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MEASUREMENTS OF THE ACOUSTIC PROPERTIES OF MYCELIUM-BASED MATERIALS USING AN IMPEDANCE TUBE

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ABSTRACT

Mycelium-based materials were tested for acoustic purposes. Different fungi were grown on substrates and formed to fit into the available impedance tube for transmission loss (TL) and absorption rate (AR) measurements. Results supported previous findings about mycelia being acoustically appropriate for sound insulation, especially in the spectral region of speech. Absorption rates between 0.1 and 0.6 were measured. Furthermore, thickness appears to be the most important factor. However, large-scale production, design, and lifespan are critical issues, and further experiments are needed to develop industry-level products.

Keywords: *transmission, impedance tube, speech intelligibility, mycelium, sustainability*

1. INTRODUCTION

Acoustic paneling for room acoustic or automotive solutions incorporate various materials. These are generally foams, porous structures with high absorption coefficients allowing for acoustic damping and isolation in many application areas. On the other hand, the use of natural materials can contribute to sustainability. Especially, biodegradability plays a significant role in environment friendly production and recycling. It is the capability of a material to be broken down by living organisms, such as bacteria, fungi, or water molds, and reabsorbed by the natural environment.

1.1 Mycelium as material

The mycelium is a root-like structure of a fungus consisting of a mass of branching, a network of fungal threads or hyphae. Mycelia often grow underground, but can also thrive in other substrates. The fruiting bodies of fungi, such as mushrooms, can sprout from a mycelium.
To create the optimum substrate for culturing and breeding, a temperature of 18-25 Celsius, HEPA-filtered air, and a sequentially operated mixer are needed. An additional cold vaporizer with hydrogen peroxide would be an innovative solution in optimization. In the substrate, the mycelium will grow and penetrate 1-4 weeks in case of constant temperature. For the substrate, different materials can be used - i.e., hemp, sawdust, wood waste, coffee-ground - anything with high cellulose content. The substrate must be pasteurized, free from fungicide materials and other fungus (this happens in heat stress for several hours around 80°C), and dried on air or in a heated oven. In contrast to usual materials, mycelium is different in production, storage and design. Only a few companies offer industry grade and high quality solutions, e.g., by providing pre-mixed substrate and mycelium [1, 2].
Mycelium has an uneven growth, it is inhomogeneous, especially by contrasting surface and internal part. The substrate (which is generally responsible for the mass) produces larger cavities and gaps that are filled by the mycelium. Some strains of fungus have good water solubility, and thus, the liquid can be sprayed over the substrate. For example, the *Ganoderma* fungi can be breed in big tanks under sterile circumstances (Fig.1.).
At the end, high temperature (overheating) is used to stop the growing process. Forming, cutting and designing can be performed before and/or after the heat stress. For example, if the material is to replace wood or plastic, the overheating

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and forming take place in a pneumatic heat press. If the application area is acoustics, a foam-like state without pressing is recommended. Fire, moisture resistance, tension and compression tests are also important for usability [3].

Figure 1. Example of mycelium-based materials of different forms and sizes.

More research is needed to optimize the manufacturing process, especially in larger "industrial" scale in a time- and cost-effective way. Currently, industry-grade production offers a wide range of applications on large scale, especially on the field of packaging [4]. Acoustic paneling is very similar in size and form. Furthermore, on a smaller scale, local production contributes to sustainability (by avoiding long-distance shipping and enabling local recycling), to local employment and individual production.

1.2 Acoustic measurements

The most important material properties to describe acoustic behavior of porous absorbers are tortuosity, porosity, flow resistivity, and surface openness [5, 6]. They can be measured directly with dedicated equipment or indirectly.
There are two main methods to measure acoustic properties (indirect methods). One of them is using a Kundt's tube also known as an impedance tube [7, 8]. The material is located at the one end of a tube, while the other end is closed with a loudspeaker producing a standing wave. Microphones are fixed along the tube, and the acoustic properties can be calculated by the transfer function method. This compares the sound pressure levels as function of frequency. Small sample sizes can be used, but it is assumed to have perpendicular sound incidence, which is usually an invalid assumption in real life environments. The other method is having a reverberant or anechoic room. This is more realistic, but deals with very large sample (and room) sizes.
This paper presents the method of breeding, followed by the acoustic measurement setup to determine the basic acoustic properties. Based on the results, current state and future perspectives will be discussed from the engineering point of view, focusing on the spectral range of speech.

2. MEASUREMENT SETUP

To create the samples, different types of fungal germ were used on different substrates. After 5-6 weeks, six samples were selected for the measurement. Beech wood chip substrate was used for two *Ganoderma* and two *Pleurotus* samples (see Fig.2.). The diameter of the samples shrank from 45 mm to 42 mm after drying, thickness was 36 mm. Two additional *Ganoderma* samples were grown on a mixture of fine beech wood sawdust and hemp junk (thickness only 12 mm). These were then compressed in a heat press, followed by CNC cutting.

Figure 2. Examples of homemade breeding on beech wood chips substrates using *Ganoderma lucidum* and *Pleurotus* in small size for acoustic testing.

In the experiment, the measurement system of the Mecanum company was used. A detailed description of the equipment with a video of the procedure can be found on the homepage [9]. Although the two- and four-microphone methods are the most common, we opted for a three-mic solution (Fig. 3.) [10]. Both absorption and transmission loss could be measured simultaneously. During repeated sessions, all six samples were measured with both sides (flipped) facing the sound source, thus, 12 curves were plotted on AR and TL diagrams, respectively.

Figure 3. The measurement setup with the impedance tube and data acquisition device.

The frequency range was from 115 Hz to 4300 Hz, sufficient for most of transportation noise and speech experiments.

3. RESULTS

Absorption coefficient is measured directly, whilst transmission lost is calculated. In a normal Sound Transmission Loss (TL) test, a sample is placed between two test chambers in the tube. Based on the sound level reduction the material provides and various acoustical characteristics of the test chambers, the TL can be determined. Generally, heavier walls and acoustic barriers have a higher transmission loss than lighter materials.
Figures 4-5 show measurement results of the sound absorption coefficient and transmission loss for all samples on a linear frequency scale. GBSH denotes the thin, GBC denotes the thick *Ganoderma* samples, PBC denotes the *Pleurotus* samples. The numbers and the letter indicates sample number and side.

4. DISCUSSION

There exist only a few products commercially available for acoustic purposes, i.e., the Sinewave panel (diffusor), or the Mogu, based on textile waste substrate with only a thin layer of mycelium on top [1, 2]. As a result, only a few papers are available about acoustic testing, focusing on the role of the substrate mix and density during absorption [5, 11-13]. It was demonstrated that the mycelium performs well in contrasted to conventional materials (plywood, foam, etc.). The measurements were generally between 300 Hz and 4 kHz using road noise for vehicle industry applications. However, this range is also important for building acoustics and speech technology (intelligibility measurements). The main finding is that lower density gives a higher absorption and lower through transmission protection. Denser material results in better through transmission shielding and lower absorption.
In a master thesis, results were presented using two tubes with 100 mm and 29 mm diameter [3]. The upper working frequency for the smaller tube was 6860 Hz, and only 1990 Hz for the larger tube. The measurement was evaluated from 50 to 6400 Hz and 1600 Hz respectively. Results showed good acoustic absorption. Most of the hemp/straw samples performed equally with low effects of thickness and density. Denser and samples with a closed surface showed a shift to the lower spectrum. Increasing density generally improved the absorption until a certain point, and it can contribute to lower fragility as well. Reverberation room results supported the main findings, absorption values were all above 0.8 in the one-third-octave-band 315 Hz and up [3, 14]. Impedance tube tests were not too optimistic; absorption can be even better in reality.
In our measurement, absorption greater than 0.1 can be observed above about 500 Hz, reaching a maximum of about 0.6. There are large differences among the samples and also between the two sides of a sample indicating an inhomogeneous inner structure. Absorption results are noisy below 400 Hz, because the setup was originally optimized for measurements focusing on the 800-3500 Hz frequency range. The results could be improved at lower frequencies by increasing the tube diameter (and with different microphone spacing).
The pressed GBSH samples are more effective at lower frequencies, below 2500 Hz, while the PBC is more linear over the entire range. On the other hand, one PBC sample showed a continuous rise as function of frequency. Large differences are present in the absorption using the same sample reversed, which makes a conclusive evaluation difficult.
TL is a quantification of how much sound energy is prevented from traveling through an acoustic treatment, it is the ratio of the sound energy transmitted through a sample versus the amount of sound energy on the incident side of the material. TL values were calculated from measurement data and show very low level of noise. The thin samples (brown curves) are the least effective, while the thicker samples provide better results. Although there are variations among the samples based on the placement (which side faces the source), thickness seems to be the most important parameter, as expected.

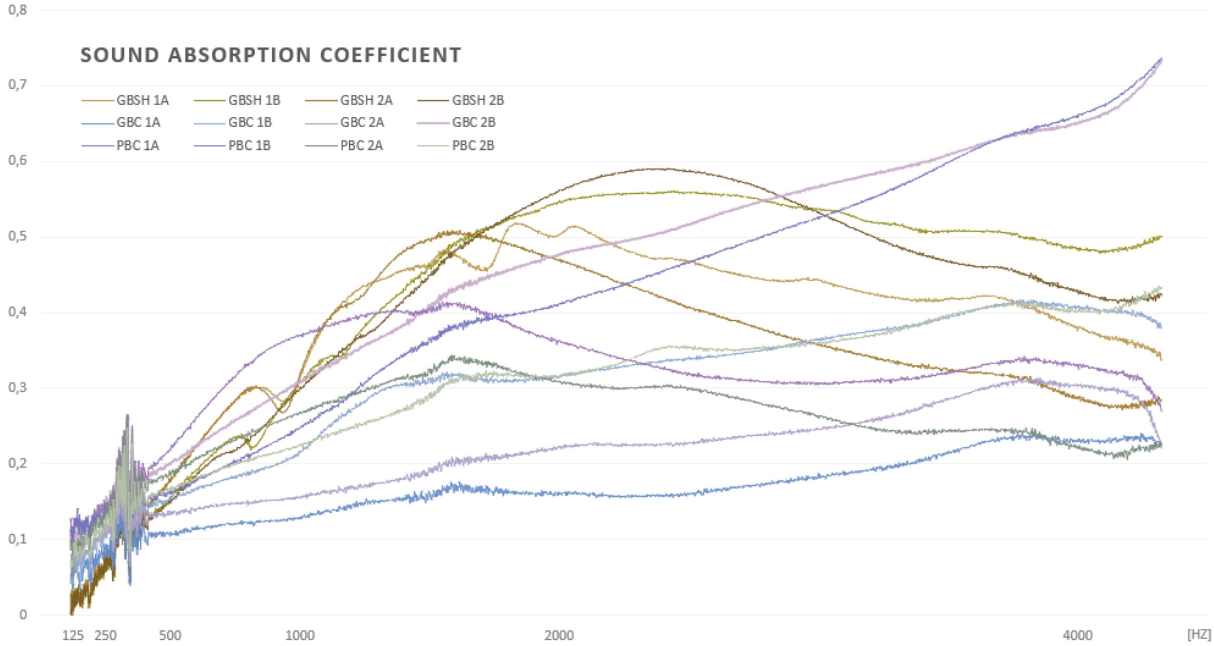

Figure 4. Results of six samples, each with both sides facing the sound source (denoted side A and side B).

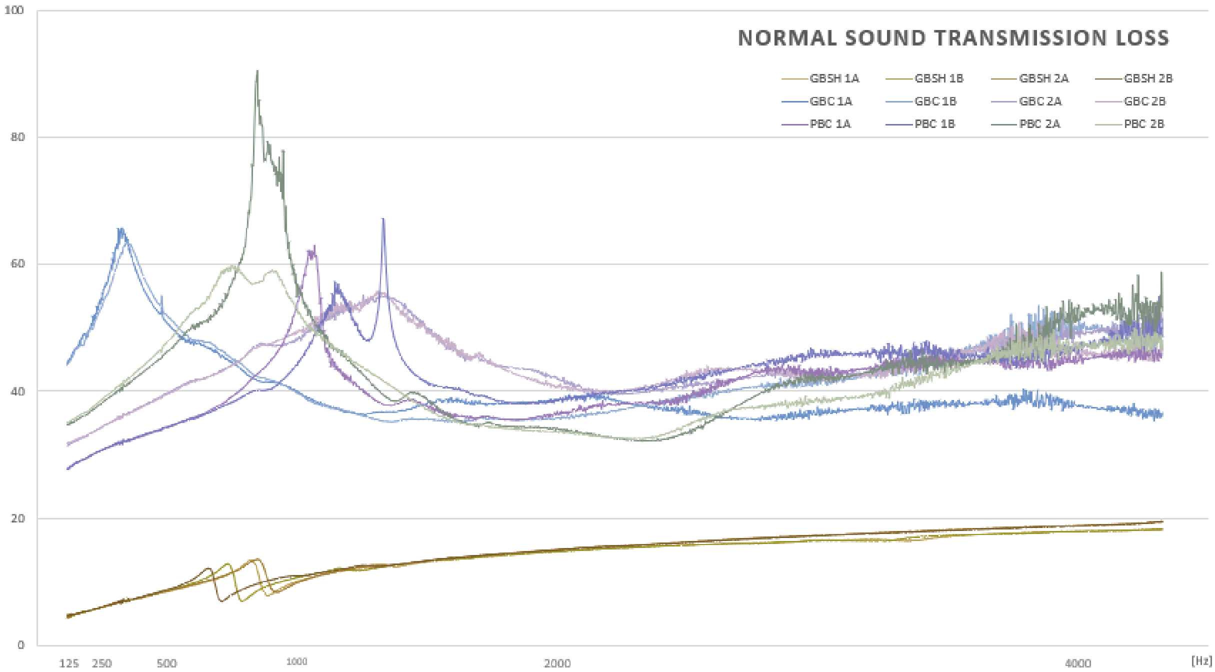

Figure 5. Results of six samples, each with both sides facing the sound source (denoted side A and side B).

4.1 Planting and harvesting

Creating larger size samples and panels takes more time than conventional materials used in sound proofing. Particle size can matter during compression. Using beech saw dust it was shown that reducing the particle size and increasing the compression pressure and/or temperature, results in increasing density that is significant from the point of view of friction [15].
A literature study on material properties shows that acoustic absorption and thermal insulation are suitable functions for this material [16-19]. A designed panel was compared with existing mycelium, other bio-based and more conventional products in terms of acoustics, safety, health, durability, sustainability and price [3]. Balancing acoustic absorption with mechanical properties and connecting the panels to the wall are important issues.

4.2 Future perspectives in sound engineering

Mycelium is a biodegradable material with light weight, good thermal and acoustic properties. On the other hand, samples could be fragile that makes production, design and application (screwing on the wall) difficult [20-23]. Furthermore, the effect of aging is unknown. More research is needed on mechanical properties and optimization, but both building acoustics (speech intelligibility) and automotive industry (traffic noise) could benefit, as the lower frequency range up to 4 kHz can be damped effectively.

5. CONCLUSION

This paper presented impedance tube measurements of acoustic properties of mycelium based materials. Two strains and two different substrates were used for sample sizes with different thickness. Impedance tube measurements were performed for determining the absorption and transmission loss in the 115-4300 Hz range using a 3-microphone method. Differences between the samples showed large variability. Due to the unsymmetrical structure of the samples, measurements were sensitive to the placement of the samples (which side is facing the sound source). Mycelium-based materials can be a good alternative for sound absorbing. Durability (fragility) and lifespan (unknown aging) are the most important problems. Although production is more difficult, sustainability could be a key issue in future developments.

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