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An evaluation study of mycelium based acoustic absorbers grown on agricultural by-product substrates

M.G. Pelletier[a,*], G.A. Holt[a], J.D. Wanjura[a], E. Bayer[b], G. McIntyre[b]

[a] USDA-ARS, Cotton Production & Processing Research Unit, 1604 E. FM 1294, Lubbock, TX 79403, USA
[b] Ecovative Design, 70 Cohoes Avenue, Green Island, NY 12183, USA

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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 switch-grass, rice straw, sorghum stalks, flax shive, kenaf and hemp. The various substrates were tested as this novel composite is limited in the control over density, with the main control being the selection of the constituent parts. The testing of the material for use in acoustics utilized an impedance tube and measured the standing wave ratios in accordance to ISO standard 10534-1. The results of the study show the mycelium based boards are a promising bio-based composite alternative to standard traditional foam insulation board. Results suggest an optimal performance at the key automotive road noise frequency of 1000 Hz. A further advantage provided by this new material is that it can be produced economically in comparison to the traditional petroleum based foams with the further advantage of bio-degradation when the product is disposed of at its end-of-life use. Based upon this work, future research is planned to examine this novel new composite in other acoustic applications where shape modifications can further enhance the performance.

1. Introduction

This research examines the use of a novel new renewable resource in acoustic absorption applications. The material under test is based on vegetative stage, mycelium, of a fungi in the phylum of Basidiomycetes, which is grown 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, flax shive, kenaf and hemp. 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 by-products 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) in a manner that is competitive to more traditional particle board composites built using rice-straw and other agricultural by-products such as composites as reported by Yang et al. (2003) and Sampathrajan et al. (1991). The 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.

A new application, for sound absorption panels, of this novel composite material is being examined in this study for use in the application of sound absorption panels. One proposed applications of interest for such panels are the potential for use in automotive sound absorption panels as well as more typical construction installations for acoustic noise damping. As automotive applications are one of the primary motivators for this investigation; testing was conducted to explore the sound absorption properties in the range from 300 Hz through to 4000 Hz as that range is the dominant road-noise spectrum of interest.

Of note is that the use of mycelium for a binder limits control over density, whereby the sound properties of these proposed boards are derived by the selection of the composite's constituent components. Thus, the main variable of interest to a producer, is the selection of the available substrates. However, it should also be noted that sizing of the particles also plays a role as the finer grinds limits the available oxygen to the mycelium and results in a denser board with less penetration of the mycelium fibers into the depths of the board. Thus, the grind of the material is expected to be a factor as acoustic properties are known to be influenced by the porosity, tortuosity, flow resistivity and the characteristics lengths (Takahashi and Tanaka, 2002; Park and Palumbo,

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

* Corresponding author. Tel.: +1 806 746 5353; fax: +1 806 746 5028.
E-mail addresses: mathew.pelletier@ars.usda.gov, greg.holt@ars.usda.gov (M.G. Pelletier).

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2009). Noting however that this study is the first foray into the potential for acoustic absorption panels for this novel new material, the investigation was limited to a broad survey of various mixtures of available agricultural by-product residues. The investigation examined numerous mixes comprising a wide variety of different agricultural by-products to determine the best mixtures for this application. While noting that most acoustic testing is currently performed via the two-microphone impedance-tube transfer-function method, ISO standard 10534-2 (1998), we note 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. As accuracy was a key criteria for our testing, the testing for this study utilized the more accurate original ISO standard 10534-1 (1996), with further application details found in Beranek (1988, 1996), McIntosh et al. (1990) and Rossing (2007). In ascertaining which frequencies the panels should be tested for, a literature search revealed that the dominant road noise, based on a −3 dB 1/2 power cut-off, typically ranges from 500 to 1600 Hz for large trucks and over a narrower region from 800 to 1600 Hz for typical consumer grade automobiles (Mak et al., 2012; Sandberg, 2001, 2003; Sandberg and Ejsmont, 2002; Soto et al., 1994). Noting from Jarzinski (1990) and Jiang et al. (2009) that sound vibration absorption is affected by particle sizes and polymer properties, a wide range of agricultural by-products were testing during the course of this research ranging from cotton, kenaf, sorghum, hemp, rice and switch grass. The specific objectives of this research were to determine the sound absorption characteristics of the composite formed by the interaction of agricultural by-products with mycelium to produce acoustic absorption panels.

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 screanning to exclude particles less than 0.853 mm (#20 mesh screen). The agricultural by-products were tested as both sole constituents and in 50–50% mixtures ratios comprised of the following {Rice Straw, Hemp Pith, Kenaf Fiber, Switch Grass, Sorghum Fiber, Cotton Bur Fiber and Flax Shive}.

The mycelium was grown onto the by-products via the process reported by Holt et al. (2012), which consisted of the main processing steps of:

- fiberized agricultural by-products,
- steam processing the fiberized agricultural by-products to render mold spores inert,
- inoculating the stream processed fibers with Basidiomycetes based fungi,
- placing the inoculated fibers into 16 cm × 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.

2.2. Acoustic testing

In developing the requisite impedance tube apparatus for the acoustic testing, it was observed that while the distance between maxima's as well as mimina locations adhered to theoretically expected distances; a significant offset was observed between the minima locations to the maxima locations that were likely occurring due to non-linearity's in the system. To avoid this non-linearity, the testing protocol selected for this study was the previous acoustic impedance tube testing standard, ISO 10534-1 (1996), due to its inherent accuracy advantage over the later ISO standard, as it provides a direct measure in place of a 2 point extrapolation via a model based estimate. Of particular note in the development of the testing protocol was the reference in the literature, ASTM E1050 (2010) which discuses attenuation along the length of the tube that attenuates the maxima the further away from the reflection plug. To address this concern, the magnitude of the attenuation was tested to obtain a correction factor, alpha, by measuring the pressure amplitude as a function of the distance along the tube to provide the tube attenuation coefficient. This testing however revealed that if the maxima peaks were limited to the first or second peak closest peaks to the reflected specimen, it was found that the attenuation was minimal across the frequency range of interest for our tube, and could be assumed to be negligible for the purposes of this testing. As part of the validation testing of this assumption, a plain brass plug, providing a pure 99.9% reflection, was tested for reflection coefficient at both the first and second maxima peaks which produced results that were found to be within less than 1% deviation between the peaks across the frequency range of interest. Given this, the protocol for this study followed the ISO 10534-1 (1996) recommendation for measuring, with respect the reflection specimen, the first pressure minima, followed by the next closest pressure maxima.

The equipment utilized in the construction of the impedance testing was[1]:

- 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 ±24 dBu.
- Analog Devices, Norwood, MA, Electret microphone amplifier provided by Analog Devices integrated circuit: SSM2166.
- Electret phantom power was set to 3.3 V.
- Olympus America, Center Valley, PA, Electret microphone.
- Extech Instruments, Nashua, NH, NIST traceable Sound Level Meter 407732.
- Extech Instruments, Nashua, NH, NIST traceable Piston Sound Level Calibrator 407722.
- Impedance tube was constructed out of PVC schedule 80 with an inner diameter of 4.76 cm.
- The reflection plug was machined to a tight, but movable, fit out of 3 deep solid brass.
- Samples were attached to the brass plug via a hot glue developed for use with plastics, ceramics and metals, model #9-80459 by Craftsman, Sears Holding Co., Hoffman Estates, IL.
- Relative humidity for each test was obtained with a National Institute of Standards and Technology, "NIST", traceable humidity sensor manufactured by the Control Company, Friendswood, TX, an ISO 17025 Calibration Lab that holds an A2LA Accreditation. We would also note that we verified the Control Company's humidity sensor against a high-end General Eastern chilled dewpoint humidity sensor model Hygro-M2.

2.3. Experimental methods

The experimental test was conducted per standard method supplied in ISO 10534-1 with the following added necessary procedures that are not covered in the standard method protocol:

- Initial system configuration was developed by placing the microphone in free space on a mount immediately in front of the speaker and adjusting the two cascaded equalizers until