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Acoustic and thermal study of coconut fiber agglomerated with cassava starch

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Abstract: In this work, a thermal and acoustic study of specimens made from coconut fibers agglomerated with cassava starch was conducted. Measurement for acoustic characterization were performed in third-octave frequencies bands, between 100 and 5000 Hz (maximum frequency of absorption coefficient). Sound absorption coefficient (α) was measured in a transmission tube according to ISO 10534-2: 2001. Agglomerated coconut fiber with cassava starch material exhibits an acceptable sound absorption coefficient (greater than 0,65) across a wide frequency range (between 1000 and 5000 Hz). In addition, procedures described in ASTM E2611–19 were implemented to determine the sound transmission loss (STL), expressed in decibels (dB). Acceptable STL values for a natural fiber insulator were obtained. Improvements in STL were observed when increasing the thickness from 1,2 to 1,4 cm, at higher frequencies (17,3 dB at 5000 Hz). The results demonstrate the capacity of the tested specimen as a sound absorber, with absorption coefficient greater than 70% for a considerable range of frequencies, starting at 1000 Hz and above. Similarly, the thermal study based on ASTM C-177 indicates an average thermal conductivity coefficient of 0,174 W/m·K, in a range of inlet temperatures between 52°C and 137°C, confirming that it has good insulation properties, although still not comparable to some industrial materials.

Keywords: Biomaterial, coconut fiber, waste resources, acoustic conditioning, sound insulation, thermal insulation.

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1. Introduction

In Panama and Mexico, it is known that there is a humid tropical climate, which entails the extended use of air conditioning for climatization. Cooling represents almost 2,9% and 6,7% of the total world energy consumption and the global cooling consumption of the residential sector is expected to increase to 34% in 2050 and 61% in 2100 (Santamouris, 2016).

Materials used in the building sector are mostly manufactured from petrochemical sources (Carlos Javier et al., 2023), responsible for more than 33% of energy-related greenhouse gas emissions worldwide (Hurtado et al., 2016; Kumar et al., 2020). The development of new materials of natural origin contributes to increasing energy efficiency and energy savings (Topcu et al., 2020) due to the lower energy involved in their production and transportation. Also, the efficiency in thermal systems requires the use of thermal insulating materials (Ortiz Caicedo et al., 2023). The development of novel materials derived from waste products has garnered significant attention in recent decades, serving as an alternative in the field of environmentally friendly building. This approach not only contributes to reducing carbon footprints but also promotes environmental and economic sustainability. Furthermore, the utilization of locally available materials enhances local capacities, fostering both environmental and economic sustainability.

Acoustic comfort is another element to consider in the sustainable building sector. The absence of favorable acoustic conditions in indoor design can lead to various problems for users, ranging from acoustic discomfort to hearing loss risks. When spaces lack proper soundproofing, unwanted noise from external sources—such as traffic, construction, or loud neighbors—can intrude upon quiet environments. This constant exposure to high noise levels can result in several problems, including difficulty concentrating, increased stress levels, and fatigue. Installation of sound absorbing and insulating materials presents an alternative to address these problems (Arenas & Sakagami, 2020). Absorbing materials can absorb sound energy, reducing both reverberation and noise levels in enclosed spaces. On the other hand, sound insulation materials help protect indoor locations from noise by preventing the transmission of sound waves (Martínez Ibarra, 2017; Navacerrada et al., 2021).

As a contribution to the evaluation of new materials derived from waste products, this study describes the methodology employed to obtain acoustic and thermal properties of a particular material of this kind: a combination of coconut fiber and natural binders, which are common and readily available waste along the coasts of Panama and Mexico. This material is proposed as an alternative to use in environmentally friendly buildings.

Coconut is a tropical fruit obtained from the coconut tree (Cocus Nucifera); one of the most cultivated palm trees in the world. The food industry benefits from this species, focusing on the use of coconut meat or pulp, while discarding the rest of the plant. In Panama, according to data from the census of 2022, there was a harvest of more than 12 million coconut units, highlighting the provinces of Chiriquí and Colón, and the Kuna Yala region as the largest growers (INEC, 2023). In Mexico, total coconut production reached 1.12 million metric tons in 2021, positioning this country as the ninth producer globally, with Indonesia holding the top spot at 17.16 million metric tons (FAOSTAT, 2023). This fruit consists of four parts: the exocarp, a thick and fibrous brown outer shell; the mesocarp, also known as tow, where the fiber is extracted; the endocarp, a thinner layer containing the pulp or endosperm; and each part serves specific purposes in industry (Lizano, 2005).

Studies on thermal and acoustic materials derived from natural fibers have demonstrated that these materials possess valuable properties such as low thermal conductivity (Abdullah et al., 2021), and sound-absorbing characteristics (Bousshine et al., 2022). This is attributed to their cellulose structure, which allows them to store air inside and to dampen air currents. Motivated by these considerations, the present research focused on the study of the mesocarp (fiber) section of the coconut mixed with cassava starch. This natural binder functions as an adhesive, enhancing the fiber's rigidity based on relative proportions. Furthermore, the effect of the binder's quantity on the thermal/acoustic performance of the material was evaluated, allowing verification of the optimal proportions to fulfill the acoustic and thermal insulation functions.

2. Materials and methods

The test samples were manufactured using an artisanal process. This process consists of four main steps: selection, cutting, cleaning, and grinding. In contrast, the preparation of cassava involves selection, cutting, blending, filtering, and heating. Mature coconuts with brown or grayish bark were chosen, which are the primary waste product of the various food businesses in Panama, where the pulp is sold.

The manufacturing process of coconut fiber panels agglomerated with cassava starch began with selecting mature coconuts with brown husk. Once chosen, they were cut, placed in aluminum trays, and left to dry under the sun for two days in a low-cost, prefabricated greenhouse. When the coconut fibers were dry, they were cut using scissors and stored in a place with low humidity.

The cassava starch was cut into small pieces to obtain the liquid produced by this root for preparing the binder. After obtaining small portions, this material was slowly liquefied and filtered to store the starch. It was then heated over low heat for 15 minutes, stirring constantly until it became viscous, and left to cool for 15 minutes. After this, the fiber and binder are mixed and dried again.

It is used 221,74 grams of coconut fiber and 521,74 grams of cassava starch in liquid form, aiming to maintain a ratio of 29,82% coconut fiber and 70,18% cassava starch in liquid form, as previously analyzed in the undergraduate work performed by Quintero and Nieto (2023) and in a separate publication (Quintero et al., 2023).

The concentrations for the test samples in the "porous area" were 29,82% coconut fiber and 70,18% binder, considering the grams weighed by the binder in liquid state and the coconut fiber in natural state. These percentages were minimum levels that were previously established to ensure an adequate mixture between fiber and binder, to avoid fiber loosening from the sample. (Quintero & Nieto, 2023). Once they were mixed and the sample has been dried, the final weight of the sample is less than the sum of the mixture of both parts. For this reason, we call the weight of the liquid binder. In the case of the samples with the "agglomerated area", the concentration in this section was 25,00% fiber and 75,00% binder in liquid state. These percentages were obtained by weighing each material in a calibrated weight before mixing.

Three panels of 30 cm x 30 cm were manufactured as follows: coconut fibers were placed in wooden molds. The starch-based binder from cassava was poured over coconut fibers and by gravity, it fills the existing spaces between the fibers. The mixture is compacted and then left to dry in the sun. Due to this manufacturing method, there is one side with a high concentration and another with a low concentration of cassava starch-binder. The final weight of the panels was 300 g, and the calculated density was 222,22 kg/m3. The manufacturing processes to obtain coconut fiber and cassava starch are illustrated in Figure 1.

Figure 1. Manufacturing processes to obtain coconut fibers and cassava starch.

The samples for the acoustic study were obtained from previously manufactured panels. The acoustic samples were discs with a diameter of 3,5 cm. The obtained samples thickness are 1,0 cm, 1,3 cm, 2,0 cm, and 2,6 cm.

A cutting-extraction process was performed to obtain the discs, using a cylinder with this diameter and turning machine. The samples were categorized into two types, the first with an agglomerated surface (high concentration of cassava starch-binder) and the second with a minimal amount of binder applied (low concentration of cassava starch-binder).

The samples categorized with a high concentration refer to the face where the cassava starch-binder was applied. The samples classified with low concentration imply the analysis of the sample in the more porous face. This classification aims to evaluate the acoustic impact of the binder on the material absorption capacity. Figures 2A and 2B illustrate the material used for the acoustic study, while Figure 2C depicts one of the three samples employed for thermal study.

Figure 2. Samples for the acoustic study (coconut fiber-cassava starch-binder): (A) with a high concentration, and (B) with a low concentration. (C) Panel sample for thermal study.

The thermal-acoustic characterization of the material was conducted using standardized tests according to 10534-2:2001, 2001, ASTM E2611–19, 2019 and ASTM C-177.

The acoustic absorption coefficient was measured across various frequency bands according to ISO 10534-2:2001 (2001). Materials are generally considered sound absorbing if they have an NRC (noise reduction coefficient) value greater than 0,70. Additionally, sound transmission loss (STL) represents the reduction of sound energy that passes through structural building elements, such as walls, floors, ceilings, etc. (Kesharwani et al., 2020). It is related to the specific frequency at which it is measured and is expressed as sound reduction in decibels (dB). STL was measured using the procedure outlined in ASTM E2611–19 (2019). The experimental device employed is a transmission tube designed to measure both variables simultaneously. This measurement facility is available at the Acoustics and Vibrations Laboratory of the Institute of Applied Sciences and Technology at the National Autonomous University of Mexico. The device was designed and manufactured as part of Felipe Arturo Machuca-Tzili's doctoral thesis in 2017 (Machuca, 2017).

Finally, assuming a specific temperature range, the thermal conductivity of the material was experimentally determined according to ASTM C-177-19 (2019). These thermal characterization tests were conducted in an acrylic box ("hot box") designed to promote unidirectional heat flow.

2.1. Evaluation of the sound absorption coefficient

In these experiments, the acoustic absorption coefficient was measured in third-octave bands, evaluating samples of the material with thicknesses of 1,0 cm, 1,3 cm, 1,5 cm, 2,0 cm, and 2,6 cm.

All samples with low binder concentrations (1,0 cm, 1,3 cm, 2,0 cm, and 2,6 cm) were tested only with their more porous side facing the incident sound. For samples with a high concentration of binder (1,5 cm), tests were conducted on both sides of the specimen, allowing for the comparison of sound absorption results on both faces. In the following discussion, the area with a higher concentration of cassava starch is referred to as the "agglomerated area," while the opposite side is termed the "porous area," referring to the region with a lower concentration of cassava starch, as illustrated in Figure 3.

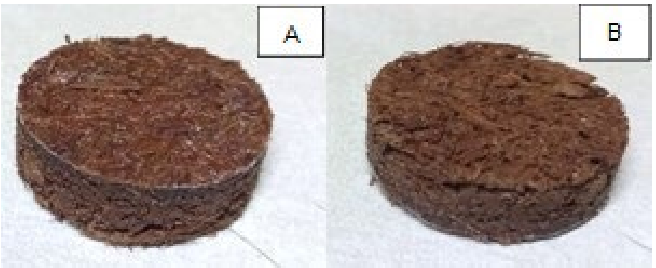

Figure 3. Study areas in samples with a high concentration of cassava starch-binder. (A) High concentration- agglomerated area, and (B) Low concentration- porous face.

Measurement of the sound absorption coefficient was conducted according to ISO 10534-2:2001 (2001) and was integrated into third-octave frequency bands spanning 100 to 5000 Hz. The equipment used in the test is presented in Table 1.

Table 1. Equipment used for sound absorption measurements, designed, and manufactured by Machuca (2017).

Instrument	Characteristics
Transmission tube adapted as an impedance tube	Made of stainless steel, total length 42 cm, inner diameter 3,5 cm
Polarization source for 4 microphones	Brand Bruel & Kjaer type 2829
Audio interface	M-Audio, M-Track Eight
Stereo power amplifier	Yamaha, Ax-380
Desktop personal computer	CPU Intel i7-4770, 3,40 GHz, 12,0 GB RAM, Windows 10 64-bit.
Weather station	Extech Instruments, WTH600
GNU Octave	Free software for data processing, version 7.3.0

The nomenclature implemented to abbreviate the characteristics of the absorption tests is presented in Table 2.

Table 2. Nomenclature implemented to define the absorption tests.

Samples	Description	Panel	Side facing the incident sound
AACF-1,0cm	Average absorption coconut fiber -1,0 cm thickness	1	Porous
AACF-1,3cm	Average absorption coconut fiber - 1,3 cm thickness	1	Porous
PA_AA-1,5cm	Average absorption coconut fiber - 1,5 cm thickness	2	Porous
AA_AA-1,5cm	Average absorption coconut fiber - 1,5 cm thickness	2	Agglomerated
AACF-2,0cm	Average absorption coconut fiber - 2,0 cm thickness	1	Porous
AACF-2,6cm	Average absorption coconut fiber - 2,6 cm thickness	1	Porous
AA_A-2,6cm	Average absorption standard material A -2,6 cm thickness	-	Porous
AA_B-2,6cm	Average absorption standard material B -2,6 cm thickness	-	Porous
AA_C-2,6cm	Average absorption standard material C -2,6 cm thickness	-	Porous

2.2. Evaluation of the sound transmission loss (acoustic insulation capacity)

Measurements of sound transmission loss (STL) were conducted in accordance with ASTM 2611-19 (2019), using the same equipment previously described. The experimental setup included a fully configured transmission tube with an attached second tube section to receive transmitted sound. Three circular samples were used, with diameters of 3,5 cm and thicknesses of 1,1, 1,2, and 1,4 cm, respectively. These samples were selected from surfaces with higher binder concentrations.

2.3. Evaluation of thermal conductivity

Thermal conductivity (k) represents the ability of materials to conduct heat. High values of this property indicate that the material is a good conductor of heat (referred to as thermal conductors). (Palomo, 2017) Materials with high resistance to heat transfer are classified as thermally insulating; thus, they can protect enclosures from adverse temperature effects. Additionally, we can infer that insulators contribute to energy efficiency, as they help reduce the energy consumption of cooling and heating systems without compromising comfort (Schwarz et al., 2024).

To determine the thermal conductivity, Fourier's law was assumed, which is represented by the following expression:

$$\dot{Q}_{cond} = kA\frac{\Delta T}{\Delta x} \tag{1}$$

Here, $\dot{Q}_{cond}$, k, A, ΔT and Δx are the heat transferred through a surface, the thermal conductivity of the material, the area of the surface, the temperature difference between two points located perpendicular to the surface, and the separation between these points, respectively. This expression represents the simplest heat diffusion process, unidirectional heat conduction through a homogeneous material and in a steady state.

The thermal study of the material involves determining its thermal conductivity using a method grounded in fundamental principles. The experimental setup consists of:

- Unidirectional heat flow through the test sample (refer to Figures 4 and 5).
- A thermal source that enables measurement of heat input (electric heating plate).
- Temperature sensors positioned at specific points within the experiment.
- The surface area under investigation (sample dimensions).
- The spacing between temperature evaluation points.

To meet the assumed experimental conditions, four thermocouples connected to a data acquisition system are employed. Two thermocouples are placed on top of the sample, while the remaining two are positioned below it. After averaging the results, the inlet and outlet temperatures can be defined. This arrangement allows for the determination of two primary parameters for evaluation. Additional experimental data related to heat flow is obtained directly from the electrical source (DC), providing insight into energy usage throughout the experiment. It is important to mention that the data required by the calculation is when the system reaches a steady state.

For the experimental setup, type J thermocouples were employed, alongside a type K thermocouple, a digital thermometer, and an analog mercury thermometer were used to calibrate all sensors of the experiments. This calibration procedure ensured optimal functioning of the thermal sensors (type J). To complete the experimental setup, the design and manufacture of an acrylic box were required (Figure 4). The tests were conducted using samples measuring 9,0 cm x 9,0 cm x 1,5 cm, placed centrally, and surrounded by a thermal insulation material (fiberglass). The nomenclature used to define variables in the tests is presented in Table 3, while the instruments employed to determine thermal conductivity are detailed in Table 4.

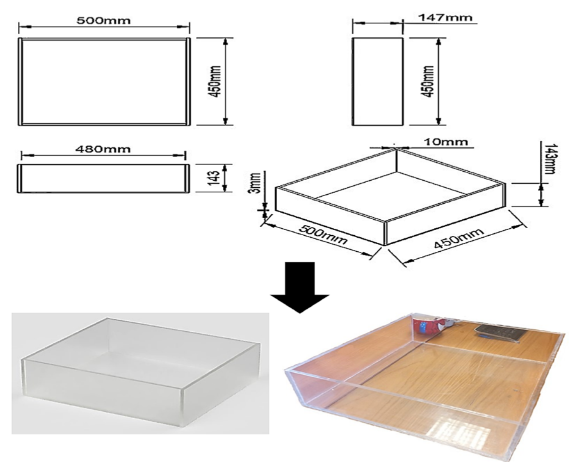

Figure 4. Acrylic box design for thermal tests.

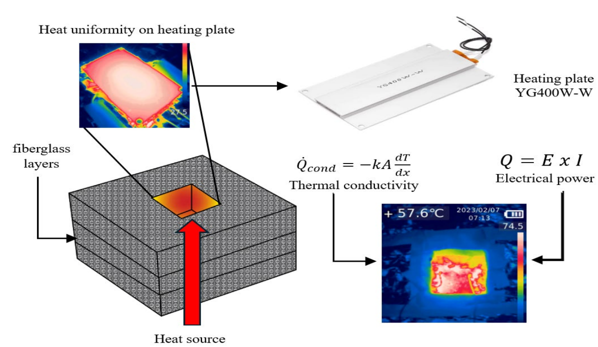

Figure 5. Verification of unidirectional heat flow condition in thermal test. Thermographic image obtained by the infrared camera.

Table 3. Nomenclature that is used to define the variables present in the calculation of thermal conductivity.

Variable	Description	Unit
$\dot{Q}$	Net heat flow	W
T_{in}	Inlet temperature	°C
T_{out}	Outlet temperature	°C
$T_m = \frac{(T_{in} + T_{out})}{2}$	Average temperature	°C
$\Delta T = T_{in} - T_{out}$	Temperature difference	°C
A	Area	m²
Δx	Thickness	M

Table 4. Instruments used to carry out thermal evaluations.

Equipment	Characteristics
J-type thermocouples	Type J with a temperature measurement range from 0°C to 750°C
K-type thermocouple	Type K with a temperature measurement range of -200°C to 1250°C
Digital thermometer	Unit-T brand, model UT325
Analog thermometer	Mercury, with temperature measurement range from 0°C to 150°C
Data acquisition system for thermocouples	Measurement computing, USB TC
Thermographic camera	Unit-T, UTi260B, PRO version “Professional Thermal Imager”
Multimeter	Extech Instruments, MN36
Heating plate	YG400W-W, with maximum heating temperature at 260°C
Electric stove	Taurus, with 2 burners
Voltage/current source	Nice Power, with maximum voltage and current of 30V and 10A respectively.
Laptop	MSI, 16GB RAM, Intel Core i5 processor
Instacal y TracerDAQ	Measurement computing software for recognition of data sent by thermocouples.
Weather station	DIGI-SENSE, to know conditions of relative humidity and ambient temperature

Prior to performing the measurements, verification of the heating plate was conducted to confirm accurate temperature distribution across its surface. This evaluation was performed utilizing a thermographic camera (refer to Figure 5). The positions of thermocouples were as follows: Two (2) below the sample and two (2) above at equal distances. The configuration was a sandwich arrangement: heater plate on top, the two (2) thermocouples stuck to the coconut fiber sample, and on top of those two (2) more.

Following confirmation of unidirectional heat flow, thermal tests were conducted. The initial step involved selecting a low supply voltage, typically ranging from 5V to 10V, to generate a temperature gradient exceeding ambient temperature. This process takes approximately 10 to 15 minutes. Subsequently, the voltage or electrical current was increased to achieve powers equal to or greater than 1,0W, which was established as the test condition. These power levels were chosen based on previous measurements, which resulted in temperature gradients of 12°C or higher.

Finally, the thermocouples were allowed to reach equilibrium temperatures, meaning they waited for the inlet and outlet temperatures to stabilize. In the case of this experiment, the steady state condition was reached in a period ranging from two to eight hours, depending on the sample and the applied voltage. Table 5 presents the experimental results for an energy input of 8,1 Watts, which was utilized for characterizing coconut fiber. Figure 6 demonstrates two examples of how the testing procedure reached equilibrium temperatures, both for glass fiber and coconut fiber samples.

Table 5. Experimental data in the evaluation of the thermal conductivity of coconut fiber. Evaluation with 8,1 Watts of energy supply and 0,015 meters of thickness.

Variable	Experimental data	Unit
$\dot{Q}$	8,10	W
T_{ch0}	140,95	°C
T_{ch1}	132,7	°C
T_{ch2}	49,98	°C
T_{ch3}	54,50	°C
T_{in}	136,82	°C
T_{out}	52,24	°C
T_m	94,53	°C
ΔT	84,58	°C
A	0,0081	m²
Δx	0,015	m
k	0,177	W/m·K

3. Experimental results and discussion

3.1. Acoustic measurements

3.1.1. Sound absorption

Considering the results shown in Figures 7 to 9, we can assume that the agglomerated coconut fiber exhibits an acceptable sound absorption coefficient across a wide frequency range, potentially surpassing the values of certain industrial absorbing materials. Specifically, the samples with a thickness of 2,6 cm outperform others, maintaining a sound absorption coefficient between 0,65 and 0,94 for frequencies between 1000 and 5000 Hz. Materials with an NRC value greater than 0,70 indicate excellent sound absorption capabilities.

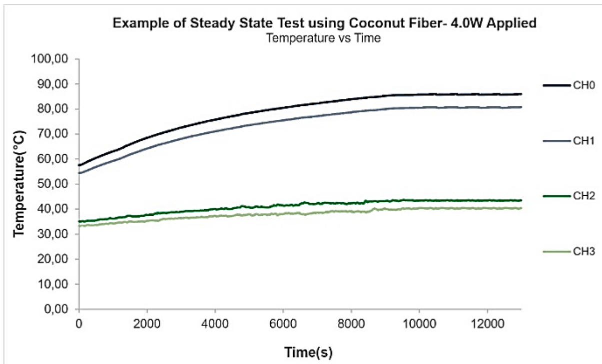

Figure 6. Steady state reached during coconut fiber sample test.

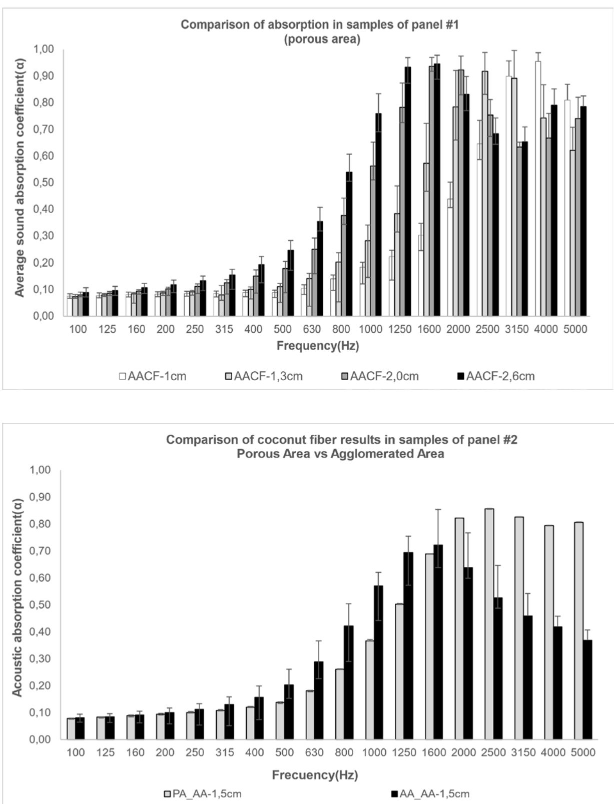

Figure 7. (a) Comparison of sound absorption in samples measured from the porous side, and (b) comparison of sound absorption in samples measured from the porous side vs. agglomerated side.

To compare the sound absorption results of the material under study with other absorbent materials used in the industry, tests are conducted with two foams and a synthetic fiber with different amounts of surface porosity. The white foam is referred to as material AA_A, the black foam as AA_B, and the black synthetic fiber as AA_C. The coconut fiber and cassava starch-binder sample correspond to AACF sample. When comparing the results obtained from the coconut fiber samples to the selected materials with a thickness of 2,6 cm, coconut fiber has better sound absorption at frequencies lower than 1600 Hz. At frequencies higher than this (between 1600 Hz and 5000 Hz), the studied selected materials exhibit better characteristics. Despite this, the coconut fiber samples with a thickness of 2,6 cm show acoustic absorption coefficients exceeding 65% at high frequencies, making them still functional for applications aimed at improving reverberation time in spaces and other absorbent material applications in buildings.

It has been decided to express plots in third octave bands because they provide a more detailed view of the sound absorption behavior in a more specific frequency range, being useful to detect small variations that may go unnoticed with full octave bands. This can hide significant peaks or dips in absorption. In contrast, third octave bands allow such irregularities to be clearly identified. As can be seen in Figure 8 at frequencies of 1500, 3000 and 4500Hz.

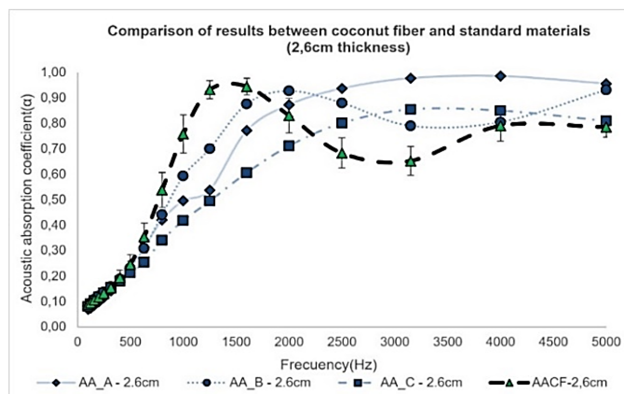

Figure 8. Comparison of sound absorption in coconut fiber samples (thickness of 2,6 cm) vs selected standard sound absorbing materials.

In addition, the sound reduction class number (NRC) was calculated, which is defined as the average absorption in the frequency range between 250 and 2000 Hz in octave frequency bands (Martínez Ibarra, 2017). Regarding our results in third octave frequency bands, these encompass the results between 160 and 2500 Hz. The NRC obtained for coconut fiber is higher than that achieved for the standard materials studied, with an NRC of 0,461 for the coconut fiber, while for the reference materials AA_A, AA_B, and AA_C with similar thickness, NRCs were 0,401, 0,437, and 0,349, respectively. These results are presented in Tables 6 and 7.

Table 6. Sound reduction class (NRC) for coconut fiber compared with other standard sound absorbing materials.

Sample	Thickness	NRC
Standard material AA_A	2,6 cm	0,401
Standard material AA_B	2,6 cm	0,437
Standard material AA_C	2,6 cm	0,349
Coconut fiber and cassava starch-binder	2,6 cm	0,461

On the other hand, when comparing the sound absorption coefficients of samples with agglomerated and porous areas, it is noteworthy that the agglomerated area showed better sound absorption at the lower frequencies between 100 and 1600 Hz (see Figure 7b). Conversely, the porous area exhibited better results at higher frequencies between 2000 and 5000 Hz. From these findings, we can conclude that the material surface exposed to an incident sound will depend on the frequency range of interest in each case. However, it is important to note that absorption coefficients greater than 50% were observed at higher frequencies. In Yuhazri et al. (2019), a sample of coconut fiber agglomerated with polyurethane showed absorptions coefficients between 0,10 and 0,75, in a range of frequencies of 500 to 5000 Hz. The sample studied has a thickness of 0,65 cm (Yuhazri et al., 2019).

Table 7. Sound absorption coefficient (α) for porous area samples with different thicknesses.

Frequency (Hz)	Sound absorption coefficient (α) Thickness (cm) 1,0	1,3	2,0	2,6
100	0,075	0,073	0,08	0,089
125	0,077	0,080	0,086	0,096
160	0,081	0,084	0,094	0,107
200	0,083	0,088	0,102	0,118
250	0,085	0,091	0,112	0,133
315	0,085	0,080	0,125	0,155
400	0,088	0,100	0,151	0,194
500	0,088	0,111	0,179	0,247
630	0,105	0,141	0,251	0,355
800	0,140	0,204	0,378	0,539
1000	0,184	0,282	0,563	0,759
1250	0,224	0,385	0,783	0,933
1600	0,304	0,573	0,936	0,945
2000	0,440	0,784	0,923	0,831
2500	0,646	0,918	0,754	0,684
3150	0,900	0,892	0,634	0,653
4000	0,955	0,743	0,667	0,791
5000	0,810	0,622	0,740	0,786
NRC	0,196	0,295	0,412	0,461

3.1.2. Sound insulation

STL results presented in Figure 9 demonstrate an approximate proportionality to sample thickness and frequency, consistent with the behavior observed for sound absorption. Maximum STL values were attained in tests with a sample thickness of 1,4 cm. Specifically, STL of 15,1 dB at 4000 Hz and 17,3 dB at 5000 Hz were recorded for these optimal thicknesses. Acceptable STL values for a natural fiber insulator were obtained. Improvements in STL were observed.

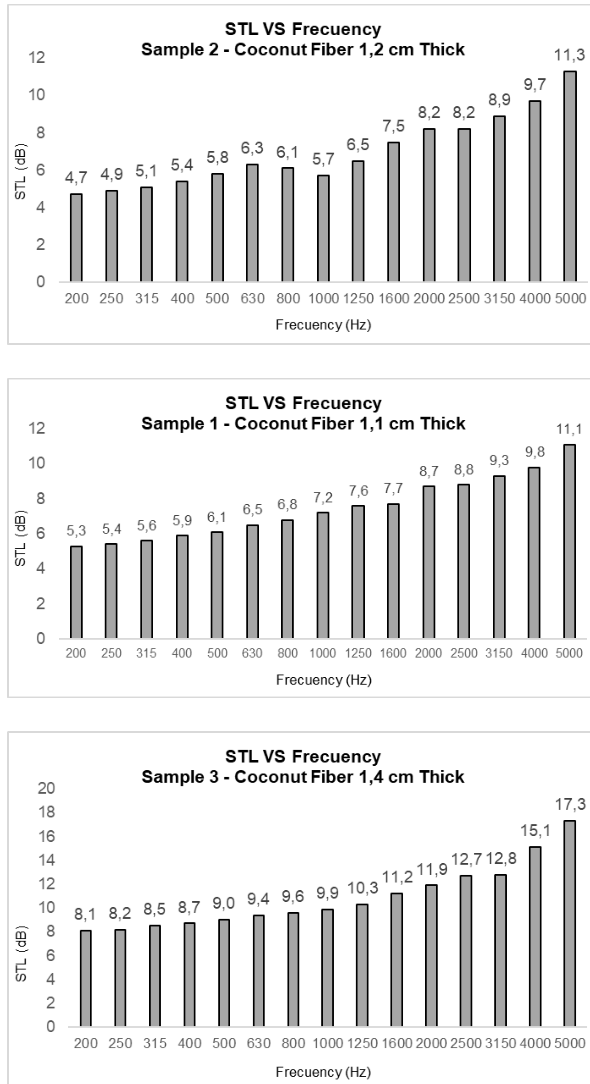

Figure 9. Sound transmission loss (STL) in samples of coconut fiber: (a) sample 1, (b) sample 2, and (c) sample 3.

These STL results fall within ranges comparable to other studies conducted with natural fibers, including the following:

In Ankush Kesharwani's 2020 study, natural fibers without binder were reported to have STL values between 0,2 and 2,7 dB for frequencies ranging from 160 to 5000 Hz. Additionally, Kesharwani analyzed jute, kenaf, banana, hemp, and jute fibers, noting that these exhibited better ST levels compared to coconut fiber, which ranged between 0,4 and 18,5 dB. Notably, the maximum value was observed for Kenaf fiber at 6300 Hz (Kesharwani et al., 2020).

In Lamyaa Abd Alrahman Jawad's 2020 study, significant improvements in STL were observed when increasing the thickness of luffa fibers from 2,0 to 3,0 cm. This resulted in a 15-20% increase in STL values. Furthermore, STL increased with elevated material density. The researchers obtained STL measurements between 1 and 20 dB at frequencies ranging from 125 to 4000 Hz, corresponding to material densities of 600, 880, and 970 kg/m^3 (Jawad & Salih, 2020).

The main distinction between this study and previous research lies in the introduction of cassava starch as a binder. Simply put, this innovation enhances insulation performance compared to scenarios without a binder. This outcome aligns with the expectation that increased starch concentration would boost the material acoustic insulation capabilities.

It is important to note that we can't directly compare the sound transmission loss (STL) results obtained from coconut fiber samples bonded with cassava starch to those from other materials. There is limited information available on STL tests conducted on this specific type of composite material. However, based on the available data, coconut fiber reinforced with cassava starch demonstrates comparable performance to previously reported results.

3.2. Thermal results

In the thermal study, three distinct coconut fiber panels were examined. Thermal conductivity was determined based on the average temperature of each panel (refer to Table 8). The measured values ranged from 0,15 to 0,18 W/m·K across all experimental trials, indicating satisfactory reproducibility in the testing procedure. Variations in the results can be attributed to two factors, considered in this study:

1. Heterogeneity within the three panels (aggregated material), considered that the tested panels were manufactured using an artisanal process.
2. Changes in power input during testing

These influences are evident when analyzing inlet and outlet temperatures under different power levels. For instance, Figure 10 illustrates the temperature readings for panel 2 at various power inputs: 1,7W, 2,2W, 4,0W, 5,1W, and 8,1W. At the lowest power level (1,7W), the temperature differential was 18,28°C. Conversely, at the highest power input (8,1W), the temperature difference increased to 84,58°C, representing a significant shift in test conditions.

Other factors that may affect measurements are variations in contact between the thermocouple and the sample: the quality of contact between the thermocouple and the plate can affect the precision of the measurements. Also, the residual moisture in coconut fibers: coconut fiber probes can retain different levels of moisture, which implies interference in thermal conductivity measurement.

Table 8. Average thermal conductivity for the three panels of coconut fiber and cassava starch-binder.

Samples	Thermal Conductivity (k)	Unit
Panel 1	0,184 ± 0,0412	W/m·K
Panel 2	0,178 ± 0,0058	W/m·K
Panel 3	0,159 ± 0,0105	W/m·K
Average value	0,174 ± 0,0192	W/m·K

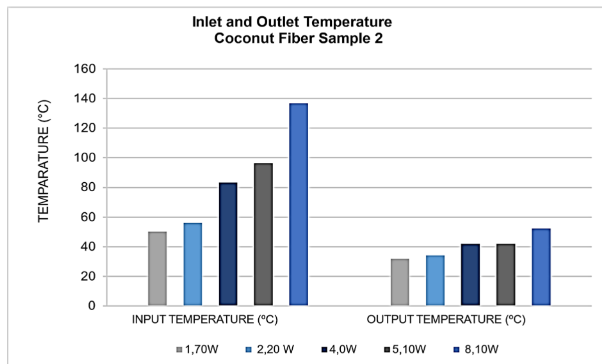

Figure 10. Evaluation of the inlet and outlet temperature in sample 2.

According to Bui et al. (2020), thermal conductivity values for coconut fiber samples ranged from 0,052 to 0,024 W/m·K across densities from 30 to 120 kg/m^3 (Bui et al., 2020). These researchers used natural coconut fiber without a binder, which aligns with typical commercial applications of coconut fiber.

For this study, the samples used in our work have a density of 222,22 kg/m^3 and a thickness of 1,5 cm. They were prepared using cassava starch as a binder. Consequently, we compared our thermal results with existing literature on coconut fiber mixed with binders. For instance, Espinoza Montero et al. (2022) conducted research on coconut fiber treated with synthetic binders, obtaining thermal conductivity coefficients within the same range as our measurements (Espinoza Montero et al., 2022) Specifically, their findings showed: thermal conductivity values ranging from 0,052 to 0,024 W/m·K across densities from 30 to 120 kg/m^3 and the use of natural coconut fiber without a binder, consistent with typical commercial applications of coconut fiber. Natural coconut fiber without binders (0,033 ± 0,031 W/m·K), untreated coconut fiber with the addition of PLA (0,06926 ± 0,50 W/m·K), coconut fiber treated with acetone (0,079± 0,001 W/m·K) and coconut fiber treated with acetosol (0,133± 0,001 W/m·K).

The disparity in results is due to the use of a natural binder (cassava starch) instead of a synthetic one. For our study, the average thermal conductivity of the material was approximately 0,174 ± 0,0192 W/m·K. This value is comparable to those obtained for coconut fiber treated with acetosol (0,133 ± 0,001 W/m·K).

4. Conclusions

From the measurements and analyses conducted in this study, a 2,6 cm optimal thickness was determined for practical application of the material under investigation. In this work, it was evaluated four thickness at the one with 2,6 cm demonstrate better sound absorption. Test samples with this thickness demonstrated adequate sound absorption coefficients across high and low frequencies. This thickness also implies the need for a small amount of material, as optimal thickness reduces costs and the stress on buildings.

Agglomerated coconut fiber with cassava starch material exhibits an acceptable sound absorption coefficient greater than 0,70, between 0,65 and 0,94 for frequencies between 1000 and 5000 Hz. These results indicate good sound absorption capability. In addition, acceptable STL values for a natural fiber insulator were obtained. Improvements in STL were observed when increasing the thickness from 1,2 to 1,4 cm, at higher frequencies (17,3 dB at 5000 Hz).

Samples evaluated with their porous side facing the incident sound exhibited superior sound absorption compared to those evaluated from their agglomerated side. The sound absorption of the porous side is proportional to the thickness of the samples and to the frequency, resulting in enhanced insulation at high frequencies. Conversely, in terms of thermal conductivity, the coconut fiber agglomerated with cassava starch did not achieve sufficiently low value to surpass other excellent thermally insulating material. Notably, however, the obtained results were remarkably close to some industrially used thermally insulating materials, with the advantage of being derived from completely natural origins.

For further studies, the agglomerated area could produce more compact material, which might lead to an increase in sound reflection and, consequently, sound reduction. It is recommended to perform a more detailed superficial (optical microscope or SEM) inspection of the material to verify the condition of the agglomerated area and determine if the pores are fully sealed, as this could make the material more reflective rather than absorptive. Although the tested samples were manufactured using an artisanal process demonstrate acceptable results, it is necessary to verify potential improvements in the manufacturing process.

Conflict of interest

The authors have no conflicts of interest to declare.

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