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Cellulose-based Material for Sound Absorption And Its Application – A Short Review

Muchlisinalahuddin[1,3], *Hendery* Dahlan[1,3], *Melbi* Mahardika[2,3], *Meifal* Rusli[1,3*]

[1] *Mechanical Engineering Department, Faculty of Engineering, Universitas Andalas, Kampus Limau Manis, Padang 25163, Indonesia*
[2] *Research Center for Biomass and Bioproducts, National Research and Innovation Agency (BRIN), Cibinong, Indonesia.*
[3] *Research Collaboration Center for nanocellulose, BRIN-Universitas Andalas, Kampus Limau Manis, Padang, 25163 Indonesia.*

Abstract. Cellulose is a natural fiber potentially used as a sound absorber material due to its excellent properties, biodegradability, and lower environmental impact than synthetic materials and can be sourced from various plant-based materials, such as wood, Cotton, and Hemp. Which effectively traps and absorbs sound waves. The fibers dissipate the energy of sound waves as they pass through the material and absorb sound energy across a wide range of frequencies. Cellulose can be installed as loose-fill insulation, rigid panel form, composite with other matrix material, or foam. It's important to note that the specific characteristics and performance of cellulose-based sound absorbers can vary depending on the manufacturing process, fiber treatment, and the overall design of the sound-absorbing material. The size of cellulose fibers used in sound absorption can impact their effectiveness. Microfiber and nanofiber cellulose show different sound absorption characteristics. Microfiber has a good absorption coefficient at lower frequencies, and nanofiber cellulose performs better at higher frequency ranges. This paper involves a short-review study of experimental methods and parameters used to regulate cellulose's sound absorption performance, which seems to be a potential alternative as an acoustic absorber, thereby reducing sustainability concerns related to synthetic materials in acoustics applications.

1. Introduction

Noise is defined as sound pollution that disrupts human activities, necessitating the use of specific methods to address the issue [1-2]. One example of this noise is noise that occurs in urban areas [3] and noise resulting from construction work [4-7]. The consequences of this noise cause Outer Hair Cells (OHCs) damage[8]. Because of the enormity of this impact on humanity, WHO (World Health Organization) acted by developing noise-related rules and standards to provide recommendations for protecting human health from exposure to environmental noise originating from various sources[9]. As a result of these issues, several studies and research to combat noise have been conducted, including the use of natural and synthetic materials MPP [10]. Natural materials are mostly focused on fibrous materials due to their excellent sound insulation [11].

Until now, methods for developing natural fibrous materials as sound absorbers have been widely used, including natural materials (bamboo fiber, kenaf, sisal, coconut fiber, giant reeds, kenaf, hemp, kapok, sugar cane leaves, pineapple leaves, coconut belts, and rice husks, coconut fiber, palm fruit bunches, and pineapple leaves) [12-17]. Also, fibrogranular composite materials from fibers (coconut fiber and rice husk granules, coconut fiber, palm fiber from empty fruit bunches, and cylindrical pineapple leaf fibers have also been researched at low frequencies for sound absorption) [18-21]. In addition, research on synthetic fibers as sound insulation is being conducted since this material is resilient, flexible, and has a microscopic geometry [22-25]. Research on nanocellulose materials has not been widely developed to date as a sound-absorbing material, making this cellulose material a material with high potential for various industrial applications at this time [26].

This paper aims to look at the characteristics of cellulose as a natural material used as a sound-absorbing material and see its function as a filler. Researchers who have done this with various types of cellulose will also be shown here, as will the sound absorption coefficient values achieved throughout the testing process, based on several research results.

* Corresponding author: meifal@eng.unand.ac.id

2. Cellulose

Cellulose is the main component that makes up plant cell walls from higher trees to primitive organisms like algae, flagellates, and bacteria [27] and the shape of the plant cell wall structure can be seen in Figure 1. Cellulose can be extracted from a variety of sources including woody plants, microorganisms, agricultural cultivation waste, and some animals [28-30]. There are four types of cellulose sources, notably wood and non-wood cellulose, as well as cellulose derived from marine fauna and bacterial activities [31]. There are 2 forms of cellulose, namely cellulose nanocrystals (CNC) [32], cellulose nanofibrils (CNFs)[33], and their derivatives, such as Cellulose Acetate (CA), cellulose triacetate (CTA), and ethyl cellulose (EC) [34-35]. Below are several factors that have caused cellulose-based research to become a topic of interest in the last decade, including:

1. Cellulose is a biopolymer with the largest quantity available in nature. Estimated production amounts reach 10^9– 1,5 x 10^{12} tonnes/year [36][31].
2. Cellulose is a renewable material.
3. Nanocellulose has a density of 1,58g.cm^{-3}[37], a high stiffness value of 143 GPa[38], and a tensile strength of 7,5 GPa [39].
4. Nano-sized cellulose has a large surface area (250m^2.g^{-1}) and an aspect ratio or ratio of length to diameter (L/d) reaching >100. This characteristic is very useful for applications in the field of nanocomposites that require increased strength, toughness, and improved barrier properties [40-41].
5. At the nanostructure level, it is hydrophilic and has reactive hydroxyl functional groups, especially at C_6-OH which can be modified for further applications [42]
6. Cellulose is biocompatible with cells in the human body. This shows that cellulose has good biological properties and compatibility [43]
7. Cellulose, as a material sourced from nature, can be degraded biologically, although in very little crystalline phase.
8. Cellulose is non-toxic. Studies on feeding cellulose isolated through the oxidation process of 2,2,6,6-tetramethylpiperidine-1-oxyl radical (TEMPO) orally to mice[42][44] showed a low toxicity impact of cellulose.
9. Nanocellulose has grown in popularity in the last decade, both socially and economically [45]

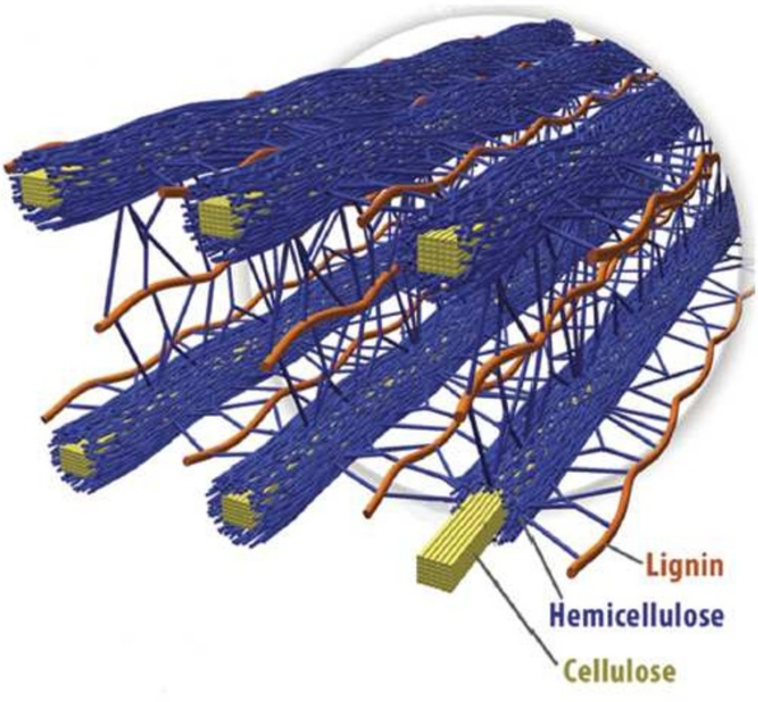

Fig 1. Spatial arrangement of cellulose hemicellulose and lignin in the cell walls of lignocellulosic biomass [46]

3 Classification of cellulose

Cellulose is an organic compound and is a polysaccharide that contains fibers. The process usually carried out for the separation of cellulose from hemicellulose and lignin is the isolation of α-cellulose which consists of a delignification and bleaching process. According to size, morphology, preparation technique, and source, nanocellulose can be classified into three main categories: (1) Cellulose nanocrystals (CNCs), also known as nanocrystalline cellulose (NCC) or cellulose nanowhisk ers (CNWs), are rigid rod-like particles measuring 10–30 nm in diameter and less than 500 nm in length[[47-49]. CNC generally obtained by hydrolysis of raw cellulose material with strong inorganic acids or enzymes[50].

In the hydrolysis process, the amorphous areas of cellulose are degraded into sugars, the crystalline areas are retained, and finally, whisker-like or spherical CNCs are obtained [51-52]. Compared with cellulose raw materials, CNC has α a higher degree of crystallinity ranging from 54 to 88% [53]. Cellulose nanofibrils (CNFs), also referred to as nanofibrillated cellulose (NFC) or microfibrillated cellulose (MFC), consist of individual nanofibrils and aggregates [54-55] and cultivation conditions, typical BC fibrils have a diameter of 20–100 nm and a length.

4 Methods for making cellulose and testing

4.1 Initial preparation

The initial process started with the formation of nanocellulose as a sound-absorbing material, namely raw material. In this raw material, cutting or chopping was carried out to reduce the size of the fibers. The shredded material was 112-224 m in size and was cleaned with Auades. This cleaning is intended to eradicate any bacteria found in the material. The cleansed material is then boiled for two hours. The idea is to soften the material so that the next step will be easier. The boiling was done at 900°C. This procedure was carried out in three stages: alkalization, bleaching, and acid hydrolysis. The goal of alkalization is to eliminate lignin and contaminants from the fiber surface. In this process, the material was soaked in 2% NaOH by weight at 700°C for 3 hours.

The soaking process in the backer was carried out using a magnetic stirrer. The aim of using this tool is so that the mixture is evenly distributed over all sides of the material. The next stage, or second stage, is bleaching. The bleaching process was performed using hydrogen peroxide (H_2O_2). Proses ini bertujuan untuk menghilangkan lignin sisa alkali dan hemiselulosa. The effect of this hydrogen peroxide material is as an oxidizing agent in the bleaching process, which will cause the fiber to change color. Perhydroxyl ions (-OOH) result from the decomposition of hydrogen peroxide into alkaline solutions. –OOH ions attack lignin and cellulose groups [56]. Bleaching was carried out by soaking in NaOH 4% by weight and H_2O_2 7.2% by weight at 550°C for 2 hours using a magnetic stirrer. The final stage is acid hydrolysis, which attempts to break hydrogen bonds to lower the size from micro to nano. Acid hydrolysis was performed using 64% H_2SO_4 at 600°C for 45 minutes using the water bath method, as shown in Figure 2. for bleaching empty fruit bunches.

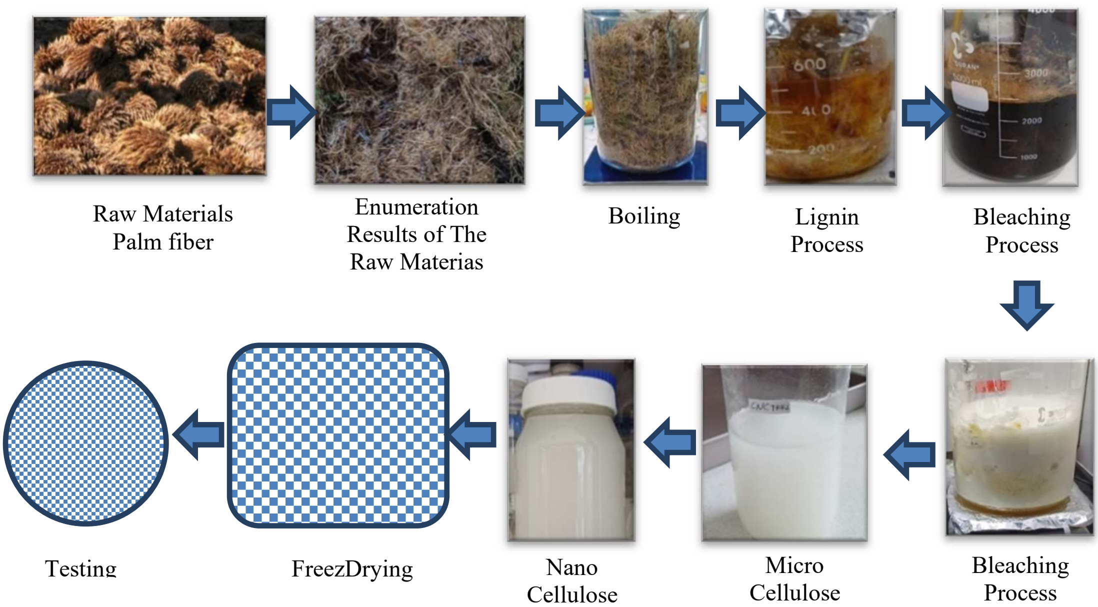

Fig 2. Lignification and Bleaching Process

4.2 Sound absorber testing

In general, numerous methods are utilized for sound absorber testing, including FTIR, which is used to detect the chemical bonding of the fibers at each stage of chemical treatment. The second type of foam material is ultra-lightweight cellulose-based foam material (ULW-CFM). The sound absorption method of ULW-CFM is primarily based on three factors: (1) When the sound wave hits the material's surface, one part is reflected, while the other part enters the material's interior, causing the air particles to vibrate. The fibers brush against the vibrating air, creating viscous resistance and transforming sound energy into heat energy. ; (2) When sound waves pass through a medium, the density of air particles will be different, resulting in a temperature gradient between particles, which will consume part of the sound energy through heat conduction; (3) Vibration of the fiber itself will also convert heat energy into mechanical energy.

The shape and condition of the cellulose surface can then be determined using tools like SEM and transmission electron microscopy (TEM). Thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC) are commonly used to investigate the thermal characteristics and degradation of cellulose samples. The sound absorption coefficient in the standard direction can also be calculated using an impedance tube. The standard sound absorption coefficient applies to sound waves incident perpendicular to the material's surface. The sound absorption coefficient is determined by measuring the sound pressure that strikes the material's surface and is reflected.

4.3 Mechanical properties

In research on cellulose aerogel as an aerogel material, carboxymethyl cellulose CMC/DFF(down feather fibers) composite aerogel with low density (0.0389–0.0428 g/cm^3) and high porosity (around 97%). Fluff fiber is used as a reinforcing material to prepare cellulose composite airgel to improve mechanical and insulating properties as in Table 1 and Figure.3. By using these fibers, a sound absorption coefficient of 0.991 is produced [57].

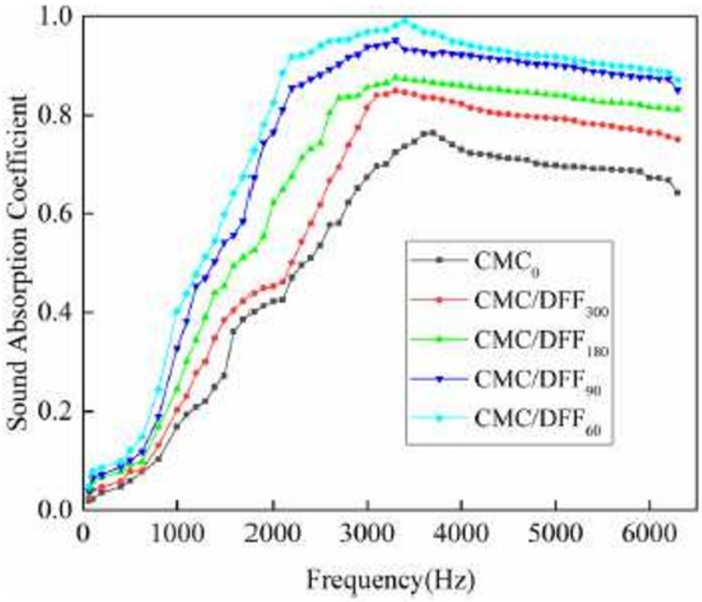

Fig 3. Sound absorption properties of CMC composite aerogels [57]

Next, there is research using cellulose nanocrystal (CNC) aerogel material as a multifunctional acoustic cellulose material using calcium chloride as a CNC crosslinker for drying (freeze-drying). From these results, it is known that the acoustic absorption results are very good, with a high maximum absorption coefficient of 0.99 (at a frequency of 2960 Hz [58]. There was additional research on the sol-gel production of flexible silica-cellulose hybrid aerogels (SCHA) utilizing recycled cellulose fiber (RCF). With an average thickness of 8 mm, the sound absorption coefficient value obtained is relatively high, namely 0.453-0.628 at low frequencies (1500 Hz) and 0.86-0.94 at high frequencies (3600 Hz) [60]. Furthermore, cellulose hydrogels were studied in the field of sound absorption, specifically by dissolving cotton staple as the main material, and cellulose hydrogels were treated by directional freezing to solve the problems of irregular distribution and coexistence of open and closed pore structures in traditional cellulose aerogels (CAs).

From this research, the sound absorption coefficient of directional cellulose aerogel reached 0.88 at 4500 Hz and has low density (0.0554 gr/cm-3), high porosity (89.32%), and good thermal stability and mechanical properties. good, with a compressive stress of 0.35 MPa at a strain of 70%. As a result, CA treated with directed freezing has an exciting prospect in this application[59]. Furthermore, hierarchical pore architectures of cellulose nanofiber (CNF) and melamine foam (MF) were developed in an environmentally friendly manner for the first time. When compared to unmodified MF, composite foam with a thickness of 20 mm and a CNF concentration of 0.4 wt%

increased its sound absorption capability by approximately 107% at 500 Hz, while the NRC (noise reduction coefficient) increased by 80% [60]

In addition, research into sustainable bioaerogel synthesis utilizing renewable biomass yields outstanding sound absorption results at frequencies ranging from 200 to 6000 Hz, with a maximum sound absorption value of 0.97 [61]. The sound absorption coefficient value of silica-cellulose airgel with a thickness of 10 mm is 0.39-0.50 and is better than cellulose aerogel (0.30-0.40) and commercial polystyrene foam. When the cellulose fiber concentration changes from 1.0 to 4.0% by weight, Young's modulus of cellulose silica aerogel can be increased by 160%, up to 139 KPa [64]. Furthermore, research combining cellulose and silica has also been carried out. The results obtained an optimum SAC value of 0.9896.

Thus, the results of this research show that the resulting model can accurately predict the actual SAC value for utilizing Si-cellulose as an acoustic insulation material. [62]. Then, when airgel is made from rice straw and Polyvinyl alcohol (PVA), with the addition of glass fiber and glutaraldehyde (glutaraldehyde), it produces high porosity (up to 93.72%), super low thermal conductivity (0.032-0.048 W/mK), high Young's modulus (0.201-1.207 MPa), and high sound absorption (with a sound absorption coefficient of 0.87) [63]. A sound absorption coefficient of 0.95 was discovered in research on airgel made from bacterial cellulose. This demonstrates good sound absorption characteristics in the frequency range of 200-5000Hz [64]. The sound absorption coefficient of Ultra-lightweight cellulose-based foam material (ULW-CFM) with silica was also investigated. From the results of this research, it was found that the absorption value reached 0.65 above 5000 Hz [65]. Table 1 shows the progression of the use of cellulose material as a sound-absorbent material to date.

Table 1. Cellulose material absorption value

Years	Cellulose	Materials	Absorption Value	Authors
2017		CMC_0 CMC/DFF_{300} CMC/DFF_{180} CMC/DFF_{90} CMC/DFF_{60}	0.764 ± 0.02 0.849 ± 0.01 0.875 ± 0.02 0.951 ± 0.01 0.991 ± 0.02	Weihao Sun1[57]
2021		The cellulose hydrogels were obtained by dissolving cotton staple as the main material	0.885 at 4500 HZ	Ching-Wen Lou, at all [59]
2021		Cellulose nanofiber (CNF) and melamine foam (MF) were combined, MF/CNF-FT0.1%, F/CNFFT 0.2%, and MF/CNF-FT0.3%	0.9 in the range of 3500-6400 Hz at 250, 500, 1000, and 2000 Hz.The NRC values of MF/CNF-0.1% and MF/CNF-FT0.4% are 0.42, 0.45,	Lu Shen et all.[60]
2021		Cigarette filters	0,65	Rubén Maderuelo-Sanz1[66]

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2021		Bacterial Cellulose Bioaerogel	0,97	Zheng Cheng et all
2022		silica-cellulose hybrid aerogels (SCHA) using recycled cellulose fibers (RCF).	086 - 098	Debabrata Panda, et all[67]
2022		Aerogels from rice straw and polyvinyl alcohol	0,87	Ngan NT Thai et all [63]
2022		Silica-cellulose aerogel composite for acoustic insulation	0,99	S. Silviana[63]
2023	 CNC Aerogel	Cellulose nanocrystal (CNC) aerogels by employing calcium chloride as the green crosslinker of CNC,	0,85	Ju-Qi Ruan, et All[58]

5 Future challenges and prospectus

Cellulose, the major component of lignocellulosic materials, plays an essential part in plant life. The process of turning cellulose into derivative products by modifying its properties allows the production of new materials that are more effective, particularly as sound absorbent materials. The technique of recycling chemicals used in cellulose insulation is projected to boost efficiency and reduce pollution to the environment. A thorough examination of cellulose properties is a key stage in cellulose usage. This will improve the efficiency of the processes employed to attain the objectives.

As a result, the necessity for more systematic work on the characterization of these materials, both experimentally and theoretically, necessitates the development of new standards and strong techniques to assess their sustainability. This breakthrough will make cellulose sound absorbers more prevalent and contribute to more ecologically friendly industrial initiatives. environment

6 Conclusion

This paper presents a recent review of the acoustic properties of sustainable materials. It is obvious that there is growing interest in the acoustic performance of ecologically friendly items derived from the natural material Cellulose as a viable alternative to typical synthetic materials. This material has a lesser environmental impact than traditional materials in general. In the industrial sector, the use of cellulose as a sound-absorbing material with biodegradable material qualities derived from renewable resources is an essential concern. In this review, we explained cellulose and its derivatives, as well as their use as good sound-absorbing materials. Cellulose is a natural, biodegradable polymer.

That is one of the most commonly utilized. Furthermore, the characteristics and sources of cellulose, as well as its mixing with several other polymers, preparation processes, and functional properties, are briefly discussed. Among these is silica-cellulose aerogel, a low-cost polymer made from regenerated cellulose fiber and methoxytrimethylsilane (MTMS). The investigated silica-cellulose aerogels with different concentrations of cellulose fibers showed excellent thermal and acoustic insulation properties. Silica-cellulose aerogels are more flexible than silica aerogels and show better mechanical properties compared to cellulose aerogels. The manufacturing method can be improved for industrial applications.

Furthermore, its interaction with diverse natural polymers and function as a carrier warrant further exploration. With many acoustic materials being recyclable, research on the use of environmentally friendly materials derived from residues, factories, or industrial processes has received a lot of attention, so the use of natural materials will increase development and economic value in the future.

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