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DEVELOPMENT OF SUSTAINABLE SOUND ABSORBING PANELS MADE OF JUTE FIBERS

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ABSTRACT

This paper presents an optimization study of sustainable sound-absorbing panels made of jute fiber, developed for two different applications: the first, with a thickness of 40 mm, is optimized for wall mounting, while the second consists of a 20 mm thick panel designed for suspended ceiling installations with an air cavity. The design process began with an experimental study of the acoustic performance of loose jute fibers, with the objective of achieving Class A performance ($\alpha_w \geq 0.90$) according to ISO 11654. This study was conducted in collaboration with the Danish company Hubbub ApS.

Keywords: *acoustic optimization, sound absorption, jute fibers, natural fibers, sustainable material.*

1. INTRODUCTION

In recent years, the development of sustainable sound-absorbing materials has gained significant interest due to global CO_2 emission reduction targets. Natural and recycled fibers, which find applications both in building construction and industrial noise control engineering, may represent a more sustainable solution for thermal and sound insulation compared to traditional synthetic fibrous materials. While a knowledge gap still exists between traditional synthetic fibers, which have been studied for over fifty years, and natural fibers, an extensive body of literature is now available on fibrous materials of plant origin, such as hemp, wood fibers, and coconut fibers [1][2].

However, unlike traditional fibrous materials, whose acoustic performance can be optimized through the manufacturing process, the physical characteristics of natural fibers cannot be precisely engineered and generally exhibit significant variability in diameter, distribution, and orientation; factors that strongly affect their acoustic performance. Therefore, the acoustic optimization of sound-absorbing products made from plant-based fibers must consider and fine-tune other parameters that play a fundamental role in the acoustic behavior of the fibrous material and strongly affect its overall performance.

The present project was promoted by the company Hubbub ApS to develop fully natural indoor sound-absorbing panels, including both the fibers, the binder that provides structural cohesion, and the aesthetic covering.

2. MATERIALS AND METHODS

The aim of this study was to develop two jute fiber-based sound-absorbing panels for indoor environments: a thicker panel (40 mm) for wall applications and a thinner panel (20 mm) for suspended ceilings with an air cavity. The panels were manufactured in India using jute fibers and natural latex as a binder. The jute fibers were obtained without the use of chemicals from plants of the *Corchorus Capsularis species*, belonging to the *Malvaceae family*, which are abundant in the monsoon regions of the East. The production process, which employs natural latex as a binder, results in a panel that is 100% biodegradable.

The Johnson-Champoux-Allard (JCA) [3][4] equivalent dissipative fluid model was employed for the acoustic design

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and optimization process of the two panels. The transport parameters, required as input data for implementing the JCA model, were determined through an inverse characterization approach, based on the experimental measurement of the normal incidence sound absorption coefficient on a small quantity of loose fibers (**Figure 1**), progressively compressed to test different densities. A variation of the sample density ρ implies a change in the material's open-cell porosity ϕ, which can be evaluated from the density of the solid skeleton ρ_s as:

$$\phi = 1 - \frac{\rho}{\rho_s} \tag{1}$$

The airflow resistivity σ can be related to the material porosity ϕ and to the effective radius r_e of the equivalent monodisperse fibrous medium:

$$\sigma = \frac{\frac{\eta}{(2r_e)^2} \times \sqrt{1-(1-\phi)}}{0.21\left(\frac{0.71}{1-\phi} - 3\sqrt{\frac{0.71}{1-\phi}} + 3 - \sqrt{\frac{1-\phi}{0.71}}\right)} \tag{2}$$

Analytical equations were used to express the remaining three transport parameters – tortuosity α_∞, viscous and thermal characteristics lengths Λ, and Λ' – either as a function of the porosity ϕ or the effective radius r_e:

$$\alpha_\infty = \left(\frac{1}{\phi}\right)^{0.9574} \tag{3}$$

$$\Lambda = A_1 r_e (1-\phi)^{-A_2} \tag{4}$$

$$\Lambda' = A_3 r_e (1-\phi)^{-A_4} \tag{5}$$

The effective radius r_e and the unknown coefficients A_i were determined through a minimization procedure, described in detail in reference [5], based on the experimental results of the normal incidence sound absorption coefficient, measured at different combinations of thickness and density according to the ISO 10543-2 standard. This approach allowed us to correlate variations in transport parameters with changes in material density. Considering these density-functions for the transport parameters used as input in a JCA model, along with the diffuse field assumption and the finite-size correction method proposed by Rhazi et al. [6], the panels' thickness and density were optimized. The optimization process involved evaluating different combinations of thickness, density, and air cavity, based on predictions of the random incidence sound absorption coefficient, which represents the acoustic performance measurable in a reverberation chamber according to the ISO 354 standard. The optimization target, requested by Hubbub ApS, was to develop two panels capable of achieving Class A performance ($\alpha_w \geq 0.90$) according to ISO 11654. The entire process was experimentally validated at the end of the design phase on 10.8 m^2 of panels, specifically produced in accordance with the optimization results, tested in a reverberation chamber.

Figure 1. Loose jute fibers and their installation in the plane wave impedance tube.

3. EXPERIMENTAL RESULTS

The experimental normal incidence absorption coefficients measured on loose fibers at different combinations of thickness and density are shown **Figure 2**.

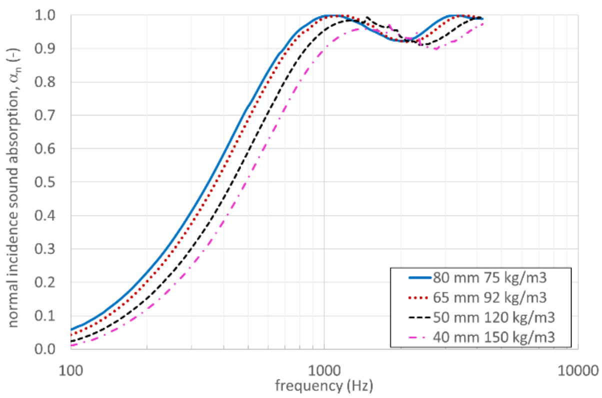

Figure 2. Normal incidence sound absorption: experimental measurements on loose fibers for different combinations of thickness and density.

The loose fibers were compressed from 80 mm to 40 mm, enabling the experimental measurement of densities within the range of 75 – 150 kg/m^3. The five transport parameters – including porosity, airflow resistivity, tortuosity, and the characteristic viscous and thermal lengths – were determined as a function of material density, as described in the previous paragraph. **Table 1** presents the values of these parameters for densities ranging from 120 to 240 kg/m^3.

A comparison between the experimentally investigated densities and the values for which the transport parameters were estimated suggests that the applicability of the optimization approach extends across the experimental interval. However, for values outside the investigated range, a higher degree of uncertainty should be expected. Since the target performance was expressed in terms of average sound absorption α_w, the random incidence sound absorption coefficients were computed from the density-dependent transport parameters and considering a finite-size correction for a 10.8 m² surface. The results are shown in **Figure 4**.

Table 1. Physical parameter values derived from measurements on loose fibers as a function of density.

ρ [kg/m³]	*ϕ [-]*	*σ [kNs/m⁴]*	*α∞ [-]*	*Λ [μm]*	*Λ′ [μm]*
120	0.91	15.9	1.10	65	133
140	0.89	21.1	1.12	50	123
160	0.88	27.3	1.13	39	115
180	0.86	34.8	1.15	32	108
200	0.85	43.7	1.17	27	102
220	0.83	54.3	1.19	23	97
240	0.82	66.8	1.22	19	93

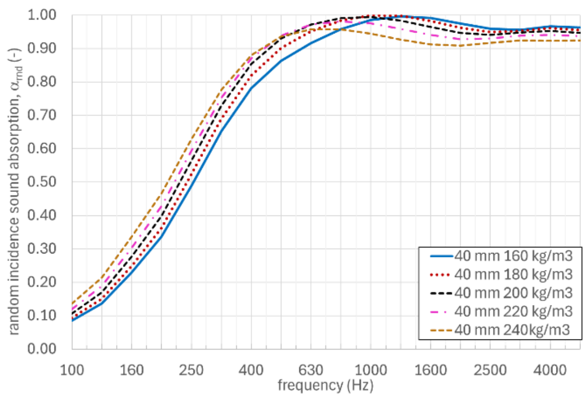

Figure 3. Random incidence sound absorption coefficient: JCA prediction at different densities.

From these results, the average sound absorption coefficient α_w was computed according to ISO 11654 for each density. For instance, **Figure 4** presents the calculated diffuse incidence sound absorption values in octave bands and illustrates the α_w computation procedure for the 40 mm panel at different densities.

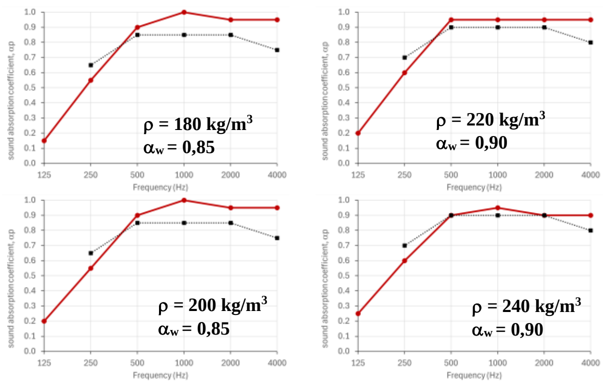

Figure 4. Diffuse incidence sound absorption values in octave bands, computed for the 40 mm panel at different densities, and the α_w reference curve as provided by the ISO 11654.

Table 2 summarizes the results of the optimization approach, presenting the average sound absorption coefficient α_w, which was evaluated from the random incidence sound absorption. This was computed using the transfer matrix method (TMM) at different densities, for two panel configurations: *i)* 40 mm wall-flush mounted, and *ii)* 20 mm ceiling mounted with a 200 mm airgap.

Table 2. Calculated α_w values as a function of panel density for wall-mounted and suspended ceiling configurations.

Density [kg/m³]	***160***	***180***	***200***	***220***	***240***
α_w *wall- mounted*	0.80	0.85	0.85	0.90	0.90
Density [kg/m³]	***120***	***140***	***160***	***180***	***200***
α_w *ceiling-mounted*	0.80	0.85	0.90	0.90	0.90

The performance target for Class A sound absorption is met for $\alpha_w \geq 0.90$. Therefore, results indicate that for the 40 mm wall-mounted panel, a minimum density of 220 kg/m^3 is required to achieve Class A performance, while for the 20 mm ceiling panel with a 200 mm air cavity, a minimum density of 160 kg/m^3 is necessary. At the end of the analytical optimization phase, for each configuration nine prototype panels measuring 1 m x 1.6 m were produced for experimental testing in a reverberation chamber, according to ISO 354. The experimental results, representing diffuse incidence sound absorption (third-octave bands), are compared with the analytical predictions in **Figure 5**.

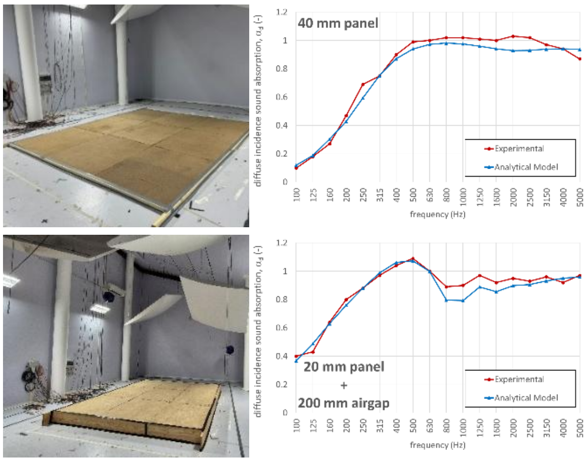

Figure 5. Comparison between experimental results and analytical predictions for 40 mm panels (wall-mounted, density 220 kg/m^3) and 20 mm panels (suspended ceiling with 200 mm air cavity, density 160 kg/m^3).

Reaching an average sound absorption coefficient $\alpha_w = 0.95$, both the configurations were certified with a Class A acoustic performance, thus confirming the predicted results. The analytical model proved to be reliable, accurately approximating the diffuse incidence sound absorption across the entire frequency range. However, it slightly underestimated the acoustic performance for $\alpha_{rnd} > 1.00$, which is physically meaningless and highly dependent on laboratory characteristics.

4. CONCLUSIONS

In this project, two sound-absorbing panels made of jute fiber were developed, both fully biodegradable, thanks to the natural origin of the fibers and the use of a natural latex binder. The adopted acoustic optimization process allowed the development of two Class A panels ($\alpha_w = 0.95$) for both the 40 mm wall-mounted and the 20 mm suspended ceiling solutions.

The proposed methodology demonstrated high reliability while minimizing experimental efforts, as measurements were conducted on a small quantity of fibers using a widely available plane wave impedance tube. These measurements were complemented by a fast analytical processing step, implemented in MATLAB, which enabled the calculation of the physical and acoustic properties of the fibrous material as a function of density.

The adoption of this procedure significantly reduces panel prototyping efforts, cutting costs and development time.

Additional technical information regarding natural-based fibrous panels can be find [7].

5. REFERENCES

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