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1aAAb5. Development of an ecological, smooth, unperforated sound absorptive material

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Material selection for acoustically comfortable environments is a very important issue especially for rooms for speech and music as well as for large volumes like shopping centers and foyers. Energy efficient and sustainable materials are devised in construction industry for healthy environments; hence, ecological sound absorbing materials for acoustically sensitive environments are being preferred to get credits for international certification procedures like LEED and BREAM. Nevertheless, most of the acoustic materials in construction industry are perforated with mineral wool based absorption materials behind and have great effects on design of the building environments. Architects usually prefer seamless imperforated materials to avoid changes in the appearance of design environments for acoustical requirements. This article is about development of an ecological imperforated acoustical material which is made of reed and pumice stone. Different layers of pumice stone and reed glued with an ecological binder are evaluated according to frequency range they are effective and an optimization is done to create an acoustic material that is effective especially in medium frequencies. Acoustical performance of the material is justified with measurements of sound absorption coefficient in Kundt Tube.

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INTRODUCTION

Sustainability and ecology are very hot topics in architecture recently. Buildings are designed and constructed according to procedures like LEED and BREAM to get certified as energy efficient. Comfortable acoustical conditions in buildings are one of the necessities to provide livable environments in modern times. On the other hand, most of sound absorptive materials used to provide acoustical requirements in construction industry are perforated with mineral wool based sound absorptive materials behind and the ones that have seamless surfaces are very high in price. Architects do not prefer to change the appearance of designed environments owing to acoustical requirements using perforated materials. Besides, mineral wool based materials that are used as backing material with sound absorptive materials are synthetic fibers that cause emission of carbon dioxide, methane and nitrous oxide in production phase which affects their carbon footprint [1]. In this paper, a preliminary study on acoustically efficient, ecologic and unperforated material made of reed and two layers of pumice stone with an appropriate binder is developed and the results of the sound absorption characteristics of the material is justified with Kundt Tube.

Porous sound absorptive materials can be classified is three main groups: cellular, granular and fibrous according to their microscopic configurations [1]. In this study cellular, granular and fibrous sound absorptive materials are used as layers of a composite sound absorber. Resulting sound absorption characteristics are investigated by measurements in a standing wave tube.

MATERIALS

Reed

FIGURE 1. Reed

Reed is an easy to find material that has been used for centuries in construction but its acoustical properties are being discovered recently. In this study fibrous reeds are used as a backing material like mineral wool that is used behind perforated materials for absorption. Reed can be described as a biomass material; living or recently dead biological material that is sustainable as they form a part of normal carbon and nitrogen cycle, only renewable energy is used for production which makes it carbon neutral [2]. Although thicker reeds can be classified as non-fibrous material, the reed used in this study is a thin type of reed (2mm to 5mm diameter) that can be classified as fibrous material. Reed has slit like cavities different from most of other fibrous materials that have small pores like cotton and wool which makes it a good absorptive material at low frequencies[3]. Investigations about reed's sound absorption properties by Oldham et al.(2011) conducted both with impedance tube and reverberation room methods indicated the results are promising. Besides, reed is resistant to fungal attacks [2,4]. To sum up, reed is organic, cheap, has excellent thermal and structural behavior, has low impact on environment, water resistant and has hollow tubes with knots which is a promising configuration for acoustical needs involving sound absorption [5].

Pumice Stone

FIGURE 2. Pumice Stone and Pumice Powder

Pumice stone is a volcanic, lightweight, porous stone with great isolation properties, pozzolanic and resistant to atmospheric conditions [6]. Pumice stone has been used in construction for centuries and its good acoustical properties are known for a long time. In this study, different layers of pumice stone are configured to get effective results in terms of sound absorption. The first layer of pumice stone powder is laid as a cellular membrane with very thin thickness about 1-2mm so that it permits sound wave to go through itself although it appears as unperforated. Behind this layer, larger particles of pumice stone, about 5-10mm granules in diameter are used as a granular absorptive medium.

Lime Stone

FIGURE 3. Lime Stone

The binder is a very important ingredient for a sound absorptive material as it affects the porosity [3]. Cement is a commonly used binder element in construction but its carbon footprint is very high at its manufacturing stage as limestone, sand and other metal ores are heated up to 1500 °C with coal to form clinker [7]. The objective set in the study is to develop an ecological material. This makes selection of the binder very critical and significant in the sense that it should possess good acoustical properties, require low production energy and not contain greenhouse gases. There are many natural binders available such as resin, flour and particle board [8]. However, their use in construction is rather limited. Consequently, as a preliminary experiment, lime is used as the binder in this study. Lime is more acceptable binder as less energy is used to produce a binder from row limestone. In research by Gle et al. (2011), two lime-based and one cement-based binders are used to form a hemp concrete for comparison in terms of their sound absorptive properties. It is proved that hemp concrete with lime as the binder has higher sound absorption characteristics.

The Configuration of the Materials

FIGURE 4. The Layer of Configurations: Reed, Pumice Powder&Lime, Pumice Stone& Lime

The objective of this study is to develop a sound absorptive material with a fine finish. Therefore, the first layer is a plane surface made of pumice powder and limestone as a binder. The limestone is extinguished with water and in proportions of 2/3 of pumice powder and 1/3 lime is mixed and 2 mm thick plane layer is produced in 100mm and 28mm diameters for preparation of test specimens. The raw granules of pumice stone is also mixed with limestone in the same proportions of first layer and the surfaces are dried at a temperature of approximately 20 °C and 35% relative humidity for 3 days. Lastly, the layers of reed which are 2cm to 10 cm long and 2mm to 5mm in diameter are laid perpendicular to the direction of plane wave in 4cm thickness behind pumice layers. In addition, a plane wood surface to serve as a rigid backing is introduced to configuration. The temperature and relative humidity as well as the pumice and lime mixture percentages are not for a specific condition as in this preliminary study the objective is just to discover the extent the configuration of these layers can work as a sound absorptive material.

IMPEDANCE TUBE MEASUREMENT

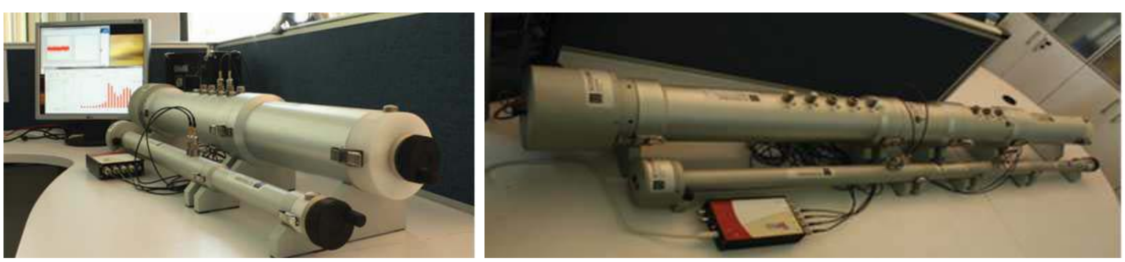


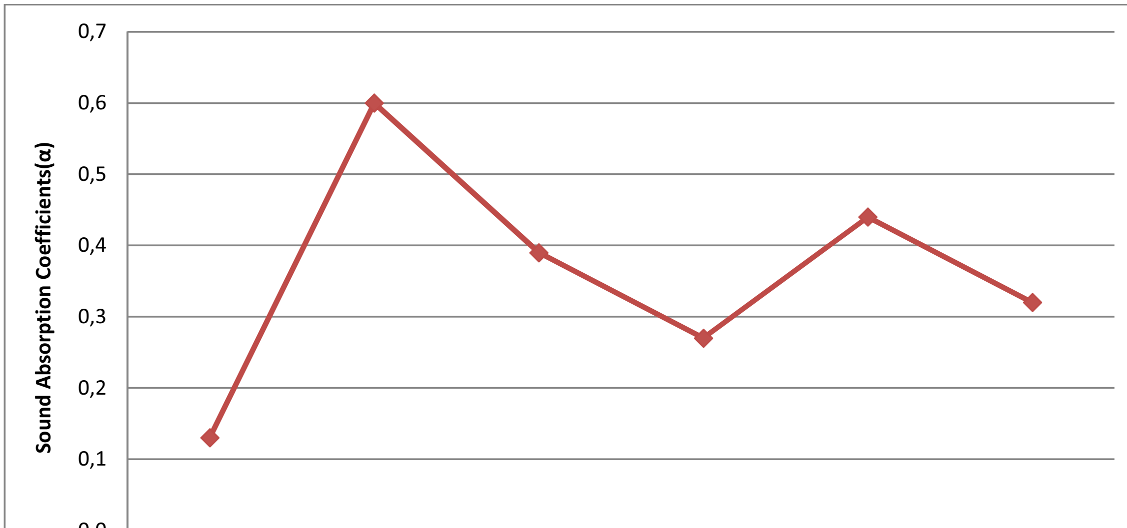
FIGURE 5. Kundt Tube

Measurement methods of absorption coefficients of materials vary according to frequencies and applications. These can be listed as the impedance tube method, ultrasound method, extended surface method, guard tube method and reverberant room method [10]. The most commonly used methods are reverberant room method and impedance tube method. The impedance tube method is more practical as it requires smaller test samples. However, being far from practical uses, the impedance tube method is limited to normal incidence of sound waves as the absorption varies with the angle of incidence. On the other hand, it is possible to measure surface impedance characteristics of test materials as a function of frequency. This information can also be used in developing mathematical models of materials. Nevertheless, the disadvantages are that only sound at normal incidence is measured and uncertainties may arise when measuring heterogeneous materials like samples taken from different regions of a large sample. In this study, the impedance tube employing two microphone transfer function method is used according to ISO 10534-2 and ASTM E1050-98 international standards. Samples in two different diameters are measured in 28mm-diameter impedance tube (S.C.S.9020B) which measures the absorption coefficients at high frequencies (800 Hz – 6300 Hz), and in 100mm S.C.S.9020B impedance tube for low frequencies (50 Hz – 1200 Hz), respectively. Both tubes are integrated with 01dB-dB4 AREVA data acquisition board and an absorption coefficient chart in 1/3 octave bands center frequencies between 125Hz to 5000 Hz is produced. In this study the pores of the samples are homogeneous, but yet the diameter of samples (28mm) for high frequencies is very small, so there are uncertainties expected in high frequency range. On the lower frequency side, the theory employs plane wave propagation. For frequencies less than 125 Hz, plane wave production gets more difficult and repeatability of experiments is hampered. Hence, the frequency ranges between 125Hz to 4000Hz are taken into account.

RESULTS

The measurements are made with three layers (pumice powder & lime (2mm)+pumice stone & lime (10mm)+reed(40mm)) and two layers (pumice powder & lime (2mm)+reed(40mm)) configurations.

The impedance tube measurement results for the three-layer configuration are illustrated in Figure 6. It can be seen that the configuration has fairly good sound absorption properties between 250Hz and 500 Hz and around 3000 Hz. The absorption coefficients at medium frequencies (500 Hz and 1000 Hz) lie around 0.33. This result is promising for a fine finish material in terms of acoustics but it still lacks much needed absorption capacity for the speech frequency range.



	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
α	0,13	0,60	0,39	0,27	0,44	0,32

FIGURE 6. Impedance tube measurement results for three layer (pumice powder & lime (2mm)+pumice stone & lime (10mm)+reed(40mm)) configuration

The results of impedance tube measurement for two-layer configuration are displayed in Figure 7. The absorption coefficients at medium frequencies are approximately 0.65. It can be seen that the two layer configuration is more effective than the first configuration in terms of absorbing capacity. This result implies that pumice powder & lime layer form a good sound permeable layer. However, the raw pumice stone layer is more reflective preventing sound waves from reaching to the reed layer behind.

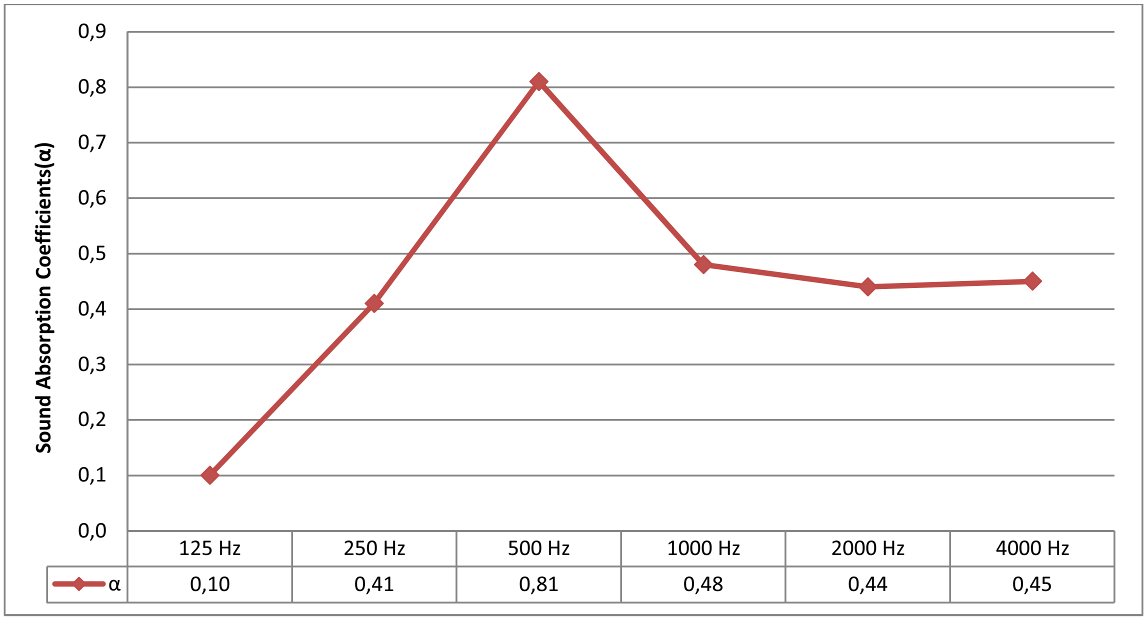


FIGURE 7. Impedance tube measurement results for two layer (pumice powder & lime (2mm)+ reed(40mm)) configuration

EVALUATION OF RESULTS

In this preliminary study on development of an ecological, smooth, unperforated sound absorptive material the combination of cellular, granular and fibrous media for sound absorption is promising for the future phases of the material investigation and development.

The granular layer made of pumice stone and lime decreases the effectiveness of the configuration in terms of acoustical properties. This layer can be removed from the configuration or measurements can be repeated using bigger or smaller particle sizes of raw pumice stone.

For the plane layer of pumice, the result is promising in terms of sound absorption. However, the dimensional stability of the top layer is rather questionable as the thickness of the layer is very thin resulting in a very brittle cover. It can be concluded that the properties of the plane surface made of pumice powder and lime should be improved in terms of its elasticity and permeability. Inclusion of an additional material to make the mixture more flexible seems as a proper choice. Absorptive properties can be increased by having a more porous layer on the top as well as an increase in the thickness of the layer.

Consequently, it can be stated that the reed layer with no binder is a good sound absorber as it is a separate layer from pumice layers. Means to keep the reed and the pumice layers together should be devised in future phases of the investigation.

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