A REVIEW ON THE ACOUSTIC ABSORPTION PERFORMANCE OF VARIOUS GRANULAR MATERIALS- THE COST-EFFECTIVE ACOUSTIC ABSORBERS FOR COMMERCIALIZATION

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Abstract

The utilization of recycled rubber and natural granular materials in the production of acoustic absorbers can help the vicinity of solving the problem of the disposal of waste material and noise pollution. The present paper reviews the analytical and experimental analyses of various granular materials aimed at the determination of their acoustic properties in terms of various analytical models. The acoustic absorption performance of the traditional rubber and natural granular materials was investigated in terms of grain sizes, flow resistivity and sound absorbing coefficient. The study reported that the effectiveness of the acoustic absorption performance of the granular materials increases with decrease in their sizes. The acoustic absorption performance of rubber crumbs, pine saw dust and rice husk have reported as good acoustic materials with a broad band absorption spectrum. The acoustic absorption performance of the above mentioned granular materials help to determine the potential of biomass granular material as a sustainable and cost effective acoustic absorber to be used at indoor and outdoor applications for sound absorption purpose. This review aimed to investigate the potentially applicable analytical approaches in order to understand the sound absorption properties of recycled waste granular materials. Furthermore the study contributes to the body of knowledge of the beneficial way of waste management by confronting the volatile price of traditional acoustic absorber. The insights of the paper may service for the business sector managers to commercialize the said concept and operational content to gain competitive advantages through cost effectiveness.

Keywords: Acoustic absorption, recycled rubber and natural granular materials

1. INTRODUCTION

In order to improve our living environment, noise control is one of the major requirements at the present time. Due to the growing concern in health and environment issues there is a great interest has noticed in using the recycled materials and green technology resources for acoustic treatment. The acoustic absorbers from recycled and natural granular materials have drawn considerable interests in noise reduction for building construction, automotive sectors, and room interior surface and household applications. The recycled and natural granular materials are sustainable, non-combustible and moisture resistant acoustic absorption materials. There are two kinds of granular materials which are consolidated and unconsolidated or loose granular materials. The sound absorption performance of any porous materials is influenced by two main parameters which are pore size and porosity. The air flow resistivity of the porous structure is controlled by pore size and porosity. The pore size in a granular composite is controlled by the grain size. The viscous and thermal effects which are responsible for the dissipation of incident sound wave energy is controlled by the pore size.

The more energy dissipation is due to more interaction of air molecules with the grain surface results in higher sound absorption of the material. . The sound absorption performance of the granular absorbent is improvable by forming bridges rather than flat boards(Cox & D'antonio, 2009). A study reported that the internal surface area in a granular composite is inversely proportional to the grain size while the flow resistivity is directly proportional to the internal surface area. The study also reported that unconsolidated granulates of grain sizes between 0.71 and 1mm and consolidated material the grain size of <2mm exhibit higher flow resistivity on the condition of applying binder at a suitable ratio. The report can be explained by the fact that smaller grains show higher flow resistivity than larger grains, leading to higher acoustic absorption performance. (Swift, Bris & Horoshenkov, 1999).

In 2002, the sound absorption performance of the rubber granular diameters ranging from 1.4 to 7mm was investigated by (Pfretzschner, 2002). The study repeatedly reported the inverse relationship between the grain size and the value of sound absorption coefficient at constant given thickness.

Smaller size of grains leads to higher value of flow resistivity and consequently of sound absorption coefficient compare to the bigger grain size. The highest values of sound absorption coefficient can be achieved for the grain size of 1-2mm was reported by (Asdrubali, D'Alessandro, & Schiavoni, 2008).

In consolidated granular materials the particles are relatively rigid and macroscopic and their dimensions are greater than those of the internal voids by many orders of magnitude. Unconsolidated materials are the assemblages of loosely packed individual particles. The example of some granular absorbing materials are granular clays, sands, gravel, limestone chips and soil which are perfect in controlling outdoor sound propagation(Iannace, Ianniello, Maffei, & Romano, 1999; Sikora & Turkiewicz, 2010).

The solid structure in rigid porous materials is perfectly rigid and stationary. The granules are separated by the interconnected voids where the air is hold. Air is a viscous fluid and the sound absorption takes place due the viscous friction of air with the pores wall. The sound energy converted into heat energy in isothermal heat transfer process, at low and high frequency region. as well as viscous effect the energy scattered from the granules also has significant effect in sound absorption of granular materials (Arenas & Crocker, 2010). Figure-1 shows the structure of granular materials with its typical microscopic arrangement.

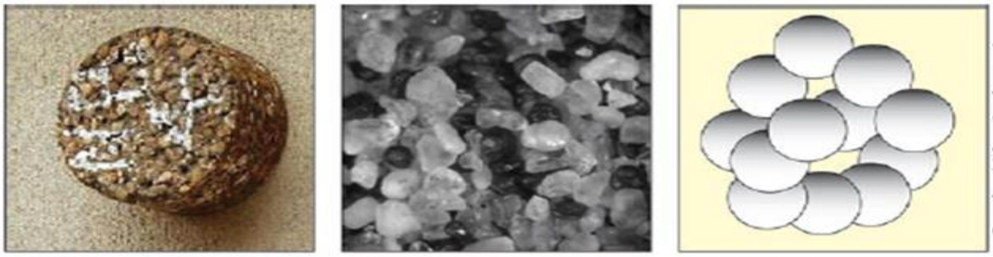

Figure-1: The structure of granular materials
Source: Arenas & Crocker, 2010

Rice husk and rice straw are two widely abundant agricultural residual wastes, which exist due to the cultivation of rice crop. The potential of these two products are reported to be used as an important resource of renewable energy. But unfortunately this energy gets wasted by open burning while disposed for the next crop which leads to the environment pollution by carbon emission. (Lim, Manan, Alwi, & Hashim, 2012).

Mahzan et al. (2009) studied the acoustic properties of rice husk. and was found the value of sound absorption coefficient is 0.899 at frequency 250 Hz. The study reported that the absorption performance of rice husk is better then virgin polyurathane and is predominant at the lower frequency.

The aim of the paper is to investigate the opportunities to improve the value of the sound absorption coefficient of conventional and natural granular materials at low frequency region in terms of three analytical models by considering the materials various physical parameters.

2. THEORETICAL CONSIDERATIONS

In order to specify the acoustical properties of any porous materials two parameters are needed to be evaluated which are- characteristic acoustic impedance and the propagation constant. Based on various theoretical overview it was assumed that simple method Delany-Bazley is consist of one and only intrinsic property which is flow resistivity. Elastic frame Bio-Allard and rigid frame Johnson-Allard models are consists of five non-acoustical parameters, which are- flow resistivity (σ)(Voronina & Horoshenkov, 2003), porosity (φ)(Cox & D'antonio, 2009), tortuosity (α_∞) (Allard, 1993; Johnson, Koplik, & Dashen, 1987), viscous (Λ) (Johnson et al., 1987)and thermal (Λ') (Champoux & Allard, 1991) characteristics length. In order to evaluate the propagation constant, surface acoustic impedance and sound absorption coefficient of any porous material the above five parameters are needed to be defined. The expression of these important five non-acoustical parameters for loose granular materials can be stated as follows:

$$\sigma = \frac{400(1-\varphi)^2(1+\varphi)^5\mu}{\varphi D^2} \tag{1}$$

$$\varphi = 1 - \frac{\rho_{bulk}}{\rho_{grain}} \tag{2}$$

$$\alpha_\infty = \frac{1}{\sqrt{\varphi}} \tag{3}$$

$$\Lambda = \frac{1}{2\pi r l} \tag{4}$$

$$\Lambda' = 2\Lambda \tag{5}$$

Where, ρ_{bulk} is the density of granular material, l is the total length of the grain per unit volume, ρ_{grain} is the specific density of grains, μ is the dynamic viscosity of air and D is the characteristic dimension of grain particle.

Simple Method: Delany-Bazley Model

It is a simple and first approximation model which derives the empirical relationship relating the propagation constant and characteristic impedance to the flow resistivity of a layer of isotropic and homogenous porous material. (Delany & Bazley, 1970). The acoustic parameters such as characteristic impedance (Z_c), the propagation constant (k) and surface acoustic impedance (Z) of the porous layer while backed with a rigid wall can be obtained as (Dunn & Davern, 1986; Lee & Chen, 2001):

$$Z_c = \rho_0 c_0 [1 + 0.057b^{-0.754} - i(0.087b^{-0.732})] \quad (6)$$
$$k = \frac{2\pi f}{Co}[0.189\, b^{-0.595} + \mathrm{i}(1 + 0.0978b^{-0.7})] \quad (7)$$
$$Z = Z_c \coth(k.d) \quad (8)$$

Where:
ρ_0 = Air density;
c_0 = Speed of sound in air;
f = Sound wave frequency;
d = Thickness of porous layer;
$b = \frac{\rho_0 f}{\sigma}$ = Dimensionless parameter; the model is applicable only for $0.01 \leq b \leq 1.0$.
The flow resistivity limit is $1000 \leq \sigma \leq 50000$ N.s m^{-4} and porosity close to 1 for this technique.

Elastic Frame Method: Biot-Allard Model

The theory of propagation of elastic wave in a porous sound absorbing materials was developed by (Biot, 1956a, 1956b) which is referenced in this investigation to address the elasticity of the frame. Hence the frame and fluid are assumed to be in motion.
In order to calculate the surface acoustic impedance of the material at normal incidence, some other parameters are also involved in this model, which are- Poisson coefficient, and bulk modulus of fluid and frame. The expression of the frequency dependent bulk modulus of fluid $K_f(\omega)$ and the bulk modulus of frame K_b can be stated as:

$$K_f(\omega) = \frac{\gamma P_0}{\gamma - (\gamma - 1)\left[1 + \frac{8\eta}{j\Lambda'^2 N_p{}^2 \omega \rho_0}\left(1 + j\rho_0 \frac{\omega N_p{}^2 \Lambda'^2}{16\eta}\right)^{1/2}\right]^{-1}} \quad (9)$$
$$K_b = \frac{2N(\nu+1)}{3(1-2\nu)} \quad (10)$$

Where, η = Viscosity of air, γ= ratio of specific heat at constant pressure to specific heat at constant volume, P_0 = Atmospheric pressure, N_p= Prandtl no, N = Shear modulus and ν=Poisson coefficient.

Generally two compression waves and one shear wave propagate simultaneously in a porous medium. Among two compression waves one is elastic compression wave and another one is acoustic compression wave. Shear wave is considered when the sound waves propagate at oblique incidence. As the study only considers the propagation of sound at normal incidence hence only two compression waves are mentioned here to predict the propagation constant and surface acoustic impedance of the material(Biot, 1956a, 1956b) and (Allard, 1993).

Rigid Frame Method: Johnson-Allard Model

Rigid frame model can be implemented for the analytical prediction of propagation constant and surface acoustic impedance of fibrous material. Here the frame is assumed to be motionless so considered to be simpler method than the Biot model. In Johnson-Allard model two acoustical parameters such as, effective density and bulk modulus of rigid porous material are introduced. The expression for the effective density $\rho(\omega)$, rigid framed porous materials having arbitrary pore shapes, was introduced by Johnson et al. (1987) which can be expressed as:

$$\rho(\omega) = \alpha_\infty \rho_o \left[1 + \frac{\sigma\phi}{j\omega\rho_o\alpha_\infty}\sqrt{1 + \frac{4\,\alpha_\infty^2 \eta \rho_o \omega}{\sigma^2 \Lambda^2 \omega^2}}\right] \quad (11)$$

The bulk modulus of the fluid of rigid framed porous materials was introduced by (Allard, 1993). Champoux and Allard (1991) in development of previous work by Johnson et al.(Johnson et al., 1987) Two parameters which are- open porosity(ϕ) and the thermal characteristics length (Λ') are involved in the calculation of dynamic bulk modulus $K(\omega)$ (Allard, 1993).

$$K(\omega) = \frac{\gamma P_o}{\gamma - (\gamma - 1)\left[1 - j\frac{8k}{\Lambda'^2 N_p \rho_o \omega}\sqrt{1 + j\frac{\Lambda'^2 N_p \rho_o \omega}{16k}}\right]^{-1}} \quad (12)$$

In general the acoustic absorption properties of porous material are defined by the characteristic impedance$Z_c(\omega)$, the complex wave number$k_c(\omega)$, surface acoustic impedance Z and the absorption coefficient(α). The expressions of$Z_c(\omega)$, $k_c(\omega)$ can be evaluated by the following equations (Allard, 1993; Cox & Dantonio, 2009; Kino, Ueno, Suzuki, & Makino, 2009):

$$Z_c(\omega) = \frac{1}{\phi}\sqrt{\rho(\omega).K(\omega)} \quad (13)$$

$$k_c(\omega) = \omega\sqrt{\rho(\omega)/K(\omega)} \quad (14)$$

For normal incidence sound waves, the well-known relationship between the surface impedance of a layer of porous material with thickness *d*, backed with rigid wall is:

$$Z = Z_c(\omega).coth(\,k_c(\omega)d \quad (15)$$

The expression of sound absorption coefficient (α) of a porous material in terms of surface acoustic impedance of porous layer(Z) and impedance of air (Z_0) can be stated as:

$$\alpha = 1 - \left|\frac{Z - Z_0}{Z + Z_0}\right|^2 \quad (16)$$

3. RESULTS AND DISCUSSION

To predict the acoustical behavior of pine saw dust and rubber granular material, Borlea et al. (2012) calculated the sound absorption coefficient by using Delany-Bazley model. Outcome of the investigation was validated by an experiment which was conducted in impedance tube method. They reported increasing in sample layer significantly improve the sound absorption performance of the materials. The study also confirmed that the Delany-Bazley model was a good approximation for overall broadband trend of acoustical behaviour. The sound absorption. A good sound absorption performance of PVC carpet grains and tyre shred residue at suitable binder ratio was observed by employing the Johnson-Champoux-

Allard model. At 1000 Hz and 30mm thickness, the value of sound absorption coefficient was reported as 0.85 for PVC carpet grain and 0.87 for tyre shred residue (Khan, 2008). Mahzan, Zaidi (2009) made a comparison study among rice husk, rubber granulate and woods shaved material. They investigated the acoustic performance of 25% rice husk, rubber and wood shavings together with a polyurethane binder. Among them rice husk showed the best performance compare to other two materials. A comparison study of sound absorption coefficients for rice husk with rubber and woods shaved materials is furnished in table-1.

Table1. Acoustic absorption performance of bio and rubber granular materials

Materials	Sound Absorption Coefficient
Rice Husk	0.9
Rubber grains	0.583
Woods shaved	0.484

The significant role of grain size for the enhancement of low frequency acoustic absorption is illustrated in table-2 for various granular materials

Table-2. The value of sound absorption coefficient at 1000Hz and 40mm thickness (Sikora & Turkiewicz, 2010).

Materials	Grain size (mm)	Sound absorption coefficient
Rubber	1x2-4	0.861
Polipropylene	4-6	0.731
Gravelite	3-15	0.643

The above observation indicates that the grain size is inversely proportional to the value of sound absorption coefficient. The reason can be explained by the fact that smaller grains shows the higher flow resistivity than the larger grains(Swift, Bris, & Horoshenkov, 1999). The production of the acoustic materials from natural substances are cost effective and has lower environmental effect than the traditional materials. The cost of some traditional and natural acoustic materials is furnished in table-3.

Table-3: Comparison on commercial values for some traditional and natural sound absorptive materials(Asdrubali, 2006)

Acoustic Materials	Cost (€ /m^2)
Cork	19
Glass Wool	12
Expanded Polystyrene	12
Hemp	5
Flax	7

The cost reduction of acoustic materials is an important factor in current development of noise control issue. Usually some natural bio granular materials are considered to be waste materials with almost of no cost to be used as potential acoustic absorbers. Using natural waste materials and omitting health hazard processing steps are the promising strategies to trigger the use of these natural waste granular materials for future industrial mass market applications.

4. CONCLUSION

The promising absorption behavior of granular composites can be anticipated through the formulation of suitable analytical models for the enhancement of low frequency acoustic absorption. Three models - Delany-Bazley, Biot-Allard and Johnson-Champoux-Allard can be considered as efficient analytical tools for the evaluation of the acoustical parameters of the granular materials.

Grain size is the most influential parameter for enhancing low frequency acoustic absorption. An optimum amount of pores can be formed by adding binder. The flow resistivity of a porous material is directly proportional to the value of its sound absorption coefficient at certain extent. The smaller the grain size, the higher the value of acoustic absorption coefficient. Influence of grain size has a considerable effect on the acoustic properties of granular composite materials. For large grains, the absorption is generally low due to low flow resistivity, but for smaller grains the absorption increases due to high flow resistivity and tortuosity.

Natural granular materials such as rice husk, pine saw dust, and wood shavings have great potential for commercialization as low frequency sound absorbent material parallel to traditional expensive granules. The increase in sample layer thickness plays a significant role for the enhancement of low frequency sound absorption. The reason is the increase in layer thickness forces the impinged sound waves to undergo a long dissipative procedure of viscosity and thermal conduction in the air within the composite. Hence promotes the sound absorption due to more energy dissipation.

The industrial manufacturing of the acoustic absorbers from waste residues will contribute to the environmental protection, waste management and noise pollution solutions that are cheaper than the traditional alternatives. The review rests the hopes of the enormous possibility in commercialization of the waste granular materials as cost effective sound absorbent materials for acoustic absorption purpose. It postulates that industries will be benefited of applying the said findings and thoughts discussed in this paper to gain competitiveness for the respective firms whilst contribution to substantiality through the cost competitive business models.

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