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Research paper

An evaluation study of pressure-compressed acoustic absorbers grown on agricultural by-products

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ABSTRACT

This research examines the use of a novel new renewable resource in acoustic absorption applications. The new material being tested is based on a fungi that is grown on semi-hydrophobic agricultural by-product substrates such as cotton burs, switch-grass, rice straw, sorghum stalks, corn stalks and kenaf; to form a light-weight all-natural bio-composite board. The study examines the impact of a new post-processing technique that converts the raw light-weight board into a much higher density compressed board that requires no additional glue or binder. The material traits of interest to this study are the acoustical absorption properties of this new high density variant. The study tested the boards over a range of compressed densities that resulted by increasing the compression force in a laboratory board press with a fixed temperature of 205° Celsius for the following applied pressures {0, 2644, 3051, 3661, 4678 N/m^2} to achieve the following five density levels that were tested, {0.042 (uncompressed), 0.057, 0.086, 0.120, 0.169 g/cc}. Also included in the study were three reference materials {commercial acoustic ceiling tile, a cork flooring under-layment and birch plywood}. The acoustic properties of the material were characterized for acoustic absorption, in reflection and for through-transmission. The results of the study indicate this new class of densified mycelium based boards are a promising bio-based composite alternative for through-transmission acoustic shielding boards. Results show a progressive increase in sound shielding up to 0.087 g/cc after which further increases in density are statistically insignificant. This new material provides an all-natural, sustainable alternative to modern composite boards such as medium density fiber boards, “MDF” and oriented strand boards, “OSB”.

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1. Introduction

This research examines the use of a novel new renewable resource in acoustic absorption applications. The boards produced by this new process require no binding agents and relies solely on the vegetative stage, mycelium, of a fungi in the phylum of Basidiomycetes, to bind the boards together, (Holt et al., 2012). Further sustainability is derived by growing the fungi on semi-hydrophobic substrates such as cotton by-products, leaves, sticks and cotton burs and other low cost agricultural by-products such as switch-grass, rice straw, sorghum stalks, cotton burs, kenaf and corn stalks, (Holt et al., 2009, 2012). By growing the mycelium around agricultural by-products, the by-products provide food and a base structure for the fungi which in turn provides the binder to form the agricultural substrates into molded shapes that are low cost and suitable for such applications as packing material for shipping as well as construction insulation, (Alma et al., 2005; Holt et al., 2012). The fungi’s mycelium provides structural binding properties for the mixture through the growth of interconnecting fibrous threads that form chitin and Beta Glucan based structural oligosaccharides that bind the bulk agricultural materials into a composite board or complex shape capable of replacing non-renewable resource materials such as Styrofoam and poly-urethane foams (Holt et al., 2012). The new variant we are examining in this paper involves adding one additional step; high temperature compression to the boards to form a new variant that results in a much denser board that is suitable for furniture making and other applications that are traditionally fulfilled by oriented strand board, “OSB” and medium fiber density boards, “MDF”. This new, higher density form of the mycelium

Abbreviations: ISO, International Organization for Standardization; Hz, hertz.

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boards is in contrast to the original low-density boards, previously reported on by the authors, Pelletier et al. (2013).

Noting that through-transmission acoustic absorption is largely dictated by density; of interest is how well these new boards will behave for through-transmission acoustical shielding. The objective of this investigation was to examine a typical board substrate, across a range of compressed densities, to gain insight into how the density influences the acoustical shielding properties.

2. Materials and methods

2.1. Mycelium based panels

The test subjects were generated by growing fungi, of the phylum of Basidiomycetes, on top of agricultural by-products that were fiberized to different size ratios by means of either a hammer or attrition mill followed by screening to exclude particles less than 0.853 mm, (#20 mesh screen).

The mycelium was grown onto the by-products via the process reported by Holt et al. (2012). The main process steps were;

- fiberizing agricultural by-products,
- steam processing the fiberized agricultural by-products to render mold spores inert,
- inoculating the steam processed fibers with Basidiomycetes based fungi,
- placing the inoculated fibers into 16 × 16 cm molds at a depth sufficient to generate a finished nominal thickness of 2.5 cm.
- growing fungi on the fiberized by-products in a controlled environment chamber under dark warm humid conditions for 4–6 days to yield a low density fiber board, bound only with the fungi's mycelium substrate.

This process results in a low-density board, suitable for various applications such as light-weight acoustical absorbers, fishing floats and packaging materials, Holt et al. (2012).

To transform these low-density boards in the new high-density boards, reported on herein, an additional post-processing step is required.

- The densification process starts with low density boards that are then heat treated for 10 min at 100° Celsius at varying elevated pressures. To gain a range of densities for this evaluation study; the boards were pressed at the following pressures {0, "uncompressed", 2644, 3051, 3661, 4678 N/m^2} to achieve 5 levels of densities {0.042 (uncompressed), 0.057, 0.086, 0.120, 0.169 g/cc}. Of note is that, as similar to the low-density boards, no glue or binder was added in the construction of the high-density boards. The only binder is from the natural mycelium and the chitinous polymer that is deposited by the fungi's natural growth, Holt et al. (2012); in the formation of the low-density boards. As such, the only step in creating the high-density boards was to simply subject the low-density mycelium bound boards to a high pressure and heat treatment.

2.2. Acoustic testing

While noting that most acoustic testing is currently performed via the two-microphone impedance-tube transfer-function method, ISO standard 10534-2 (1998), of pertinence is that the transition away from the old ISO 10534-1 (1996) standard was due primarily to the increase in ease and speed of testing rather than an improvement in accuracy. Furthermore, our experience with the two-microphone method yielded less than satisfactory results, in comparison to the original ISO 10534-1 method; which we also evaluated. So all testing for acoustical reflection was performed utilizing the more accurate original ISO 10534-1 standard method. Application details for the 10534-1 and 10534-1 methods can be found in Beranek (1988, 1996), McIntosh et al. (1990) and Rossing (2007), Cox and D'Antonio (2009), as well as in the ISO 10534-1 and ISO 10534-2 and ASTM E-1050 standards. The primary subject of interest for this study is to assess the acoustical through-transmission properties. A literature search for suitable test standards and methods revealed a four-microphone ASTM standard method, that was based upon the Song and Bolton (2000), transfer matrix approach. Of note; the initial tests were conducted utilizing this method; unfortunately, results were poor and further investigation into the literature revealed that the ISO has yet to adopt this method as a standard. When looking into possible reasons for their lack of adoption; the paper from Salissou and Panneton (2010); sheds some light as they reported on an experimental comparison between several methods for measuring through-transmission, of which one was the four microphone method. Given this report, along with the amount of activity in the research community on through transmission acoustical methods research; it appears that acoustical through transmission measurements is still an active area of research (Iwase et al., 1998; Song and Bolton, 2000; Allard and Atalla, 2009; Doutres et al., 2010; Salissou and Panneton, 2010). In the Salissou and Panneton paper they noted high noise from the four microphone method, especially at lower frequencies, and suggested a higher accuracy method based upon a modification of the three microphone technique originally developed by Iwase et al. (1998). They noted their modification was designed specifically to streamline testing and speed of the Iwase method; not improve the accuracy. The report by Wolkesson (2013), also examined both the Iwase method and the modified Iwase method and reported the original Iwase method provided the highest accuracy between the two variations. Following the lead from these reported results; our research opted to follow the original Iwase three-microphone method to obtain the through-transmission measurements for this research. Other notable support in the literature regarding reports of significant measurement errors with the four microphone method can be traced to the difficulty in providing a suitable anechoic termination on the far end of the tube, as noted by Song and Bolton (2000); Cox and D'Antonio (2009). All of these sources reported experiences coincided with the author's experiences with the four microphone method, thereby providing additional support to the selection of the Iwase method for the through-transmission measurements, conducted for this research effort.

The equipment utilized in the impedance testing was:

- Hewlett Packard, Santa Clara CA, 33120A signal generator,
- Agilent, Santa Clara CA, DSO1024 digital oscilloscope,
- Peavey, Meridian MS, Power Amplifier IPR-1600 DSP,
- Crowne Audio, Elkhart IN, 15 cm diameter speaker,
- Behringer, Behringer City China, two cascaded equalizers, to provide a full range of attenuation of +/− 24dBu,
- Earth instrument microphones,
- Extech Instruments, Nashua NH, NIST traceable Sound Level Meter 407732,
- Extech Instruments, Nashua NH, NIST traceable Piston Sound Level Calibrator 407722,
- TC20 Earthworks measurement microphone (mounted in the end-reflection plate for through-transmission characterization),
- FMR Audio, Austin TX, RNP 8380; microphone pre-amplifier and phantom voltage source (two units; one for each microphone),
- PCB Piezotronics, Depew NY, 426B03 pre-polarized condenser microphone (used on the traveling trolley, for inside the tube