation
454.69	1.50	1.50
513.71	12.88	14.38
580.41	19.46	33.84
655.76	16.87	50.71
740.89	8.10	58.81
786.21	13.93	72.74
801.12	10.27	83.01
828.90	8.97	91.98
837.07	4.11	96.09
945.74	3.91	100.00

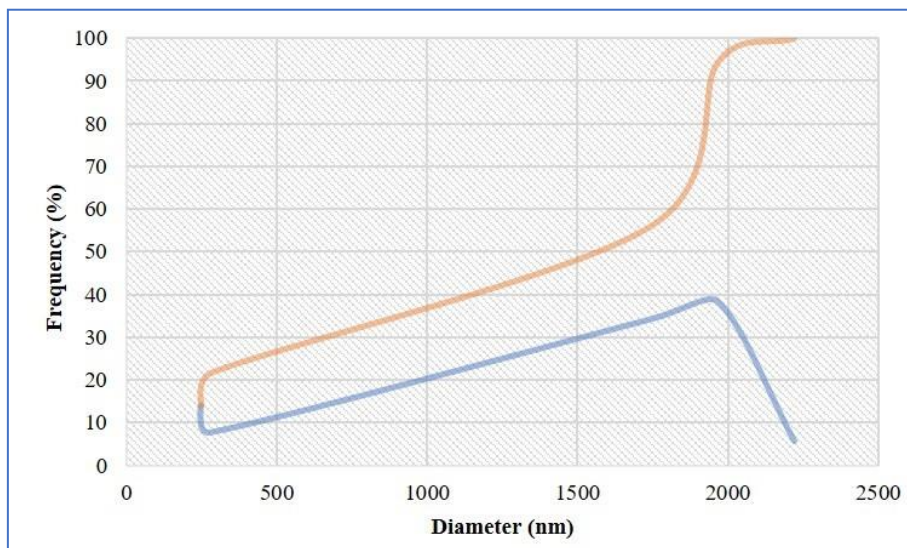


Figure 4. Distribution of cellulose fiber particle diameter sizes without synthesis

Table 3. Distribution of cellulose fiber particles without synthesis

Diameter (nm)	Frequency	Cumulation
246.98	13.95	13.95
279.04	7.70	21.65
1741.10	34.20	55.85
1967.14	38.49	94.34
2222.51	5.66	100.00

The size of nanomaterials produced through synthesis using the alkali method has many dimensional variants depending on various factors such as solution concentration, reaction temperature, reaction time, and the type of precursor used. Synthesis using the alkaline method produces smaller nanomaterials than samples treated at high temperatures, and without synthesis, organic decomposition by NaOH occurs with cellulose fibres. The resulting particle size usually ranges from 100-500 nm when nanomaterials are synthesized using alkali. Synthesis of ZnO nanoparticles using NaOH as a precipitating agent produces particles with an average size of 50-80 nm [11]. This size can be influenced by the concentration of NaOH used, where higher concentrations tend to produce smaller particles. Synthesis of nanomaterials using the acid method generally produces particles with a smaller size, ranging from 5-50 nm. Synthesis of TiO₂ nanoparticles using hydrochloric acid (HCl) as a catalyst produces particles with an average size of 10-30 nm [12]. Increasing acid concentration and reaction time can lead to a decrease in particle size. The difference in the size of nanomaterials is produced via alkaline and acidic methods can be explained by particle formation and growth mechanisms. The nucleation and particle growth process in the alkaline method tends to be faster due to the high concentration of hydroxyl ions (OH⁻) available. This can lead to the formation of larger particles.

On the other hand, in the acid method, nucleation and particle growth are more controlled because of the presence of protons (H⁺), which can inhibit excessive particle growth. Apart from that, the reaction temperature factor also significantly influences the size of the resulting nanomaterial. According to Ioannou et al. [13], increasing the reaction temperature in the synthesis of CeO₂ nanoparticles using the acid method causes an increase in particle size from 15 nm at 60 °C to 40 nm at 120 °C. This is caused by increased crystal growth rate at higher temperatures.

Synthesis at low temperatures causes the alkaline hydrolysis process to run more slowly and in a controlled manner. According to research by Li et al. [14], hydrolysis at low temperatures allows the release of cellulose fibers gradually and evenly, resulting in nanocellulose with a more uniform and smaller size. Low temperatures can inhibit the cellulose recrystallization process. As Chen et al. [9] explained, higher temperatures tend to increase the mobility of cellulose chains, which

can cause aggregation and the formation of larger crystals. Using low temperatures can help maintain the structural integrity of cellulose. According to Jiang et al. [15], alkali treatment at high temperatures can cause excessive degradation of cellulose, which has the potential to produce larger or non-uniform particles. Apart from that, low temperatures can also help control the hydrolysis reaction rate. Sharma et al. [16] showed that the hydrolysis reaction proceeds more slowly at lower temperatures, providing sufficient time for cellulose fibers to separate without causing significant structural damage.

The results of the Particle Size Analysis (PSA) test on nano cellulose, which will be used as a composite construction material, show a significant particle size distribution at the nanoscale. This analysis revealed that the majority of nanocellulose particles were between 100-500 nm in size, with an average particle size of around 300 nm. The most effective nanomaterial sizes in mortar or concrete mixtures are generally 100-500 nm. Nanomaterials of this size have high effectiveness because they can fill micropores in the cement matrix, increasing the strength and durability of the material. Nanoparticles in this size range can also act as crystallization nuclei, speeding up the cement hydration process and producing a denser structure. Nanosilica, with a size of 100-200 nm, has been proven effective in increasing concrete's compressive strength and density [4]. TiO₂ nanoparticles with a size of around 300 nm can improve cement mortar's self-cleaning and photocatalytic properties [17]. Nanoparticles measuring 400-500 nm can increase concrete's resistance to acid and sulfate attacks [18]. Nanosilica with a particle size of 200-300 nm effectively increases the strength and reduces the porosity of cement mortar [19].

3.2. FTIR Results

Fourier Transform Infrared Spectroscopy (FTIR) is an analytical technique used to identify and characterize chemical compounds in a sample based on infrared light absorption. FTIR testing serves various vital purposes, especially in chemical and materials analyses. FTIR testing is a handy tool in various fields of science and industry. This technique allows the identification and characterization of functional groups and chemical structures of materials with high precision. FTIR provides information about the chemical composition, molecular interactions, and material changes, making it an essential analytical technique in research and industrial applications. The purpose of FTIR testing is to identify functional groups in a molecule. Each functional group has a characteristic infrared absorption pattern, which can be used to identify its presence in a sample. Determine the chemical structure of a compound by analyzing the absorption bands that appear in the infrared spectrum. This allows the identification of chemical components in the sample. Identify the constituent elements in a mixture of

organic and inorganic materials. This technique helps analyze the composition of complex materials, such as polymers, composite materials, and biomaterials, as well as intermolecular interactions, including hydrogen bonds, van der Waals, and ionic interactions.

Changes in absorption bands can provide information about molecular interactions and the environment. Monitor chemical changes during the reaction. By periodically recording infrared spectra, FTIR can identify new products' formation and reactants' decomposition in the product quality control industry. This technique can detect contaminants and impurities in materials, ensuring consistent product quality. FTIR is used to analyze the chemical structure of nanocellulose and other nanomaterials. This technique helps identify chemical changes during the synthesis and surface modification processes. A practical tool is used to identify various types of polymers and plastics based on their infrared spectrum. This is important in plastic recycling and analysis of polymer materials. FTIR can provide information about the crystallinity of materials, such as polymers and cellulose. Certain absorption bands relate to the crystalline and amorphous structures in the material.

Figure 5 shows the FTIR pattern of synthetic nano cellulose using alkali at low temperatures. The x-axis shows the wave number in cm^{-1} , while the y-axis shows the transmittance percentage. The spectrum starts at 4000 cm^{-1} and ends at 500 cm^{-1} . There are several significant absorption peaks across the spectrum. The most substantial absorption peak is in the range of 1052 cm^{-1} , with the lowest transmittance of around 65%. Other prominent peaks are seen at 3330 cm^{-1} , 2893 cm^{-1} , 2159 cm^{-1} , 1637 cm^{-1} , and some in the fingerprint region (below 1500 cm^{-1}). The peak width at 3330 cm^{-1} indicates the presence of O-H or N-H bonds. The $2800\text{-}3000 \text{ cm}^{-1}$ region shows a peak that may originate from C-H stretching. The sharp peak at 2159 cm^{-1} may indicate the presence of a triple bond or nitrile group.

Figure 6 shows cellulose fibre's FTIR pattern after synthesis at high temperatures by burning. The x-axis

shows the wave number in units of cm^{-1} , ranging from 4000 cm^{-1} to 500 cm^{-1} . The y-axis shows the transmittance percentage on a scale from -0.5 to 4.0 . This spectrum shows several dominant absorption peaks. The most visible peak is around 848 cm^{-1} , with a transmittance reaching nearly 4.0 . This sharp peak indicates the presence of solid molecular vibrations at that frequency. Other absorption peaks identified include 3451 cm^{-1} , 2513 cm^{-1} , 1796 cm^{-1} , 1529 cm^{-1} , 1018 cm^{-1} , and 714 cm^{-1} . Each of these peaks represents a specific vibration of various molecular bonds or functional groups. The region above 3000 cm^{-1} is relatively flat, indicating the absence of strong O-H or N-H stress vibrations. The peak at 2513 cm^{-1} indicates the presence of dominant C-H bonds. The fingerprint region (below 1500 cm^{-1}) shows several complex peaks, providing specific information about the molecular structure. The sharp peak at 848 cm^{-1} is very characteristic and indicates the vibration of the dominant functional group in the compound.

Figure 7 shows the FTIR pattern of cellulose fibre without synthesis, where the x-axis shows the wave number in cm^{-1} , ranging from 4000 cm^{-1} to 500 cm^{-1} . The y-axis shows the transmission percentage on a scale from 40% to 100% . This spectrum has several significant absorption peaks. The most prominent peak is around 1423 cm^{-1} , with the lowest transmittance around 55% . This broad and strong peak indicates the presence of intense molecular vibrations at that frequency. Other absorption peaks identified include at 3334 cm^{-1} , 2893 cm^{-1} , 2159 cm^{-1} , 2030 cm^{-1} , 1159 cm^{-1} , 872 cm^{-1} , and 602 cm^{-1} . Each of these peaks represents a specific vibration of various bonds or functional groups in the molecule. The peak width at 3334 cm^{-1} indicates the presence of O-H or N-H bonds. The $2800\text{-}3000 \text{ cm}^{-1}$ region shows a peak that may originate from C-H stretching. The sharp peak at 2159 cm^{-1} may indicate the presence of a triple bond or nitrile group. The fingerprint region (below 1500 cm^{-1}) shows several complex peaks, providing specific information about the molecular structure. This compound's strong peak at 1423 cm^{-1} and other peaks in this region are characteristic.

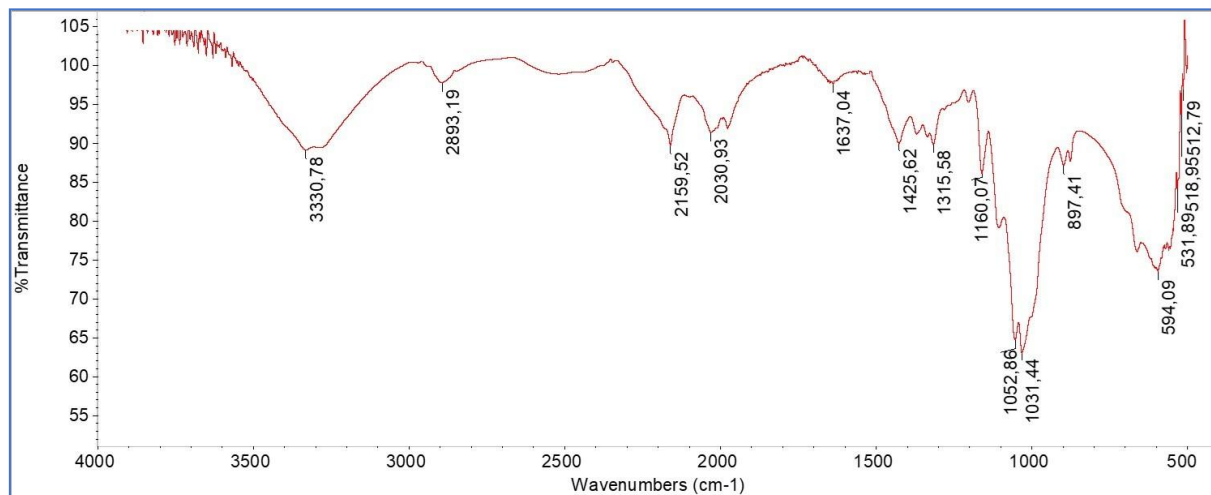


Figure 5. FTIR pattern of nanocellulose synthesis at low temperature synthesis

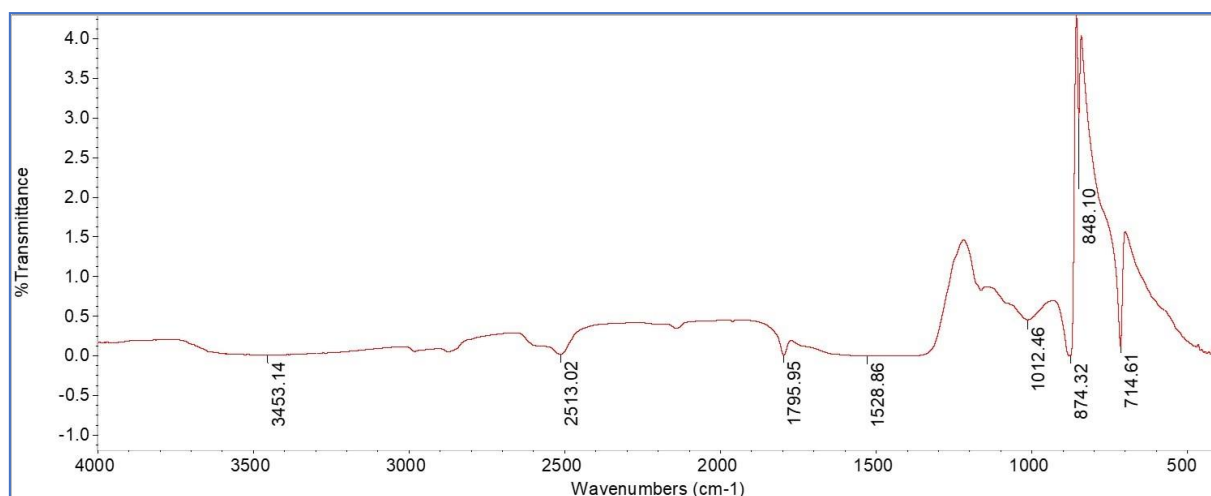


Figure 6. FTIR pattern of nanocellulose synthesis at high temperature synthesis

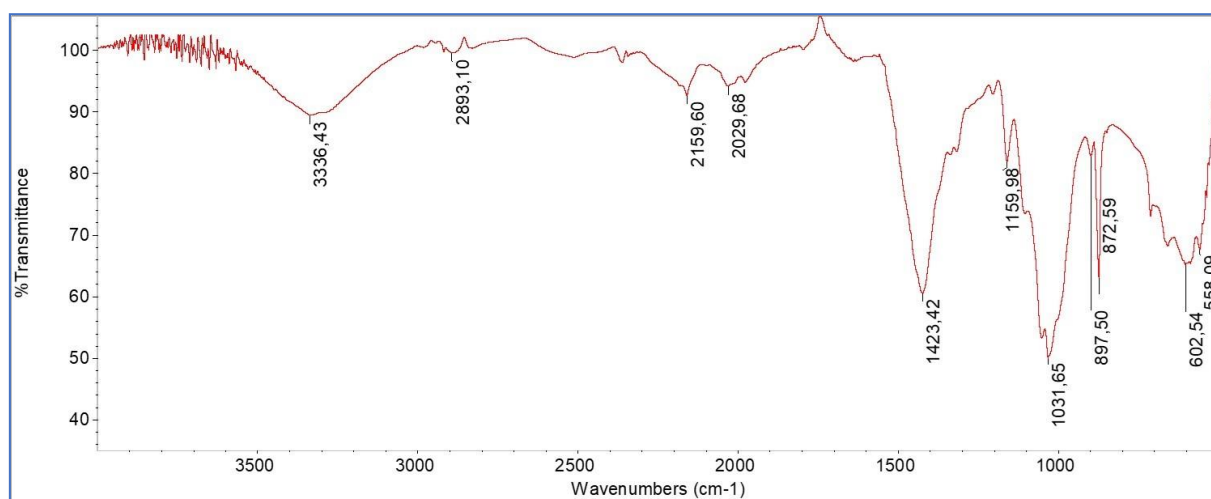


Figure 7. FTIR pattern of nanocellulose without synthesis

Fourier Transform Infrared Spectroscopy (FTIR) testing on cellulose fibers synthesized with alkali at low temperatures has the FTIR spectrum of nanocellulose showing characteristic peaks that reflect the functional groups and chemical bonds present in the sample. The broad absorption peak in the 3200-3500 cm^{-1} range indicates the presence of O-H stretching vibrations from intermolecular and intramolecular hydrogen bonds in the cellulose structure [14]. The intensity and width of these peaks indicate the level of crystallinity of the cellulose, whereas sharper and narrower peaks indicate higher crystallinity. Alkaline treatment at low temperatures tends to increase the crystallinity of nanocellulose compared to the initial waste paper raw material [20]. The peak around 2900 cm^{-1} is related to C-H stretching vibrations in the methyl and methylene groups contained in the cellulose chain [21]. The intensity of this peak can provide an overview of the degree of polymerization in cellulose.

The nanocellulose synthesis process generally causes a decrease in the intensity of this peak, which indicates

partial depolymerization of cellulose into shorter chains [22]. The spectrum region between 1000-1200 cm^{-1} displays several peaks related to the glycosidic structure of cellulose. According to a study by Sharma et al. [16], the peaks around 1160 cm^{-1} and 1110 cm^{-1} are related to the asymmetric stretching vibration of C-O-C and the vibration of the pyranose ring, respectively. The intensity of this peak can provide information about the hygroscopic properties of the resulting nanocellulose. The disappearance or significant reduction of the peak at around 1730 cm^{-1} , which is related to the C=O stretching vibration of the acetyl or uronate ester groups of hemicellulose, indicates the effectiveness of alkali treatment in removing non-cellulosic components such as hemicellulose and lignin from waste paper raw materials [4]. FTIR testing of cellulose fibers synthesized using alkali at high temperatures, showing that the results of nano cellulose synthesis from waste paper using the alkali method at high temperatures provide essential information about the chemical structure and changes that occur during

the process [23]. The FTIR spectrum shows characteristic peaks indicating the presence of cellulose functional groups [24]. The broad peak at around 3300-3400 cm^{-1} indicates the stretching of O-H bonds, a characteristic characteristic of cellulose [25]. Alkaline treatment can cause a shift or change in the intensity of these peaks [26]. The disappearance of the peak at around 1740 cm^{-1} after treatment indicates the loss of acetyl and uronate ester groups from hemicellulose and ester bonds from lignin [27]. Comparison of the FTIR spectrum before and after treatment provides an overview of changes in the chemical structure, level of crystallinity, and purity of the resulting nanocellulose [28]. This analysis is essential for optimizing process parameters and understanding the properties of the final product [29].

FTIR spectrum of cellulose fibers without any synthetic treatment shows the characteristic peaks of cellulose. The broad peak at around 3300 cm^{-1} indicates the presence of hydrogen bonds in the -OH group. The peak in the 2900 cm^{-1} region corresponds to C-H stretching. The peak at 1640 cm^{-1} indicates bound water. The peaks around 1430 cm^{-1} and 1370 cm^{-1} are related to the deformation of CH_2 and CH, respectively. The sharp peak at 1060 cm^{-1} indicates the C-O-C bond of the pyranose ring. These peaks are consistent with the cellulose structure in waste paper.

3.3. XRD Results

X-ray diffraction (XRD) is an analytical technique for studying a material's crystalline and amorphous structure. XRD testing serves a variety of essential purposes, especially in the characterization of index materials. One of the goals of XRD testing is to identify amorphous and crystalline phases in samples. Each amorphous and crystalline phase has a different diffraction pattern, which can be compared with standard data to determine the phase composition in the material. Determination of the structure of amorphous and crystalline materials includes lattice parameters, symmetry, and orientation of amorphous and crystalline materials. This is important to understand the properties of materials at the atomic level of the material.

The crystallinity index (CrI) of the sample is calculated using the following equation:

$$\text{CrI} = I_{002} - I_{am}/I_{002} \times 100\% \quad [30]$$

I_{002} is the crystal area, and I_{am} is the amorphous area multiplied by 100%.

XRD testing of samples without synthesis and XRD variants at low temperatures is shown in Figure 8. XRD diffractogram of processing uses the alkaline method at low temperatures. Figure 9 shows that XRD diffractogram of processing uses the high temperature combustion method. Figure 10 represents the XRD diffractogram without processing.

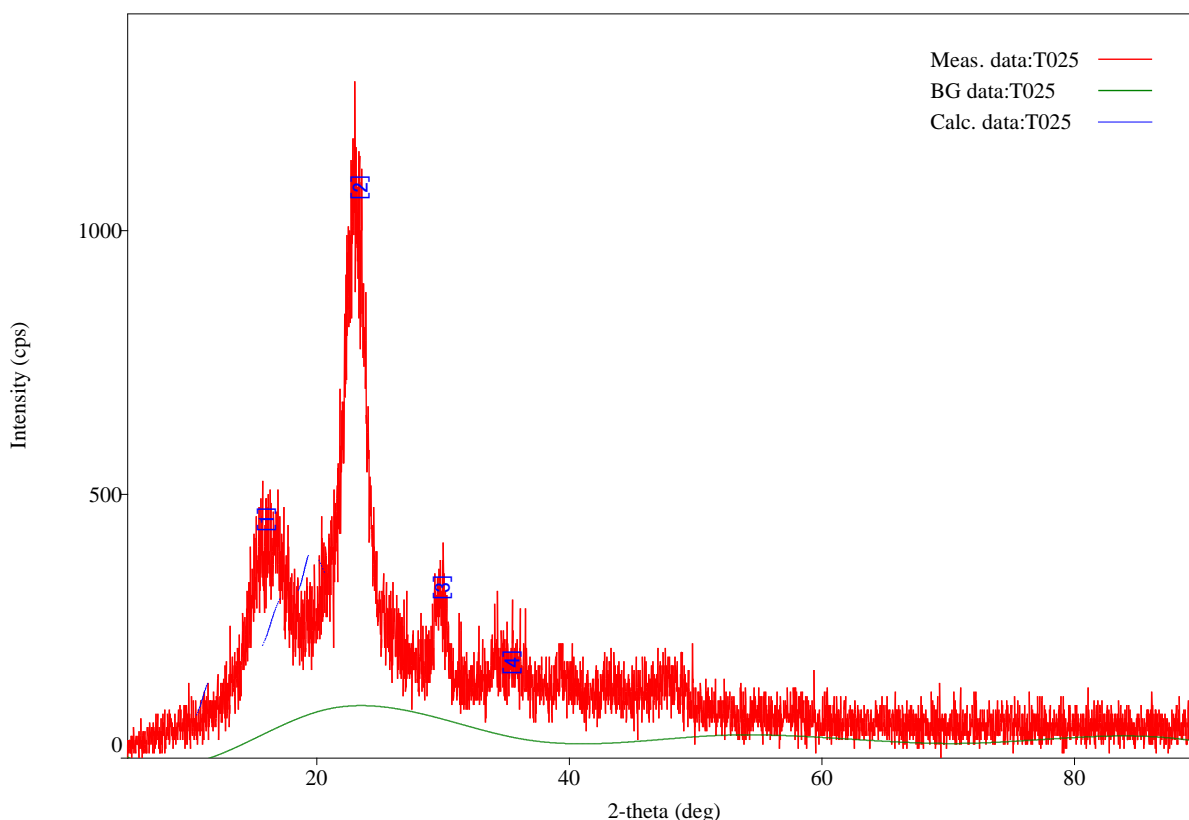


Figure 8. XRD pattern of nanocellulose synthesis at low temperature

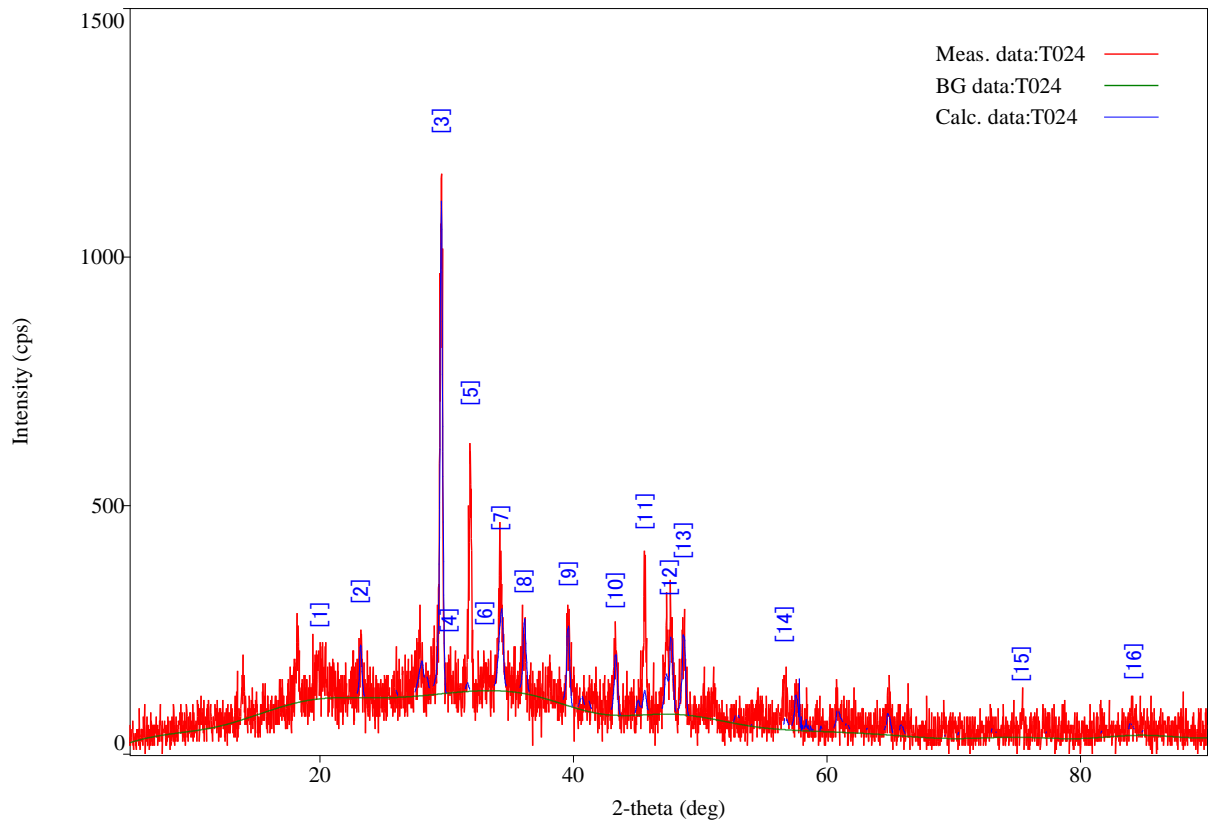


Figure 9. XRD pattern of nanocellulose synthesis at high temperature

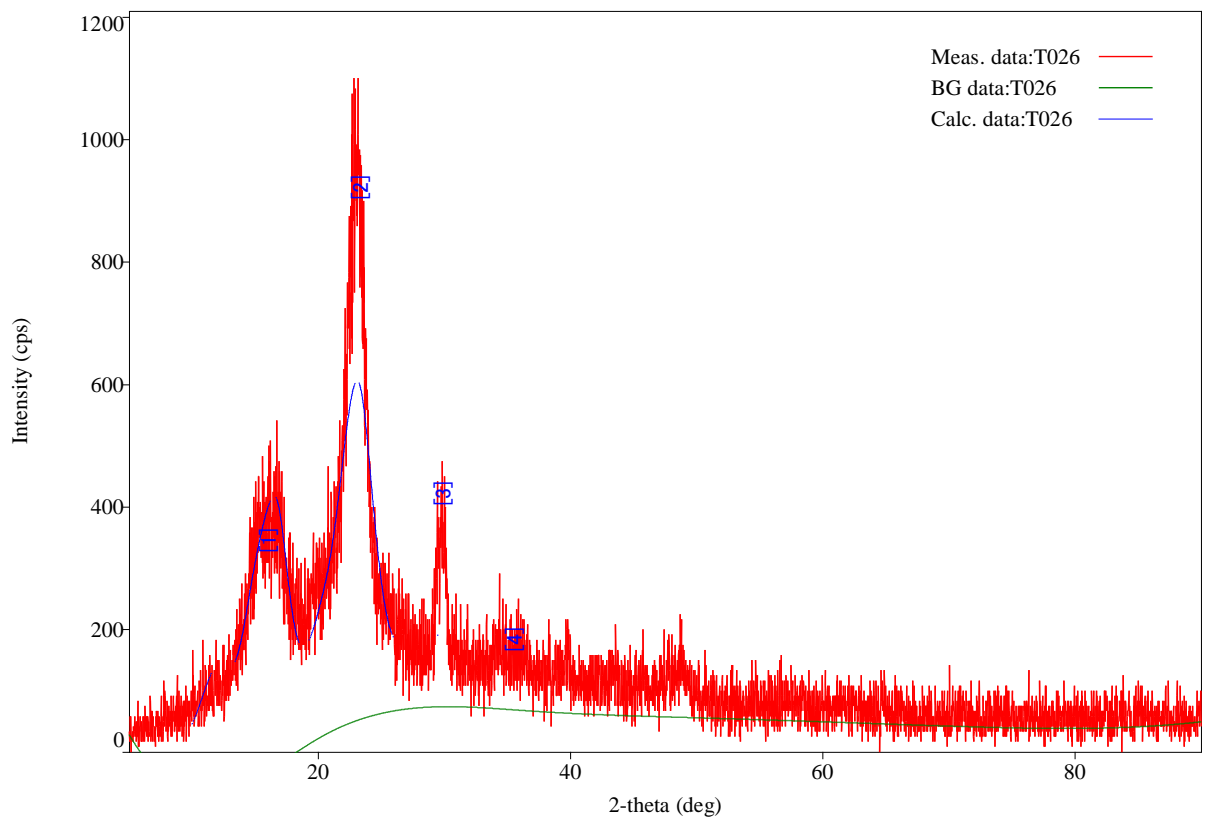


Figure 10. XRD pattern of nanocellulose without synthesis

XRD analysis of the synthesis of nanocellulose from waste paper using the alkaline method at low temperatures in Figure 8 shows the x-axis, which shows the 2θ diffraction angle in degrees, ranging from 10 to 90°. The y-axis depicts the diffraction intensity in arbitrary units (a.u.). The graph has three curve lines: red, green, and black. The red line represents experimental measurement data (Meas data/T025), the black line shows the theoretical calculation results (Calc data/T025), and the green line represents the substrate's background or diffraction pattern. The most prominent diffraction peak is at a 2θ angle of around 25°, with an intensity reaching more than 1000 a.u. This sharp peak indicates the presence of a crystalline phase. However, after passing the 2θ angle of around 30°, the amorphous structure is more dominant in the sample. Several other diffraction peaks, with varying intensities, are visible throughout the angular range. These peaks provide information about the crystalline and amorphous structures of the phases present in the material. The agreement between measured (red) and calculated (black) data is quite good, especially for the prominent peaks. This shows that the structural model used in the calculations accurately describes the samples analyzed. Overall, this diffraction pattern shows that the sample has a regular amorphous structure with a dominant phase and a crystalline structure with a small amount of crystalline phase. The observed diffraction peaks indicate the presence of varying crystalline and amorphous structures of cellulose, with the central peak typically appearing at a 2θ angle of approximately 22° reflecting both crystalline and amorphous planes, as described by Moon et al. [2] in their study on nanocellulose characterization. The decrease in peak intensity and broadening compared to natural cellulose indicates a decrease in crystallinity and crystal size consistent with the formation of nanocellulose and increases the presence of amorphous peaks. The shift of the peaks to higher angles may indicate increased compactness of the amorphous structure. Further analysis using the Scherrer equation allows estimation of the size of nanocellulose crystals, as Klemm et al. [31] discussed in their review of nanocellulose and its applications. These results support the successful synthesis of nanocellulose as a sustainable construction material from waste paper. Thus, XRD test results are essential for designing and engineering nanocellulose-based composites for innovative and efficient construction applications.

Figure 9 shows results of XRD analysis of cellulose fibres processed at high temperatures where the x-axis shows the 2θ diffraction angle in degrees, ranging from 10 to 90° degrees. The y-axis depicts the diffraction intensity in arbitrary units (a.u.), with a scale of up to 1500. The graph has three curves: red represents experimental measurement data (Meas/T024 data), black represents the background (BG/T024 data), and orange represents theoretical calculation results (Calc/T024 data). The diffraction pattern shows several sharp and clear peaks, indicating that the sample has a regular crystal structure.

The most prominent small diffraction peak is at a 2θ angle of about 32°, with an intensity reaching more than 1000 a.u. Other diffraction peaks are visible throughout the angular range with varying intensities, indicating the presence of crystalline. Each peak is labelled with a number in square brackets, indicating the Miller index associated with a particular crystal plane.

The agreement between the measured (red) and calculated (orange) data is excellent, indicating that the structural model used in the calculations accurately describes the sample. The background (black) is relatively low and stable, indicating good measurement quality. This diffraction pattern shows that the sample has an amorphous structure between complex crystal peaks with several identified crystal phases. According to French et al. [32] characteristic peaks are visible at 2θ angles of approximately 15°, 16°, and 22°, which represent the (110), (110), and (200) crystal planes of type I cellulose, respectively. Moreover, the peak's sharpness indicates the crystallinity level of the resulting nanocellulose. Park et al. [33] explained that alkaline treatment at high temperatures increases crystallinity by removing amorphous components such as hemicellulose and lignin. The crystallinity index can be calculated, providing quantitative information about changes in the crystal structure of cellulose.

XRD results without the synthesis of paper fibres from waste paper in Figure 10 show the characteristic diffraction pattern of cellulose. The x-axis shows the 2θ diffraction angle in degrees, ranging from 10 to 90°. The y-axis depicts the diffraction intensity in arbitrary units (au), with a scale of up to 1200. The graph has three curves: red represents experimental measurement data (Meas/T025 data), green represents the background (BG/T025 data), and blue represents theoretical calculation results (Calc/T025 data). The diffraction pattern shows several clear peaks, indicating the sample has a crystalline structure. The most prominent diffraction peak is at a 2θ angle of around 25°, with an intensity reaching more than 1000 a.u. This sharp peak indicates the presence of a dominant crystal phase in the sample. Several other diffraction peaks are visible throughout the angular range, especially in the 20-40° region, with varying intensities. These peaks provide information about the various crystal planes in the material structure. The agreement between measured (red) and calculated (blue) data is quite good, especially for the prominent peaks. This shows that the structural model used in the calculations accurately describes the samples analyzed. The background (green) is relatively low and stable, indicating good measurement quality and minimal noise or interference in the data. Overall, this diffraction pattern shows that the sample has a regular crystal structure with one dominant phase and the possibility of other minor phases.

The observed diffraction peaks indicate the presence of crystalline and amorphous structures in the fibers. The central peak usually appears at a 2θ angle of around 22°,

indicating the cellulose crystal plane [34]. Other weaker peaks are visible at angles of approximately 15° and 34° , related to the peak intensity and width, providing information about the degree of crystallinity and size of cellulose crystals [33]. This analysis helps understand the structure and properties of cellulose fibers from waste paper, which is essential in developing sustainable construction materials. The following is Table 4. The percentage of amorphous structure found in cellulose fibers synthesized using the alkali method at low and high temperatures and cellulose fibers without synthesis as a comparison.

Table 4. Percentage of amorphous structure of cellulose fiber

Method	Percentage (%)
No synthesis	56.80
Low temperature	83.76
High temperature	76.53

3.4. SEM Results

Scanning Electron Microscope (SEM) testing results on nanocellulose show a morphological structure that is very promising for application as a composite construction material. The low-temperature SEM morphology analysis of the synthesis is given in Figure 11. SEM of cellulose fibers is synthesized using the alkaline method at low temperatures at SU3500 5.00 kV X2.50k SE, and this excellent fibril structure provides high surface area and specificity with natural cellulose fibers not undergoing much change because they do not experience significant temperature changes, so it has great potential to improve the interaction between nanocellulose and the polymer matrix in concrete or mortar mixtures. Further observations show that nanocellulose has a uniform size distribution and good dispersion, which are essential factors in improving the mechanical properties of a concrete mixture. SEM images show the porous structure and potential of nanocellulose to enhance construction materials' thermal and acoustic insulation properties. These nanostructures increase cellulose's specific surface area and reactivity, thereby strengthening the mechanical properties of construction materials. Alkaline treatment at low temperatures can produce nanocellulose with uniform morphology and consistent dimensions [35]. Release of lignin and hemicellulose from the fiber structure through alkaline treatment aims to become purer nano-sized cellulose fibers [36]. You can also see that the fiber surface is cleaner and smoother than before treatment. The alkalinization process at low temperatures has proven to be effective in producing nanocellulose without destroying

the crystalline structure of cellulose [11]. The resulting nanocellulose has a high aspect ratio, potentially improving mechanical properties when applied as a construction material. The SEM morphology of cellulose fibers is given in Figure 12. SEM morphology of the results of the synthesis of cellulose fibers at high temperatures at SU3500 5.00 kV X2.50k SE is visible in the SEM results, which show changes in the fibers to the form of ash particles until the originality of the fibers has disappeared, which means the carbon content. Observations also show the separation of individual fibers previously bound in bundles. So cellulose ash that is not treated with alkali still contains many organic elements, which can potentially reduce the strength of concrete. Paper ash also impacts the cement setting time in the concrete mixture and can negatively affect the initial setting. These morphological changes confirm the delignification process's success and the cellulose structure's breakdown into nanocellulose [2,31]. These results align with previous studies that reported the effectiveness of alkali treatment in producing nanocellulose from various biomass sources [37,38].

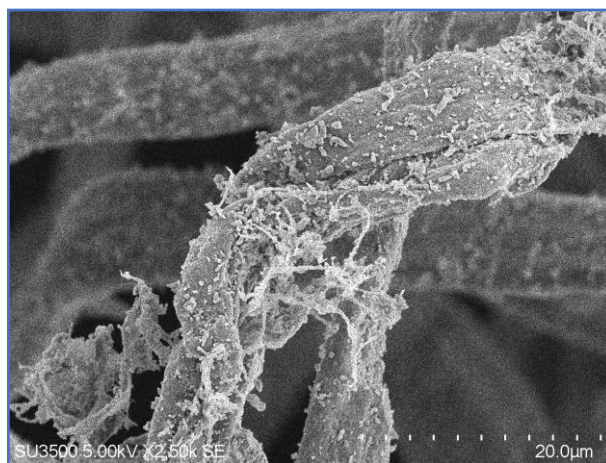


Figure 11. Morphology synthesis with low temperature

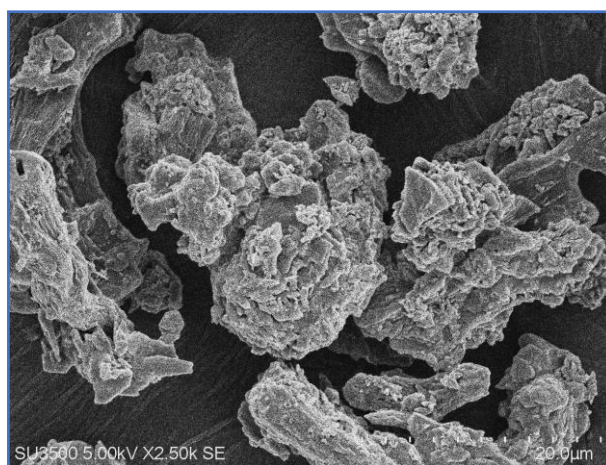


Figure 12. Morphology synthesis with high temperature

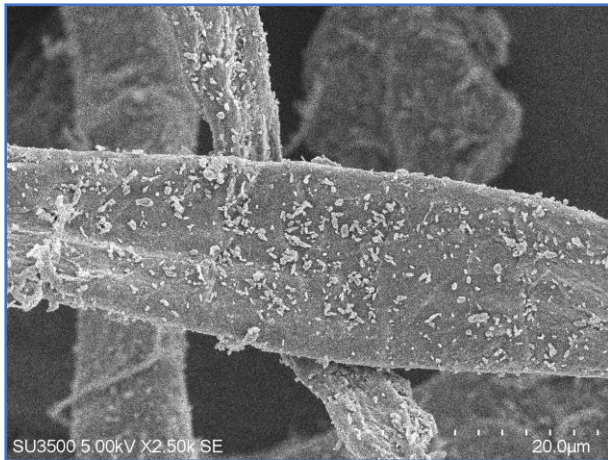


Figure 13. Morphology without synthesis

Figure 13 shows SEM analysis without synthesis of waste paper cellulose fibers in SU3500 5.00 kV. There is still a lot of dirt stuck to the fibers, which is dominated by carbon residue from dirt on used paper. If this residue is used in a concrete mixture, it will have a negative impact, one of which is on the durability of the concrete. SEM images show non-uniform fiber structures and weak bonds between fibers, resulting in low mechanical strength [39]. The surface of the fibers also appears rough and irregular, reducing adhesion between fibers and decreasing overall material performance [40]. In addition, voids and gaps appear between the fibers, which can cause excess water absorption and reduce the dimensional stability of the material [11]. This inhomogeneous structure also has the potential to reduce the material's resistance to load and pressure, limiting its application in construction [4]. Morphological characterization of NC shows stick-shaped rods and bundles with a size of around 34–49 nm [41]. This happens because natural cellulose fiber is rod-shaped. The dimensions obtained depend very much on the fiber treatment process.

3.5. EDX Results

Energy Dispersive X-ray (EDX) testing results on nanocellulose show that the chemical composition is significant for developing composite construction materials.

EDX test results on samples synthesized at low temperatures show higher and purer cellulose content than other methods. Figure 14 shows the results of the energy-dispersive X-ray (EDX) analysis, which is very relevant to the composition of cement materials. The visible peaks reflect similarities with crucial elements in Portland cement, a cement type used as a concrete binder. These contents include Calcium (Ca), which appears as the dominant element and is marked by the highest spectrum peak. This is due to the critical role of calcium in cement, especially in the form of calcium oxide or lime. Silicon (Si) also shows a significant presence, reflecting the silica

component in cement, which is essential for forming calcium silicate hydrate as the cement hardens. The aluminum (Al) detected indicates the presence of aluminate compounds in the cement, which play a role in the initial binding and strength of the cement. Iron (Fe), visible in small amounts, is a common component in cement and is also found in cellulose fibers synthesized at low temperatures. This substance is usually found in iron oxide, which gives cement its characteristic color. This elemental composition is typical for Portland cement, where calcium and silicon are the main components, with aluminum and iron as essential secondary elements. This analysis concerns the chemical properties of cement, which are also found in nanocellulose. It is important to know the influence of properties such as hardening time, strength, and durability. This shows that the results of the alkalization process at low temperatures can better maintain the cellulose structure [35], but the carbon content disappears due to alkaline hydraulics.

Figure 15. Burning cellulose fiber at high temperatures causes more significant degradation of cellulose. High temperatures can damage hydrogen bonds between cellulose chains [42]. Energy Dispersive X-ray (EDX) analysis results describe the elemental composition in a material sample. The dominance of silicon (Si) shown by the highest peak indicates the presence of significant silica content, which can come from aggregate or pozzolan in the cement mixture. Calcium (Ca) with several peaks reflects an important calcium component in Portland cement, although the proportion appears lower than that usually found in pure cement. The presence of sodium (Na), which is quite prominent, can indicate contamination or the use of additional materials that have the potential to affect cement performance. The presence of aluminum (Al) and iron (Fe) is by the composition of ordinary cement, but paying attention to the proportions is necessary. Detected carbon (C) can indicate the presence of organic material or carbonates. This composition raises some potential concerns. The high silica content compared to calcium can reduce compressive strength and slow the hydration process. Excessive sodium can trigger an alkali-silica reaction, causing long-term expansion and cracking. If the carbon comes from organic material, it can interfere with the hardening process and reduce durability. This imbalance can make cement performance less than optimal, susceptible to premature degradation, and lower resistance to attack by aggressive chemicals and environments.

Meanwhile, samples without synthesis are shown in Figure 16. The synthesis process is crucial in reducing the content of non-cellulosic components such as hemicellulose and lignin in cellulose fiber samples. Without this process, these components remain present in significant amounts [43]. Leading to a higher content of impurities, mainly inorganic elements. The graph displays the Energy Dispersive X-ray (EDX) analysis results of a cellulose fiber sample. The highest peak on the graph shows the very dominant presence of carbon (C), followed

by calcium (Ca), with two significant peaks. Silicon (Si) and iron (Fe) were also detected in relatively small amounts. This composition raises several concerns regarding cement quality and performance. The presence of high carbon content, indicating organic contamination or the presence of large amounts of additional carbon stains, can significantly disrupt the cement hydration process. This disruption can lead to reduced compressive strength, increased porosity, and ultimately, concrete with lower durability and increased susceptibility to cracking and premature degradation.

The relatively low silicon content compared to calcium and carbon can also reduce the formation of calcium

silicate hydrate, which is crucial for long-term strength. However, the absence of an aluminate component (not visible on the graph) is equally significant. Its presence is essential for setting time and sulfate resistance, highlighting the importance of a balanced composition.

This unbalanced composition has a direct impact on the characteristics of the concrete products. It can lead to reduced strength, increased permeability, and lower resistance to chemical attack and aggressive environments. As a result, the life of concrete structures may be shortened, necessitating increased long-term maintenance. Samples without synthesis have larger particle sizes and non-uniform distribution [44].

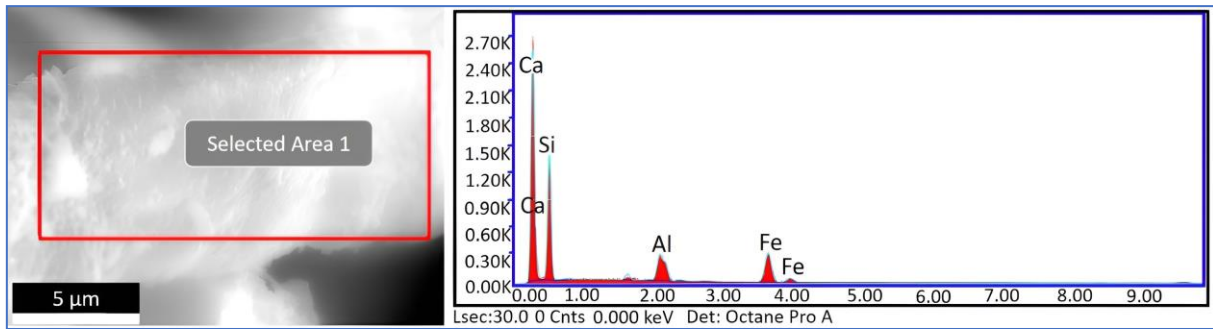


Figure 14. EDX low temperature synthesis

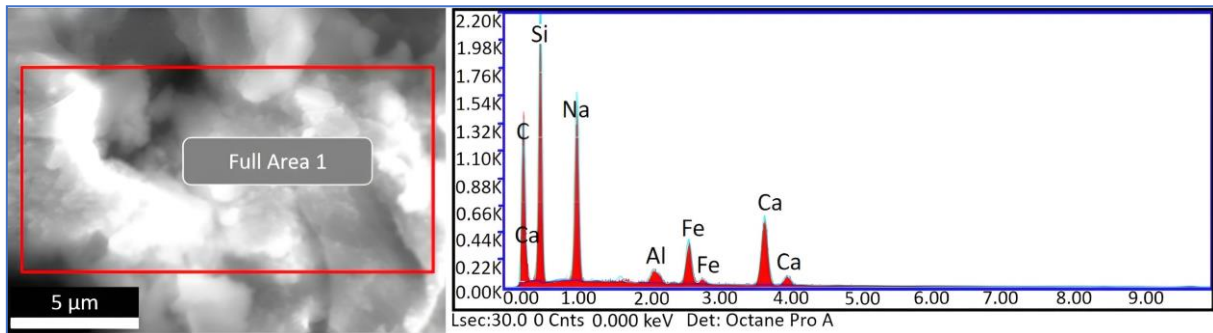


Figure 15. EDX high temperature synthesis

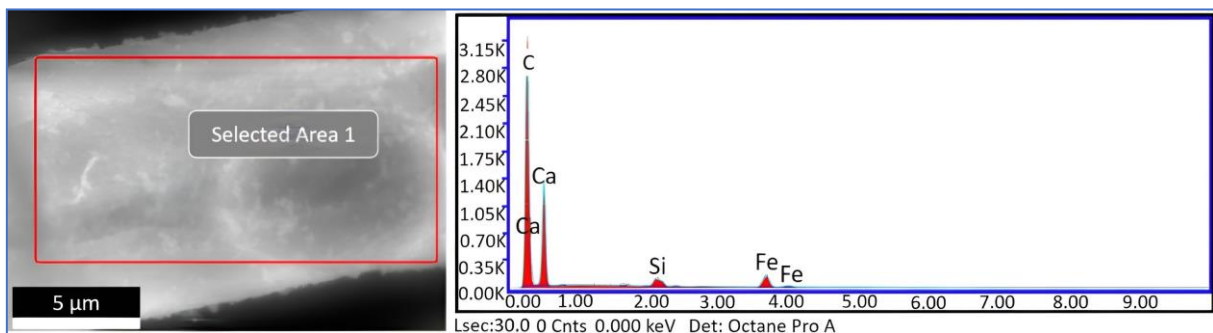


Figure 16. EDX without synthesis

4. Conclusions

This research focuses on developing nanocellulose materials from paper waste to be used as sustainable construction materials. Nanocellulose, with its unique mechanical and chemical properties, has attracted the attention of many researchers in recent years as an environmentally friendly alternative material. This research adopts a low-temperature alkaline method to obtain nanocellulose from waste paper, which can significantly reduce the environmental impact of conventional construction material production. The benefits of this research are very diverse, ranging from the economic and ecological to technical fields. From a financial point of view, using waste paper as raw material can reduce production costs because waste paper is relatively cheap and available in large quantities. In addition, with the increasing demand for environmentally friendly materials, nanocellulose products have significant market potential. From an environmental perspective, this research provides a solution to reduce the problem of paper waste, which is often a big problem in many countries. Paper waste that usually ends up in landfills can be processed into high-value products, reducing waste accumulation and greenhouse gas emissions associated with the organic waste decomposition process. Technically, this research offers innovation in construction material processing. Nanocellulose is known to have high tensile strength, good thermal stability, and the ability to form strong bonds with various other materials. These properties make nanocellulose very suitable for use in the construction industry, either as a composite reinforcement material, an additive in concrete, or as a base material for lightweight and durable building products. Using the alkaline method at low temperatures reduces energy consumption and minimizes damage to cellulose fibers, resulting in high-quality nitrocellulose.

PSA testing was carried out to determine the particle size distribution of the synthesized nanocellulose. This test is essential because the size of the nanocellulose particles affects its mechanical and chemical properties. With PSA, the nanocellulose particles from this synthesis are ensured to be in the expected nano-size range, namely around 200-500 nm. This small particle size provides the advantage of increasing the specific surface area of the material, which directly impacts the ability of nanocellulose to interact with other materials in a composite or construction mix.

FTIR testing is used to analyze the chemical composition of the resulting nanocellulose. Through FTIR, chemical bonds in the nanocellulose structure can be identified. One of the essential results of FTIR testing is confirmation of the presence of hydroxyl groups (OH), a sign of cellulose structure. These hydroxyl groups are significant because they contribute to the material's hydrophobic properties and bonding ability. In addition, FTIR testing also confirmed the loss of lignin and

hemicellulose. These two main components in natural cellulosic materials must be removed during synthesis to produce pure nanocellulose. FTIR results from this study show that the alkaline method used effectively separates these components, delivering high-quality nitrocellulose with few contaminants. XRD testing is used to examine the amorphous and crystalline structure of nanocellulose. Amorphous and crystalline structures are critical in determining materials' mechanical and thermal properties. In nanocellulose, the ratio between the amorphous and crystalline parts determines the tensile strength and stiffness of the material.

The XRD results from this study show the presence of solid diffraction peaks that correspond to the cellulose structure, the most common form of cellulose. This means that the resulting nanocellulose has a good amorphous structure, which is essential for applications in construction materials. In addition, the XRD results show that the alkaline method applied at low temperatures does not damage the cellulose fiber structure of the nitrocellulose. This critical achievement ensures that the material retains superior mechanical properties that are capable of providing good construction in binding cement in concrete. SEM testing was used to examine the surface morphology of the resulting nanocellulose.

SEM allows visualization of nanocellulose particles at the nanoscale, which helps evaluate particle shape and size uniformity. The SEM results from this research show that the resulting nanocellulose has a uniform morphology with a smooth surface. SEM images also show clear nano-fibril structures, indicating that this low-temperature alkaline method successfully decomposes coarse cellulose materials into fine nanofibers. This morphological quality is essential because a smooth and uniform surface improves the mechanical properties and adhesion of the material in composite applications.

EDX testing was carried out to analyze the elemental composition of nanocellulose. EDX allows the identification of elements present on the surface of the material. In this research, EDX shows that the nanocellulose produced mainly consists of CaO and Silica, based on the chemical composition after the cellulose treatment. The synthesis process using the alkaline method at low temperatures produces pure nanocellulose. These EDX results are significant because they show that the resulting nanocellulose is safe and effective for use in concrete mix applications without the risk of contamination by dangerous elements such as carbon values, which have a negative impact.

Overall, this research provides many benefits for the construction industry, especially in overcoming environmental problems and looking for more sustainable alternative materials. Nanocellulose from paper waste has great potential to become a future construction material with strong, light, and environmentally friendly characteristics. The synthesis method applied in this

research, namely the alkaline method at low temperatures, is an efficient innovation in terms of cost and energy. It is also environmentally friendly because it utilizes raw waste materials and reduces the use of dangerous chemicals. With further development and large-scale testing, nanocellulose could become a material solution that is not only sustainable but also provides added economic and social values. This research is a significant step forward in utilizing paper waste effectively and efficiently for industrial purposes while supporting global initiatives for sustainable development.

Acknowledgements

We are very grateful to all the lecturers in the Engineering Doctoral Study Program in Civil Engineering, Faculty of Engineering, Sriwijaya University and all those involved in this research for their direct and indirect support so that this research can be completed with good results. It can benefit science and the construction industry.

REFERENCES

- [1] K. P. (Copenhagen C. on E. E. and P. G. (Global B. P. N. Brian Dean and John Dulac (International Energy Agency), "2016 Global status report: Towards zero-emission efficient and resilient buildings," 2016.
- [2] R. J. Moon, A. Martini, J. Nairn, J. Simonsen, and J. Youngblood, "Cellulose nanomaterials review: Structure, properties and nanocomposites," *Chemical Society Reviews*, vol. 40, no. 7, 2011.
- [3] N. G. Olaiya, A. A. Oyekanmi, M. M. Hanafiah, T. O. Olugbade, M. K. Adeyeri, and F. G. Olaiya, "Enzyme-assisted extraction of nanocellulose from textile waste: A review on production technique and applications," *Bioresour. Technol. Reports*, vol. 19, no. April, p. 101183, 2022, doi: 10.1016/j.biteb.2022.101183.
- [4] L. G. Li, Z. H. Huang, J. Zhu, A. K. H. Kwan, and H. Y. Chen, "Synergistic effects of micro-silica and nano-silica on strength and microstructure of mortar," *Constr. Build. Mater.*, vol. 140, pp. 229–238, 2017, doi: 10.1016/j.conbuildmat.2017.02.115.
- [5] Y. Cao, P. Zaverri, J. Youngblood, R. Moon, and J. Weiss, "The influence of cellulose nanocrystal additions on the performance of cement paste," *Cem. Concr. Compos.*, vol. 56, pp. 73–83, 2015, doi: 10.1016/j.cemconcomp.2014.11.008.
- [6] X. Xu, F. Liu, L. Jiang, J. Y. Zhu, D. Haagenon, and D. P. Wiesenborn, "Cellulose nanocrystals vs. Cellulose nanofibrils: A comparative study on their microstructures and effects as polymer reinforcing agents," *ACS Appl. Mater. Interfaces*, vol. 5, no. 8, pp. 2999–3009, 2013, doi: 10.1021/am302624t.
- [7] N. Saba, M. Jawaid, O. Y. Alothman, and M. T. Paridah, "A review on dynamic mechanical properties of natural fibre reinforced polymer composites," *Constr. Build. Mater.*, vol. 106, pp. 149–159, 2016, doi: 10.1016/j.conbuildmat.2015.12.075.
- [8] P. Suanto, Saloma, A. P. Usman, A. Saggaff, M. Ismail, and N. H. A. Khalid, "The Characterization of Nanocellulose with Various Durations and NaOH Concentration," *Int. J. Innov. Res. Sci. Stud.*, vol. 5, no. 1, pp. 18–29, 2022, doi: 10.53894/ijirss.v5i1.343.
- [9] Y. Chen, B. Geng, J. Ru, C. Tong, H. Liu, and J. Chen, "Comparative characteristics of TEMPO-oxidized cellulose nanofibers and resulting nanopapers from bamboo, softwood, and hardwood pulps," *Cellulose*, vol. 24, no. 11, pp. 4831–4844, 2017, doi: 10.1007/s10570-017-1478-4.
- [10] C. Endes *et al.*, "A critical review of the current knowledge regarding the biological impact of nanocellulose," *J. Nanobiotechnology*, vol. 14, no. 1, pp. 1–14, 2016, doi: 10.1186/s12951-016-0230-9.
- [11] Q. Wang, Q. Yao, J. Liu, J. Sun, Q. Zhu, and H. Chen, "Processing nanocellulose to bulk materials: a review," *Cellulose*, vol. 26, pp. 7585–7617, 2019, doi: 10.1007/s10570-019-02642-3
- [12] X. Li, J. Yu, and M. Jaroniec, "Hierarchical photocatalysts," *Chem. Soc. Rev.*, vol. 45, no. 9, pp. 2603–2636, 2016, doi: 10.1039/c5cs00838g.
- [13] M. E. Ioannou *et al.*, "Synthesis and Characterization of Cerium Oxide Nanoparticles: Effect of Cerium Precursor to Gelatin Ratio," *Appl. Sci.*, vol. 13, no. 4, 2023, doi: 10.3390/app13042676.
- [14] J. Li *et al.*, "Homogeneous isolation of nanocellulose from sugarcane bagasse by high pressure homogenization," *Carbohydr. Polym.*, vol. 90, no. 4, pp. 1609–1613, 2012, doi: 10.1016/j.carbpol.2012.07.038.
- [15] F. Jiang, T. Kondo, and Y. Lo Hsieh, "Rice Straw Cellulose Nanofibrils via Aqueous Counter Collision and Differential Centrifugation and Their Self-Assembled Structures," *ACS Sustain. Chem. Eng.*, vol. 4, no. 3, pp. 1697–1706, 2016, doi: 10.1021/acssuschemeng.5b01653.
- [16] P. R. Sharma, S. K. Sharma, R. Antoine, and B. S. Hsiao, "Efficient Removal of Arsenic Using Zinc Oxide Nanocrystal-Decorated Regenerated Microfibrillated Cellulose Scaffolds," *ACS Sustain. Chem. Eng.*, vol. 7, no. 6, pp. 6140–6151, 2019, doi: 10.1021/acssuschemeng.8b06356.
- [17] L. Senff, D. Hotza, S. Lucas, V. M. Ferreira, and J. A. Labrincha, "Effect of nano-SiO₂ and nano-TiO₂ addition on the rheological behavior and the hardened properties of cement mortars," *Mater. Sci. Eng. A*, vol. 532, pp. 354–361, 2012, doi: 10.1016/j.msea.2011.10.102.
- [18] F. U. A. Shaikh and S. W. M. Supit, "Mechanical and durability properties of high volume fly ash (HVFA) concrete containing calcium carbonate (CaCO₃) nanoparticles," *Constr. Build. Mater.*, vol. 70, pp. 309–321, 2014, doi: 10.1016/j.conbuildmat.2014.07.099.
- [19] M. Ltifi, A. Guefrech, P. Mounanga, and A. Khelidj, "Experimental study of the effect of addition of nano-silica on the behaviour of cement mortars," *Procedia Eng.*, vol. 10, pp. 900–905, 2011, doi: 10.1016/j.proeng.2011.04.148.

- [20] A. Kumar, Y. Singh Negi, V. Choudhary, and N. Kant Bhardwaj, "Characterization of Cellulose Nanocrystals Produced by Acid-Hydrolysis from Sugarcane Bagasse as Agro-Waste," *J. Mater. Phys. Chem.*, vol. 2, no. 1, pp. 1–8, 2020, doi: 10.12691/jmpc-2-1-1.
- [21] K. Zhang, P. Sun, H. Liu, S. Shang, J. Song, and D. Wang, "Extraction and comparison of carboxylated cellulose nanocrystals from bleached sugarcane bagasse pulp using two different oxidation methods," *Carbohydr. Polym.*, vol. 138, pp. 237–243, 2016, doi: 10.1016/j.carbpol.2015.11.038.
- [22] Q. Q. Wang, J. Y. Zhu, R. Gleisner, T. A. Kuster, U. Baxa, and S. E. McNeil, "Morphological development of cellulose fibrils of a bleached eucalyptus pulp by mechanical fibrillation," *Cellulose*, vol. 19, no. 5, pp. 1631–1643, 2012, doi: 10.1007/s10570-012-9745-x.
- [23] W. Chen, H. Yu, Y. Liu, P. Chen, M. Zhang, and Y. Hai, "Individualization of cellulose nanofibers from wood using high-intensity ultrasonication combined with chemical pretreatments," *Carbohydr. Polym.*, vol. 83, no. 4, pp. 1804–1811, 2011, doi: 10.1016/j.carbpol.2010.10.040.
- [24] M. Jonoobi, A. Khazaeian, P. M. Tahir, S. S. Azry, and K. Oksman, "Characteristics of cellulose nanofibers isolated from rubberwood and empty fruit bunches of oil palm using chemo-mechanical process," *Cellulose*, vol. 18, no. 4, pp. 1085–1095, 2011, doi: 10.1007/s10570-011-9546-7.
- [25] N. A. Rosli, I. Ahmad, and I. Abdullah, "Isolation and characterization of cellulose nanocrystals from agave angustifolia fibre," *BioResources*, vol. 8, no. 2, pp. 1893–1908, 2013, doi: 10.15376/biores.8.2.1893-1908.
- [26] N. Johar, I. Ahmad, and A. Dufresne, "Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk," *Ind. Crops Prod.*, vol. 37, no. 1, pp. 93–99, 2012, doi: 10.1016/j.indcrop.2011.12.016.
- [27] E. Abraham *et al.*, "Extraction of nanocellulose fibrils from lignocellulosic fibres: A novel approach," *Carbohydr. Polym.*, vol. 86, no. 4, pp. 1468–1475, 2011, doi: 10.1016/j.carbpol.2011.06.034.
- [28] J. I. Morán, V. A. Alvarez, V. P. Cyras, and A. Vázquez, "Extraction of cellulose and preparation of nanocellulose from sisal fibers," *Cellulose*, vol. 15, no. 1, pp. 149–159, 2008, doi: 10.1007/s10570-007-9145-9.
- [29] S. Kalia *et al.*, "Cellulose-based bio- and nanocomposites: A review," *Int. J. Polym. Sci.*, vol. 2011, 2011, doi: 10.1155/2011/837875.
- [30] Y. Guan, W. Li, H. Gao, L. Zhang, L. Zhou, and F. Peng, "Preparation of cellulose nanocrystals from deinked waste newspaper and their usage for papermaking," *Carbohydr. Polym. Technol. Appl.*, vol. 2, p. 100107, 2021, doi: 10.1016/j.carpta.2021.100107.
- [31] D. Klemm *et al.*, "Nanocelluloses: A new family of nature-based materials," *Angew. Chemie - Int. Ed.*, vol. 50, no. 24, pp. 5438–5466, 2011, doi: 10.1002/anie.201001273.
- [32] A. D. French, "Idealized powder diffraction patterns for cellulose polymorphs," *Cellulose*, vol. 21, no. 2, pp. 885–896, 2014, doi: 10.1007/s10570-013-0030-4.
- [33] S. Park, J. O. Baker, M. E. Himmel, P. A. Parilla, and D. K. Johnson, "Park2010.Pdf," pp. 1–10, 2010.
- [34] S. Nam, A. D. French, B. D. Condon, and M. Concha, "Segal crystallinity index revisited by the simulation of X-ray diffraction patterns of cotton cellulose I β and cellulose II," *Carbohydr. Polym.*, vol. 135, pp. 1–9, 2016, doi: 10.1016/j.carbpol.2015.08.035.
- [35] H. P. S. Abdul Khalil *et al.*, "Production and modification of nanofibrillated cellulose using various mechanical processes: A review," *Carbohydr. Polym.*, vol. 99, pp. 649–665, 2014, doi: 10.1016/j.carbpol.2013.08.069.
- [36] Y. Li *et al.*, "Nanocellulose as green dispersant for two-dimensional energy materials," *Nano Energy*, vol. 13, pp. 346–354, 2015, doi: 10.1016/j.nanoen.2015.02.015.
- [37] A. Mandal and D. Chakrabarty, "Isolation of nanocellulose from waste sugarcane bagasse (SCB) and its characterization," *Carbohydr. Polym.*, vol. 86, no. 3, pp. 1291–1299, 2011, doi: 10.1016/j.carbpol.2011.06.030.
- [38] M. Jonoobi *et al.*, "Different preparation methods and properties of nanostructured cellulose from various natural resources and residues: a review," *Cellulose*, vol. 22, no. 2, pp. 935–969, 2015, doi: 10.1007/s10570-015-0551-0.
- [39] B. Wang, M. Sain, and K. Oksman, "Study of structural morphology of hemp fiber from the micro to the nanoscale," *Appl. Compos. Mater.*, vol. 14, no. 2, pp. 89–103, 2007, doi: 10.1007/s10443-006-9032-9.
- [40] Y. Zhang, H. Li, X. Li, M. E. Gibril, and M. Yu, "Chemical modification of cellulose by in situ reactive extrusion in ionic liquid," *Carbohydr. Polym.*, vol. 99, pp. 126–131, 2014, doi: 10.1016/j.carbpol.2013.07.084.
- [41] N. I. Abdo, Y. M. Tufik, and S. M. Abobakr, "A comparison of nano-celluloses prepared with various terms of time and sulfuric acid concentration from bagasse derived cellulose: Physicochemical characteristics and process optimization," *Curr. Res. Green Sustain. Chem.*, vol. 6, no. March, p. 100365, 2023, doi: 10.1016/j.crgsc.2023.100365.
- [42] W. Chen, H. Yu, S. Y. Lee, T. Wei, J. Li, and Z. Fan, "Nanocellulose: A promising nanomaterial for advanced electrochemical energy storage," *Chem. Soc. Rev.*, vol. 47, no. 8, pp. 2837–2872, 2018, doi: 10.1039/c7cs00790f.
- [43] M. M. Rahman, S. Afrin, and P. Haque, "Characterization of crystalline cellulose of jute reinforced poly (vinyl alcohol) (PVA) biocomposite film for potential biomedical applications," *Prog. Biomater.*, vol. 3, no. 1, 2014, doi: 10.1007/s40204-014-0023-x.
- [44] Y. Liu, H. Wang, G. Yu, Q. Yu, B. Li, and X. Mu, "A novel approach for the preparation of nanocrystalline cellulose by using phosphotungstic acid," *Carbohydr. Polym.*, vol. 110, pp. 415–422, 2014, doi: 10.1016/j.carbpol.2014.04.040.