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Research Article

Panels Manufactured from Vegetable Fibers: An Alternative Approach for Controlling Noises in Indoor Environments

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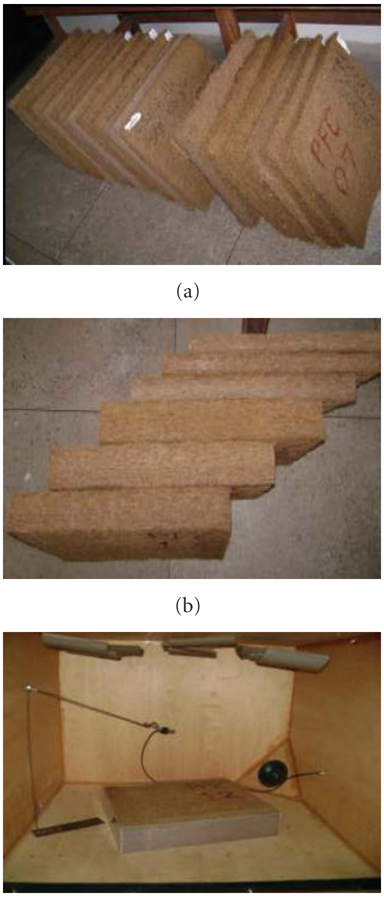
Noise control devices such as panels and barriers, when of high efficiency, generally are of difficult acquisition due to high costs turning in many cases their use impracticable, mainly for limited budget small-sized companies. There is a huge requirement for new acoustic materials that have satisfactory performance, not only under acoustic aspect but also other relevant ones and are of low cost. Vegetable fibers are an alternative solution when used as panels since they promise satisfactory acoustic absorption, according to previous researches, exist in abundance, and derive from renewable sources. This paper, therefore, reports on the development of panels made from vegetable fibers (coconut, palm, sisal, and açaí), assesses their applicability by various experimental (flammability, odor, fungal growth, and ageing) tests, and characterize them acoustically in terms of their sound absorption coefficients on a scale model reverberant chamber. Acoustic results point out that the aforementioned fiber panels play pretty well the role of a noise control device since they have compatible, and in some cases, higher performance when compared to commercially available conventional materials.

1. Introduction

Most of the products used in acoustical devices and treatments use nonrenewable source materials. Majority is made of synthetic components and involves high-production costs reflected in energy consumption and sometimes are toxic materials as, for example, fiberglass. These products are not easily available or affordable by small-sized companies. Additionally, due to the little importance given by companies and/or employers to the acoustical quality of certain environments complicates the acquisition and consequently the use of these materials.

Recently, panels made from vegetable fibers have been studied [1–7], regarding their acoustic properties. It is already known that some of them have satisfactory characteristics when used as sound absorbing elements [2–8]. However, other aspects should be considered. For example, vegetable fibers are intrinsically flammable, so it is important that they can resist to the fire spreading or fungus proliferation when used as panels for the noise control purpose in environment indoors. Regarding those panels, the requested procedures and infrastructure to determine important properties (such as flow resistivity and tortuosity) to their acoustic characterization have been developed [5], and further have been applied in other similar researches [2, 6, 7]. In one of them [2], industrial panels of various thicknesses and densities manufactured from coconut fiber and latex (see Figures 1(a) and 1(b)) were studied on a scale model reverberant chamber and an impedance tube as to their acoustic characteristics and other relevant properties together with commercially available conventional materials. It was found that some samples of the aforementioned panels give, at certain frequencies, superior performance when compared to the tested conventional materials. In addition, the performance of those panels as to flammability, ageing, fungal growth, among other aspects also was satisfactory [5–7], thus pointing out that there is a great unexplored potential concerning the use of vegetable fibers



(a)

(b)

(c)

Figure 1: (a), (b) industrial panels of varied thicknesses and densities manufactured from coconut fiber and (c) is the scale model reverberant chamber in which they have been tested. From [2].

in several branches. This paper reports on development of newly manufactured panels using different vegetable fibers, namely, coconut, palm, sisal, and açaí fibers, and on their applicability for noise control purpose. It is important to mention that all the acoustic measurements mentioned here have been carried out on a scale model reverberant chamber, the same used in [2, 3] (see Figure 1(c)).

2. Natural Fibers

Brazil is home to flora with an impressive biodiversity from which various natural products and byproducts can be extracted. Some of these products, however, are not fully used and, therefore, their waste is eventually used by other industrial sectors, such is the case of some natural fibers like the coconut fiber which is used from car seat padding to doormats [2, 5].

2.1. Vegetable Fibers. Fiber materials are thin and elongated, like filaments, which may be continuous or cut. They can be spun for the formation of wires, lines, or ropes or layered for the production of paper, felt, or other products. Common examples are cotton (CO), wool (WO), silk (SK), flax (CL), and ramie (CR). Currently, many industries, specially the automotive and plastic manufacture, are regaining interest in vegetable fibers. The work reported in this paper considers the acoustical potential of sisal, palm, coconut, and açaí fibers, which are easy to obtain, are nontoxic, derive from renewable sources, have low cost and are abundant in northern and northeastern Brazil.

(a)

(b)

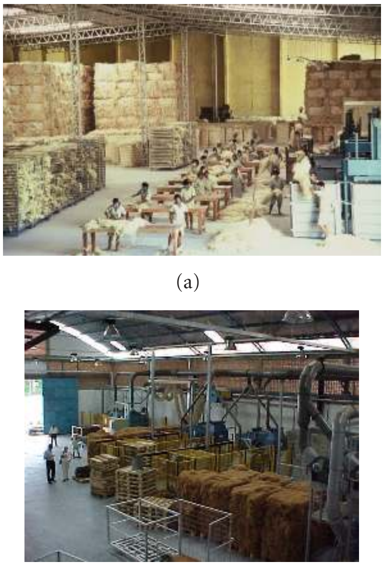
Figure 2: (a) Açaí fruit residue and (b) coconut residue.

Vegetable fibers are used mainly for manufacturing panels or blankets that are used as internal coatings. In terms of acoustic performance, common applications are in churches, auditoria, classrooms, and so forth, which must have good speech intelligibility. Theaters, TV, radio, and recording studios should also have appropriate acoustic characteristics [1, 4].

Regarding coconut and açaí fruits, there is an important advantage related to the ecological aspect, since parts of their residues (see Figures 2(a) and 2(b)), previously wasted, are now exploited in several ways, including for the social aspect, employment generation, and small communities development.

Biodegradable compounds are being intensively investigated due to problems of plastic accumulation, where these compounds need reinforcement in order to obtain better mechanical properties without compromising their biodegradability [9].

Sisal fibers can be used as reinforcement, with different applications in the automotive industry [10, 11]: cabin linings (roof, rear wall, and doors), head and back supports of seats, dashboard, and so forth. Sisal fiber (see Figure 3(a)), yields about 80 million dollars in foreign currency per year,



(a)

(b)

Figure 3: Beneficiation company of (a) sisal and (b) coconut fibers (POEMATEC).

and generates more than half a million jobs directly and indirectly through its supply chain [12]. So as coconut fiber extraction, when performed in Pará State, northern Brazil, is made in the countryside community agribusinesses that negotiate the product directly on the local market for industries that process the fiber (see Figure 3(b)).

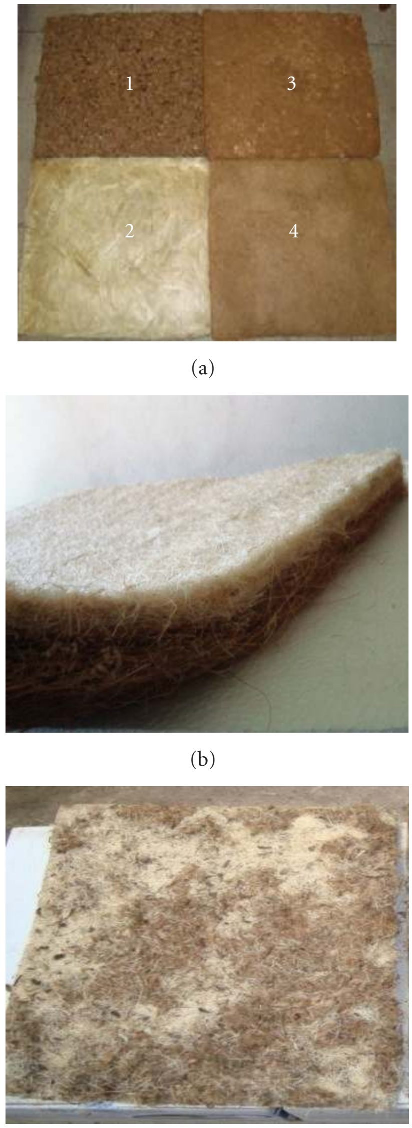
2.2. Panels from Vegetable Fibers. The panels tested in this work are handmade panels [6] and are classified as unifiber, multifiber, and mixed panels. Unifiber panels are made of layers of a single type of fiber (see Figure 4(a)). Multifiber panels are made of layers formed by two or more types (see Figure 4(b)). Mixed panels consist of mixtures of two or more types of fibers in each layer (see Figure 4(c)).

3. Development of Panels

3.1. Treatment of Fibers. Palm fibers contain a considerable residue of palm oil, which accelerates degradation and fungal growth. Therefore, the fibers have been washed with industrial neutral detergent and sun-dried. Other fiber types have been restricted to the washing and drying stages. Açaí fibers have been acquired through an extraction process developed specifically for this purpose, after the pit are obtained, already without pulp, previously washed, and dried. The sisal fibers have been acquired commercially.

3.2. Panels. There are two main aspects to consider: compatibility of fibers regarding the binding agent used and fiber treatments (chemical, thermal, etc.). The related processes are shown in Figure 5.

The cleaning stage is to minimize the impurities in the fibers. In the next stage, layers of fibers are formed by



(a)

(b)

(c)

Figure 4: (a) Handmade panels of (1) palm, (2) sisal, (3) açaí and (4) coconut fibers, (b) coconut/sisal multifiber panel, and (c) Palm/sisal mixed panel.

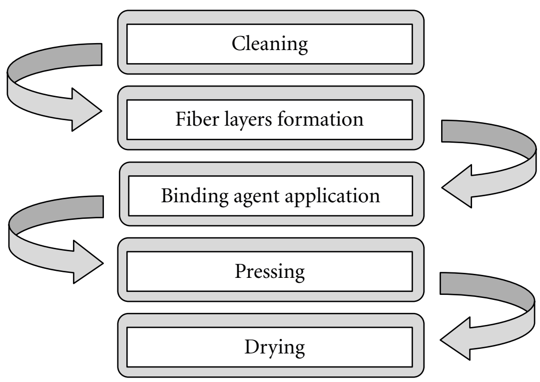


Figure 5: Cycles of panel developing process.

Figure 6: Panels and their respective samples.

(a)

(b)

Figure 7: (a) Chamber test with exhaust system and (b) combustion chamber.

pressing. A binding agent, based on acrylate and water, is then applied until the layers have enough adherences. The fiber layers are subsequently overlapped and then pressed to promote final aggregation. The panels are naturally dried by sunlight and wind.

All tested panels had approximately the same mass (about 1.0 kg) and surface area (0.3 m^2) in order to meet issues as dimension limits, for instance, concerned to the scale model reverberant chamber used to perform the acoustic measurements. The highest density recorded was 18 kg/m^3 and the maximum thickness was of 30 mm. Some physical characteristics concerned to the tested panels are summarized in Table 1.

Table 1: Some physical characteristics of tested panels.

Panels	Density (kg/m^3)	Grammage (g/m^2)	Thickness (mm)
Sisal	17	3367	20
Açaí	11	3283	30
Coconut	16	3328	28
Palm	18	3557	25

Figure 8: Samples during ageing test.

It is important to mention that the unifiber type panels have been developed in order to separately obtain the characteristics of each fiber so that other types of panels could be made by combining different fibers, seeking to correct a possible deficiency or improve any property in which a particular unifiber panel does not present a satisfactory performance.

4. Experimental Tests

The tests have been performed are flammability, ageing, olfactory, and fungal growth tests; all of them have been carried out at the Industrial Laboratory of the POEMATEC Company by qualified personnel. The specimens have been prepared (see Figure 6) according to standards that regulate the methodology.

4.1. Flammability. The purpose of this test is to measure the horizontal burning velocity of the material. The samples are placed in contact with a flame for 15 s, in a combustion chamber (see Figure 7(a)), which has an exhaust system (see Figure 7(b)).

After the contact time, the flame is extinguished and the burning rate recorded. If the flame does not exceed 100 mm in 1 minute, the sample passes the test; otherwise, it is rejected [13–15]. In general, the samples provided good resistance to flames, due mainly to high compaction, with few empty spaces (interstices) in their structures.

4.2. Ageing. The samples (see Figure 8) have been subjected to temperatures of 70 ± 2°C for 48 h in a greenhouse with air circulation and then for a period of 30 min at a temperature of 23 ± 2°C.

They then have been checked for evidence of structural embrittlement [16]. All samples showed good results, with the binding agent contributing to this, since its synthetic

Figure 9: Samples during odor test.

composition increases the humidity and heat resistance of the samples.

4.3. Odor. This test analyzes the olfactory behavior of a material, after being exposed to varied temperatures and climates [16]. First, samples are stored in glass vessels (see Figure 9), initially in dry state, and then after wetting with 5 mL of distilled water (damp state).

They have been exposed to the following conditions: 24 h at room temperature in dry state; 24 h at room temperature in damp state; 24 h at 70°C in dry state; 24 h at 70°C in damp state [16]. The odor assessment is performed by three experts, who attribute to each sample, grades from 0 to 3, with 0 meaning "virtually odorless", 1 meaning "slight characteristic odor", 2 meaning "perceptible or uncomfortable odors", and 3 meaning "intense or unpleasant odors". If all the grades are different, a fourth person determines the sample average grade. The results have been good, except for palm samples, which retained residual oil.

4.4. Fungal Growth. The purpose of this test is to detect fungi appearance, bacteria, or any other organism harmful to human health under certain environmental conditions. Airborne fungi are the main contaminants of indoor air and may initiate allergic processes, mucous, and skin irritation and fungal infections. The fungi detection process is to induce fungi formation, by exposing them to certain climatic conditions [16]. The fungi detection results have been satisfactory for all samples and, again, the binding agent has been important because it is highly resistant to fungi. After all tests, a general satisfactory performance has been observed, certifying that those materials do not compromise either the environment.

5. Acoustic Characterization

The acoustic characterization of a material is generally concerned to sound absorption and insulation. Sound absorption coefficient and transmission loss are the physical indicators normally considered. In this work, only the sound absorbing characteristics of the panels have been considered, once it was not expected that the panels would provide high insulation because they are lightweight, flexible, and have significant empty spaces in their structure [17].

Conventional acoustic materials also have been tested. Sonex Flexonic and Sonex Roc acoustic foams, with 75 mm and 30 mm of thickness, respectively, have been chosen because they are widely employed and have reported good performance. In Figures 10(a) and 10(b) are shown the scale model reverberant chamber and associated equipment: B&K type 3560c frequency analyzer (PULSE); B&K microphone type 4942-A-021 for measurements in diffuse fields; selenium 15" speaker; digital thermo hygrometer; analog amplifier; notebook; microphone support; B&K 4231 sound calibrator. The acoustical tests have been conducted at the Laboratory of Acoustics of the Acoustics and Vibration Group (GVA) of the Federal University of Pará (UFPA). The reverberant chamber that has been used is a scale model reverberant chamber [2], which was previously certified according to a specific standard for this purpose [18]. Valid principles for full-scale chambers (reciprocity principle, diffuse field, etc.) have been assumed. The referred chamber is made of plywood and supported by vibration isolators, having a total volume of 0.96 m^3. Sound diffusers made of polyvinyl chloride (PVC) have been installed. The sound source is located at one of the corners of the chamber (see Figure 10(c)), maximizing the probability of exciting all acoustic modes of chamber.

The sound absorption coefficients of the samples have been obtained using the noise interruption method, which consists in obtaining decay curves through the direct registration of the decay of sound pressure level after the chamber has been excited by broadband noise. After determination of the reverberation time of the chamber with and without a given sample, the equivalent sound absorption, A_s, expressed in square meters [18], can be calculated as a function of frequency from (1):

$$A_s = \frac{55,3V}{c}\left(\frac{1}{\bar{t}_2} - \frac{1}{\bar{t}_1}\right)(\text{m}^2), \quad (1)$$

where $\bar{t}_2$ is the average reverberation time with the sample in its interior, $\bar{t}_1$ is the average for the empty chamber, V is the volume of the chamber, and c is the speed of sound in the environment, determined by (2) [18]:

$$c = 331.5 + 0.6T\,(\text{m/s}), \quad (2)$$

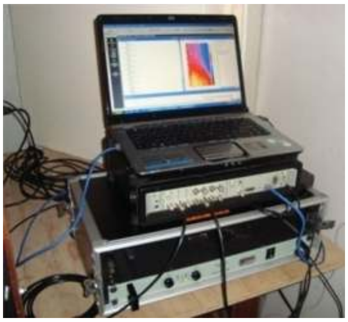
where T is the temperature of the environment in Celsius degrees. Thus, the sample sound absorption coefficient, α_s, can be obtained by (3) [18]:

$$\alpha_s = \frac{A_s}{S}\ (\text{dimensionless}), \quad (3)$$

where S is the surface area of the sample, in square meters.

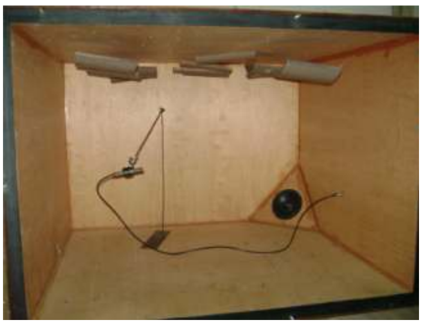
Before showing the results related to the tested panels, a comparison has been made for a same material involving the results obtained in different test environments. In order to check the results obtained from the aforementioned scale model reverberant chamber, tests concerning unifiber sisal panel have been carried out also on a full-size chamber available on Acoustic Laboratory at Federal University of Santa Maria, Rio Grande do Sul, Brazil. Results obtained from the different chambers are shown in Figure 11.

By analyzing the Figure 11 one can note that the results have been significantly different, but the curves



(a)

(b)



(c)

Figure 10: (a) Measurement setup, (b) scale model reverberant chamber and (c) chamber, interior, its diffusers, sound source, and microphone support.

have presented the same behavior for the sound absorption coefficient. Those differences are due to several factors, different equipment (sound source, microphones, analyzers, etc.) used in the two distinct chambers, weather conditions, equivalent area of the tested samples, among too many others. Thus, it was already expected that the results were different. In fact, the dimensions of the scale model chamber were crucial for the instable behavior of its sound field, mainly at low frequencies (it has been found in previous tests that the behavior of the chamber becomes enough diffuse from 500 Hz). It is important to mention that, however, the scaling factor of the scaled chamber has not been used here to shift the frequency range and make the comparison more appropriate, thus proving instead that the scaled chamber is used as a valid reverberant chamber. Additionally, data obtained for the same sample at the same (temperature, relative humidity, etc.) conditions might present significant

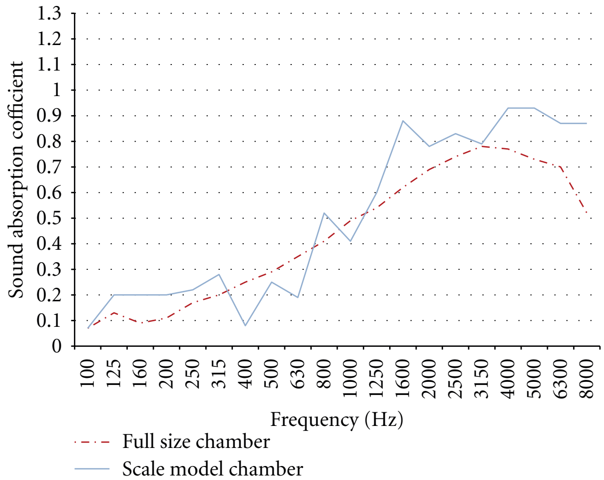


Figure 11: Comparison between unifiber panels and conventional acoustic materials sound absorption coefficients.

differences. This fact occurs due to statistical variations of parameters such as, for instance, microphone(s) and source(s) position(s), sample location, and sound field in the chamber. The first results to be shown are related to the conventional acoustic materials tested (Sonex Flexonic and Sonex Roc) in order to compare to those results provided by the manufacturer of these materials (see Figure 12).

Regarding Figure 12, the comparisons between the results have revealed some discrepancies in certain regions but they present the same sound absorption trend, that is, higher efficiency with increasing frequency. As mentioned previously, those discrepancies might be due to several factors; however, they do not compromise the work, since the study here performed sought to establish a qualitative comparison between the investigated materials, testing them in the same environment, and under the same conditions. Furthermore, the results will be used solely to form a database in order to better understand the acoustic behavior of the referred chamber and not to be used as design parameters. Besides, it is expected that those differences be minimized as frequency increases. In addition, the results have been presented up to 4000 Hz because that one is the frequency range usually given by the manufacturer.

The results obtained for the unifiber panels and the conventional acoustic materials are shown in Figure 13.

From the results shown in Figure 13, one can say that all of handmade unifiber panels have proved to be good sound absorbers, presenting greater efficiency in medium and high frequency, and operating range more common for materials of this type. It is noteworthy that the results obtained from the scaled chamber have been influenced by the degree of diffusion of its sound field (mainly at low frequencies), which is directly related to the characteristics of building materials of the chamber. So, it means that, the more rigid the internal coating material of the chamber is, the more diffuse its sound field will be, besides dimensional factors, since a small size chamber does not contribute to the sound diffusion inside it. However, it is important to

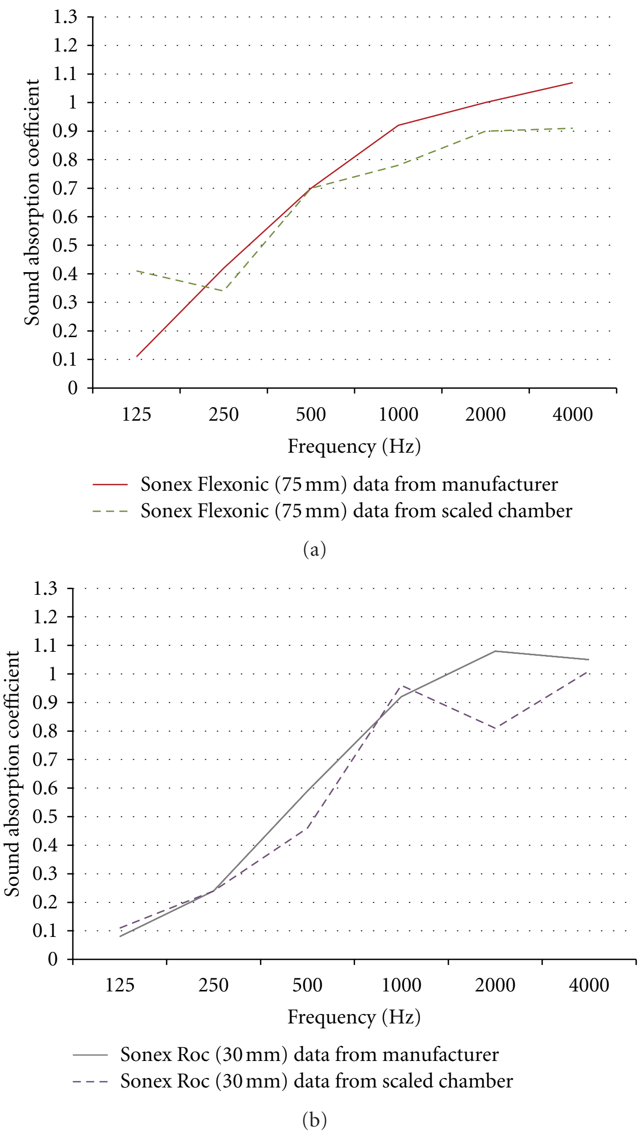


FIGURE 12: Comparison between sound absorption coefficients of palm/açaí and palm/sisal mixed panels and a palm unifiber panel.

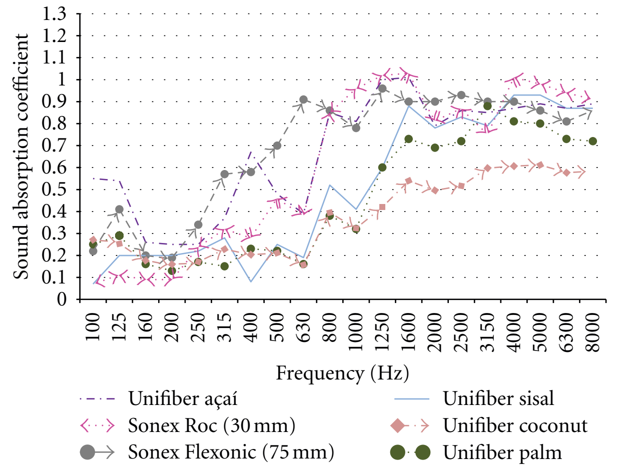


FIGURE 13: Comparison between unifiber panels and conventional acoustic materials sound absorption coefficients.

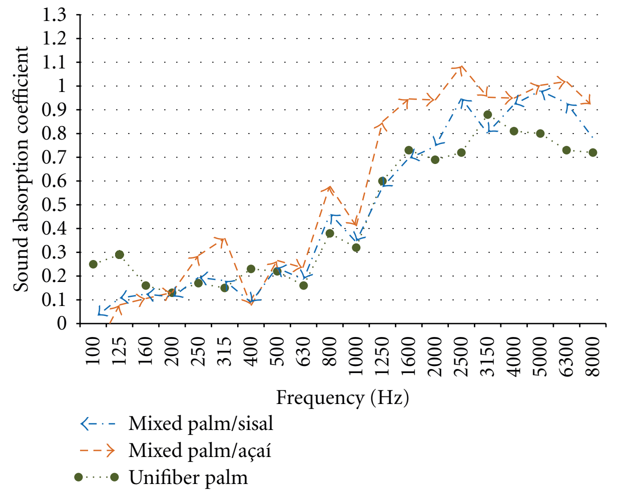


FIGURE 14: Comparison between sound absorption coefficients of palm/açaí and palm/sisal mixed panels and a palm unifiber panel.

note that here has not been used the scale factor to shift the frequency range of analysis, even at low frequencies where the behavior of the scaled chamber is weakly diffuse. Thus, like any reverberant chamber, this one also has limitations mainly at low frequencies regions (measurements has shown that the results of scaled chamber becomes less reliable below 500 Hz) but are unimportant when compared to the objective of the study. Furthermore, the materials tested here (resistive absorbers) are recommended, especially for applications in medium and high frequencies. Still regarding Figure 13, when sound absorption coefficients greater than unit are obtained, it assumes unitary value for the sound absorption coefficient of the sample in question [17].

Figure 14 shows that, above 1 kHz, the acoustical performance of the panel of palm fiber is satisfactory, and above 2 kHz, it approximates to that of commercial materials. Therefore, a panel made from palm fibers to noise control purpose can be considered an attractive option, because it is of low cost, presents a reasonable acoustic performance and adds value to related fiber which is currently used as only furnaces fuel by palm oil refining companies. Additionally, through combinations with other fibers (in mixed panels form) the sound absorption coefficient of the panel of palm fiber is increased besides correcting the deficiency presented as to odor described previously.

Figure 15 shows the sound absorption coefficients obtained for multifiber panels. It can be noted, according to Figure 15, that a multifiber panel with coconut and açaí fibers have presented a considerably higher performance than that presented by a panel made of coconut fibers only and virtually does not change the performance of the panel made solely of açaí fibers. Additionally, depending on which side of the panel is facing the environment, it is possible to obtain performances different. Therefore, a new

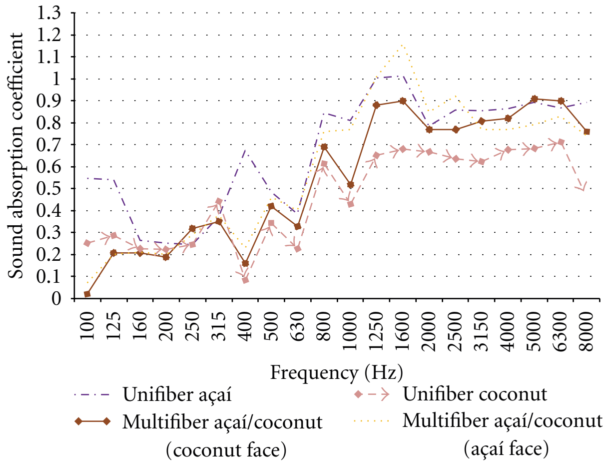


Figure 15: Comparison between multifiber açaí/coconut and unifiber coconut and açaí panels sound absorption coefficients.

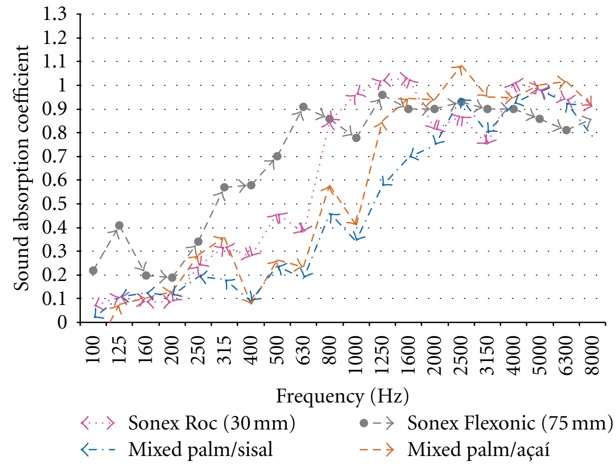


Figure 17: Comparison between sound absorption coefficients of palm/sisal and palm/açaí mixed panels and conventional acoustic materials.

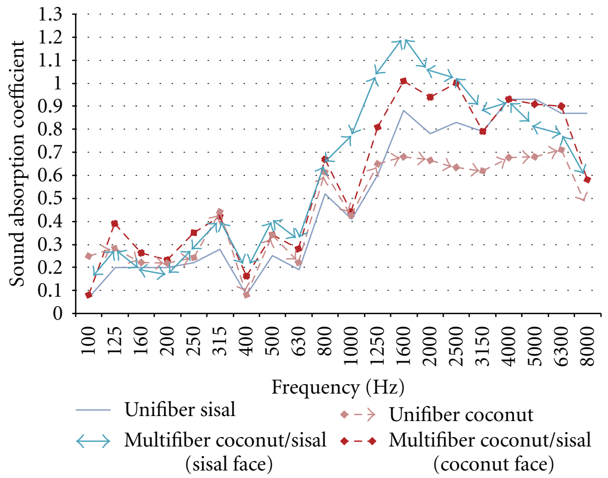


Figure 16: Comparison between sound absorption coefficients of coconut/sisal multifiber panel and coconut and sisal unifiber panels.

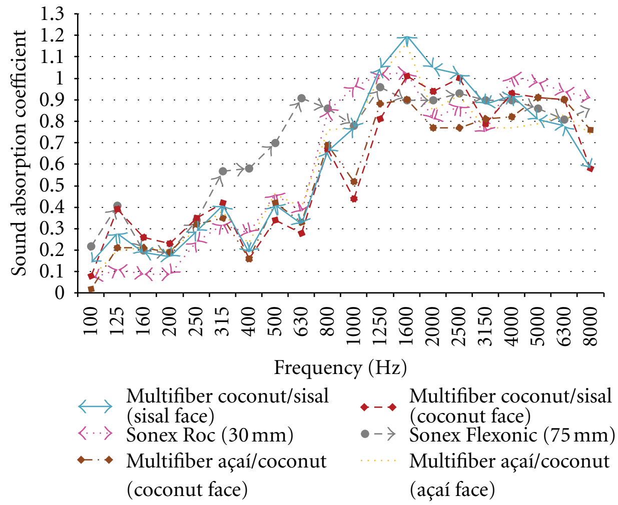


Figure 18: Comparison between sound absorption coefficients of coconut/sisal and açaí/coconut multifiber panels and conventional acoustic materials.

material (panel) was created, with different characteristics from those materials characteristics which originated this one, simply by the combination of the two fibers involved. Thus, overlapping a new layer of fiber to the previous layer, it will generate a new composition. In other materials (e.g., conventional materials) this option to overlap new layers is not possible. The same is observed when unifiber panels of coconut and sisal are compared with a multifiber panel consisting of those types of fibers (see Figure 16).

When mixed panels are compared with conventional materials, the difference is smaller than between unifiber panels and conventional materials (see Figure 17).

When the same comparison is made between multifiber panels and conventional materials, the difference is even smaller (see Figure 18), allowing one to conclude that multifiber panels produced the best performance.

It is important to mention that thickness and density, strongly influential parameters on performance, of the tested materials have not been taken into account in the performance comparisons, which would indicate the superiority of the vegetable fiber panels. Moreover, many combinations of fibers have not been tested or even manufactured; since altering the parameters involved in the manufacturing process of panels is possible obtain others panels with even better characteristics.

6. Conclusions

The tested panels have given acoustic performances compatible with, and in some cases, superior to that of well-known commercial materials. Besides, thickness and density of the newly developed panels have not been taken into account in the performance comparisons. Thus, one expects that increasing these parameters to the same extent presented by the conventional materials the performance of panels can be improved.

Many possible combinations of fibers have not been tested, due to time and cost limitations. Thus, taking into account the diversity of Brazilian natural fibers and their characteristics, it can be stated that there is a great unexplored potential for development of new sound absorbing materials.

The vegetable fiber panels made along this work have presented good aggregation and visual appearance due to the success of the manufacturing process developed. However, before they become commercially available as acoustic materials, they must pass for tests to determine other important properties in order to ensure safety in their use, since without knowledge of their acoustical characteristics and applicability, they may represent an unnecessary source of risk to the environment in which they are being employed and specially to the people that will come to attend it, in case of fire or fungus proliferation by the referred materials.

Regarding the sound absorption coefficients of tested materials, the analyses made in this study sought to establish a qualitative comparison between the investigated materials, testing them in the same environment and under the same conditions. Thus, once the results obtained for conventional materials in the scale model reverberant chamber have reasonably agreed with those provided by their manufacturer, it is consequently expected that the newly developed panels will present performances on real (full size) chambers similar to those presented on the scaled chamber.

Because manufacturing process of panels presented in this work is a handmade process and the machinery associated to manufacture the panels has not been fully developed yet, it can be stated that, if this process is optimized and automated, it is expected that their characteristics (acoustical, physical, etc.) will be improved.

Symbol List

- A_S: Sound Absorption of a sample (m^2)
- V: Reverberant chamber volume (m^3)
- c: Speed of sound in the medium (air) (m/s)
- T: Temperature (°C)
- $\bar{t}_1$: Averaged chamber reverberation time without any sample (s)
- $\bar{t}_2$: Averaged chamber reverberation time with a certain sample (s)
- α_s: Sound absorption coefficient of a sample (dimensionless)
- S: Surface area of the sample (m^2).

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References

[1] J. Ramis, J. Alba, R. del Rey, E. Escuder, and V. J. Sanchís, "New absorbent material acoustic based on kenaf's fibre," *Materiales de Construccion*, vol. 60, no. 299, pp. 133–143, 2010.

[2] R. J. A. Vieira, *Development of panels manufactured from coconut fibers for noise control of indoors [M.S. thesis]*, Federal University of Pará, Belém, PA, Brazil, 2008.

[3] R. C. Guedes, *Design and Building of a scale model reverberant chamber for acoustic characterization of sound absorbing materials [M.S. thesis]*, Federal University of Pará, Belém, PA, Brazil, 2007.

[4] L. P. Bastos, "Noise Control of generator installations: a case study," Work of Conclusion of Course, Federal University of Pará, Belém, PA, Brazil, 2007.

[5] M. P. A. Mafra, "Development of infrastructure for characterization and analysis of acoustic panels," Work of Conclusion of Course, Federal University of Pará, Belém, PA, Brazil, 2004.

[6] L. P. Bastos and G. S. V. Melo, "Acoustic performance assessment of panels manufactured from vegetable fibers," in *Proceedings of the 39th International Congress and Exposition on Noise Control Engineering (INTER-NOISE '10)*, Lisbon, Portugal, 2010.

[7] L. P. Bastos, *Development and Acoustic Characterization of unifiber, multi-fiber and mixed panels manufactured from vegetable fibers [M.S. thesis]*, Federal University of Pará, Belém, PA, Brazil, 2009.

[8] A. Pereira, L. Godinho, and L. Morais, "The acoustic behavior of concrete resonators incorporating absorbing materials," *Noise Control Engineering Journal*, vol. 58, no. 1, pp. 27–34, 2010.

[9] T. A. Kapulskis, R. C. de Jesus, and L. H. I. Mei, "Chemical modification of coconut and sisal fibers to improve their interfacial interactions with biodegradable polymer matrices," in *Proceedings of the Brazilian Congress of Chemical Engineering Scientific Initiation*, Campinas, Brazil, 2003.

[10] J. O. Morassi, "Natural fibers: general aspects and application in automotive industry," in *Proceedings of the Brazilian Congress of Materials Science and Engineering*, São Paulo, Brazil, 1994.

[11] F. A. Suinaga et al., *Sisal Cultivation in the Semi-Arid Northeast of Brazil*, EMBRAPA, Campina Grande, Brazil, 2006.

[12] N. E. M Beltrão, *Sisal Agribusiness in Brazil*, EMBRAPA, Brasília, Brazil, 1999.

[13] DIN 75200, *Determination of Burning Behavior of Interior Materials in Motor Vehicles*, German Institute for Standardization, Berlin, Germany, 1980.

[14] ISO 3795, *Road Vehicles—Determination of Burning Behavior of Interior Materials for Motor Vehicles*, International Organization for Standardization, Geneva, Switzerland, 1976.

[15] FMVSS 302, *Flammability of Interior Materials*, Federal Motor Vehicle Safety Standards, United States, 1999.

[16] ABNT, *Vehicle Seat from Coconut Fiber*, Brazilian Association of Technical Standards, Rio de Janeiro, Brazil, 1996.

[17] S. N. Y. Gerges, *Noise: Fundaments and Control*, Florianópolis, Brazil, 2000.

[18] ISO 354, *Acoustics—Measurements of Sound Absorption in a Reverberation Room*, International Organization for Standardization, Geneva, Switzerland, 1999.