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Short Communication

A novel composite sound absorber with recycled rubber particles

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Abstract

A new kind of composite sound absorber has been fabricated, using recycled rubber particles with good attenuation property as sound energy attenuation layer, low characteristic impedance materials such as polymer porous foam or perforated panel as matching layer. Its' attractive characteristics include: low-cost, broad-band sound absorption, thin in thickness and relatively simple processing. An acoustic transmission analytical model is developed and successfully applied to evaluate the sound absorption of the composite absorber.

1. Introduction

As the problem of undesirable and potentially hazardous noise has become much more complex and serious, the demands for a better environment and more diversified life styles are increased. Therefore, the thin, lightweight and low-cost materials that will absorb sound waves in wider frequency regions are strongly desired.

Polymer has been extensively applied for absorption of sound and reduction of noise [1–6]. To name a few, Falke et al. [3] and Zaschk et al. [4] studied sound absorbing PUR foams with an adhesive surface by introducing multi-functional polyetherol. Ootsuta and Shuichi [5] developed a special sound absorbent plastic material prepared by subjecting thermoplastic resin beads to heat and pressure. Swift and Horoshenkov [6] made comparisons of sound absorption between loose and consolidated rubber granular mixes. Zhou et al. [7] developed a kind of sound absorption material composed of polymer micro-particles and polyurethane (PU) foam with certain geometry cavity. In addition, polymer perforated panel has also been used in sound absorbers, typically in two manners: to be used alone with a reflective surface to provide narrow-band sound absorption and also used as facing of fibrous materials to provide sound absorption over a wider spectrum. In the later case, the perforated panels serve as protection, with the fibrous or porous materials providing the sound absorption. Though these perforated panels-based sound absorbers may overcome some of the inherent disadvantages of porous materials-based sound absorbers, they are expensive or of limited use in many application and still need a deep cavity as backside.

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The use of recycled rubber in the production of sound absorber will help combat the existing problems of both waste disposal and noise pollution. In this paper, a novel kind of sound absorber is presented and the sound absorption ability of the absorber were greatly improved through impedance matching design of structure and combination of damping effect with conventional visco-thermal mechanism as well as resonating principle. The understanding of the influence of recycled rubber particles on acoustic properties of composite sound absorber and the evaluation of the sound absorbing characteristics are discussed.

2. Experimental

2.1. Materials and sample preparation

Recycled rubber of density 1001.5 kg/m^3 has been selected as the experimental materials. The particles are highly irregular in shape ranging in 150–840 μm. The composite absorber has a layer upon layer structure with the rubber particles as the bottom layer, on the top of which is single or multiple layer of polymer porous foam or perforated panel. For all the samples, the total thickness and the thickness of the respective layers had different values as needed.

2.2. Sound absorption measurement

Two-microphone impedance tube (type 4206) of Bruel&Kjaer (B&K) is applied to measure the normal incident absorption coefficient and other acoustic parameters according to the standard procedure detailed in ISO (10534-2). The frequency range of measures is from 100 to 1600 Hz.

When sound waves are diffusely incident on the absorber, the sound absorption coefficients are measured by the reverberation-room method at 1/3 octave intervals in the frequency range 100–2000 Hz based on standard ISO (354-2003).

3. Results and discussion

3.1. Sound attenuation of recycled rubber particles layers

It is found that the powder layer has a higher sound absorption coefficient than porous sound absorbing materials with the same thickness in the low-frequency region [8]. When the sound waves are incident normally on powder layers comprised of recycled rubber particles with average particles diameter of several hundred μm, sound energy is attenuated by interaction between the vibration particles. Fig. 1 shows the absorption

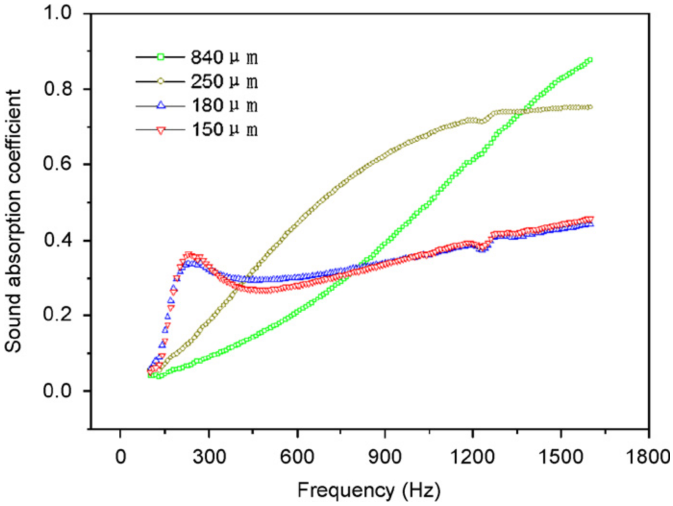

Fig. 1. The absorption spectra for recycled rubber particle layers with different particle average diameters.

spectra for recycled rubber particles layer with different particle average diameters (150, 180, 250 and 840 μm). All the particles layers have a thickness of 30 mm. It is obvious that distinct peaks of absorption coefficient appeared around 200 Hz for particles layers with average diameters of 150 and 180 μm. It is indicated that recycled rubber particles are advantageous to be applied as sound absorber in the low-frequency region. Two main mechanisms of absorption contribute to the attenuation in particles layer and can explain the high absorption in smaller particles: viscous losses due to friction between air and particles, and the friction between particles. Accompanying this high attenuation, the layers of smaller particles exhibit a high-reflection coefficient while that of larger particles exhibit a low-attenuation and a low-reflection coefficient.

3.2. *Double-layer structures of rubber particles with porous materials*

When the recycled rubber particles are applied to real-world noise problems, further widening of the sound absorption region is required and to suppress the leakage and flow of the particles. Swift and Horoshenkov [6] consolidated rubber granular mixes while the overall absorption is reduced by the consolidation. Here the double-layer structure of rubber particles layer, on top of which is laminated PU, has been studied. The measured normally incident sound absorption coefficients for the composite layer structures: U1 (foam thickness, 5 mm) and U2 (foam thickness, 10 mm) are shown in Fig. 2. It should be noted that the sound absorption functional region shifts to the high-frequency side as the PU foam layer becomes thicker and the sound absorption in higher frequency region is relatively low. It is clear that the improvement on sound absorption of the rubber particles layer due to the PU foam is limited.

3.3. *Double-layer structure of rubber particles with perforated panel*

For studying the effect of the polymer perforated panel on the acoustic absorption of rubber particle layer, the sound absorptions of polymer perforated panel backed with cavity, porous materials and rubber particles layer of 30 mm thickness are investigated. Several kinds of polymer perforated panels with different pore size and porosity have been studied. The results concerning the panel A2 (thickness $t = 3$ mm, pore size $d = 5$ mm, porosity of 4.75%) and C1 (thickness $t = 3$ mm, pore size $d = 3$ mm, porosity of 1.17%) are presented here and shown in Fig. 3(a) and (b), respectively. Obviously, the rubber particles enhanced the sound absorption bands just like porous materials, for example, PU foam or glass wool. But it should be pointed out that the rubber particles dominated the sound absorption properties of composite structure when the particles size is relatively small (150 or 180 μm); on the other hand, the perforated polymer panel did as the particles size is

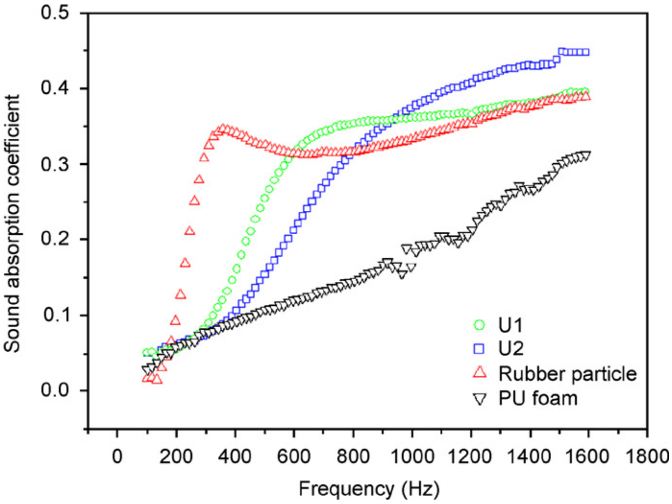

Fig. 2. The absorption spectra for double-layer structures of rubber particles with porous foam materials.

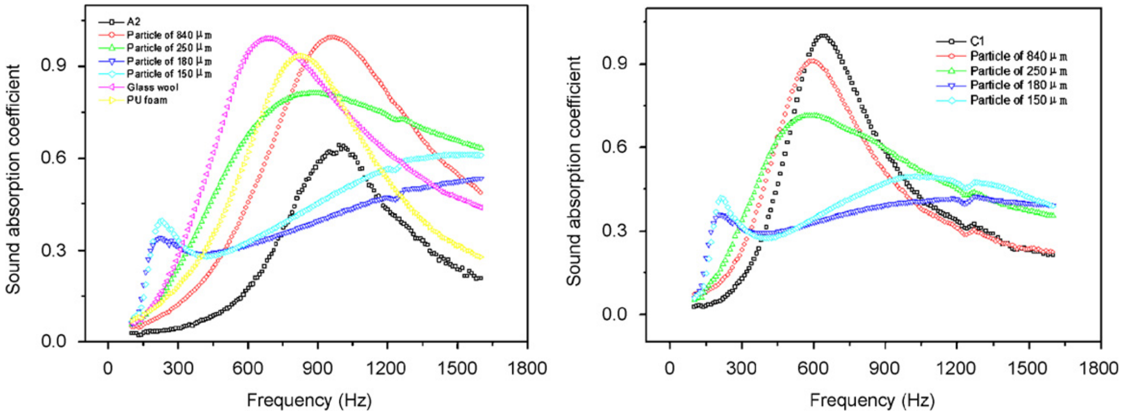

Fig. 3. (a) Absorption coefficient of perforated panel A2 with air cavity, porous materials and particles of 30 mm thickness. (b) Absorption coefficient of perforated panel C1 with air cavity and particles of 30 mm thickness.

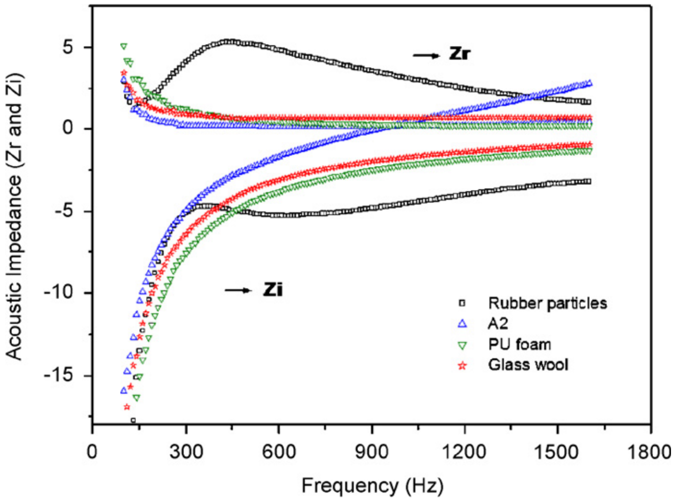

Fig. 4. Acoustic impedance of PU foam, glass wool, perforated panel A2 and rubber particles with thickness of 30 mm.

much larger. The acoustic impedance of particles layer with smaller size is relatively larger than bigger one's, and its resonance sound absorption peak appears at lower frequency region, so it influences the resonance characteristic of perforated panel and leads to the weakening of sound absorption ability of compound structure at higher frequency range. The efficiency of the sound absorber is synonymous with the best compromise between low reflection and high absorption. So it is suggested that the approach to compromise the impedance matching problem between particles and perforated panel is required.

3.4. Sound absorption of composite sound absorber

Fig. 4 shows the acoustic impedance of PU foam (40 kg/m^3), glass wool (103.59 kg/m^3), rubber particle layer (150 μm) and perforated panel A2 (with cavity of 30 mm as backside). It reveals that the porous materials such as PU foam and glass wool exhibit a better compromise than the perforated panel and particles. Thus, a multilayered structure can take the advantage of these properties to produce a better compromise than the particles layer with a single layer of perforated panel or porous materials.

Here the composite absorbers assembly with perforated panel of A2, rubber particle of 150 μm and porous materials, PU foam of 40 kg/m^3 (CP21) and glass wool of 103.59 kg/m^3 (CP22) are discussed. The sound absorption coefficients of composite sound absorber CP21 and CP22 are presented in Fig. 5. It depicts clearly

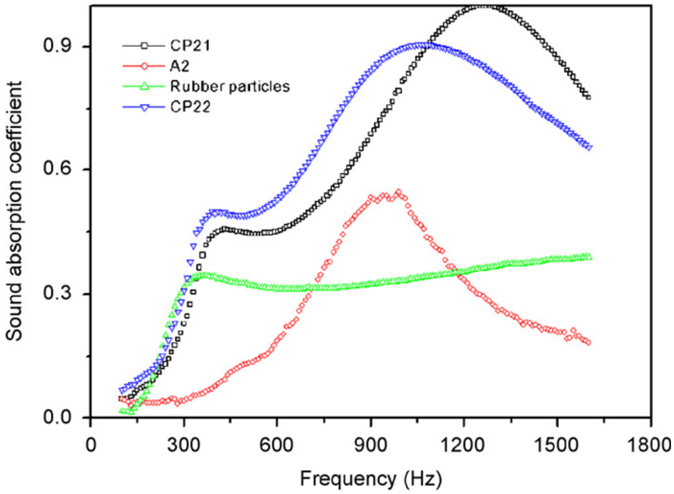

Fig. 5. Absorption coefficients of composite absorber CP21 and CP22.

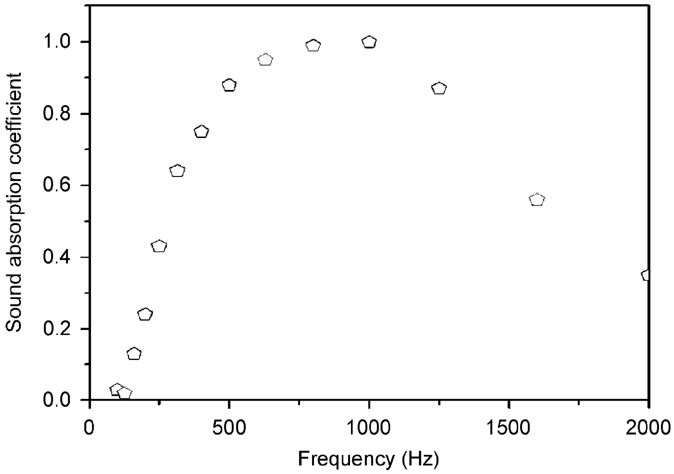

Fig. 6. Reverberation absorption coefficient of the composite sound absorber CP21.

that two resonance peaks overlapping each other to produce a broader and enhanced absorption region for each composite absorber. As shown in Fig. 6, the reverberation absorption coefficient of the composite sound absorbers CP21 are validated the great promotion of sound absorption ability in practice. For the well-known 'area effect', the reverberation-room sound absorption coefficient is somewhat higher than that of normal incident sound absorption coefficient as a whole.

3.5. Acoustic transmission analysis in composite sound absorber

Sound is mainly dissipated due to viscous loss, thermal damping and Helmholtz resonance effects in composite sound absorber. Using simplified analytical models, the effectiveness of these mechanisms in absorbing sound is examined below.

It is assumed that as the incident sound passes through the holes of the perforated panel and is immediately transmitted to the porous foam materials behind the perforated panel, the particle velocity is almost not abated [9]. The continuity of the particle velocity is thus adopted in this work to combine the surface acoustic impedance of the perforated panels and materials. In order to study sound absorption characteristics of the composite sound absorber, the scheme of the acoustic transmission analysis is shown in Fig. 7.

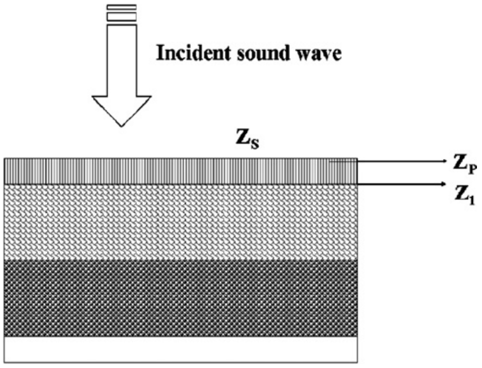

Fig. 7. Generalization of acoustic transmission analysis diagram of composite absorber.

The surface impedance Z_S of the composite absorber can be evaluated by acoustic impedance Z_P of the perforated pane and the surface acoustic impedance Z_1 of PU foam backed by the rubber particles as

$$Z_S = Z_P + Z_1 = (R_P + R_1) + \mathrm{i}(M_P + M_1), \tag{1}$$

where R_P, R_1, M_P and M_1 are, respectively, resistance and reactance of perforated panel and the compartment layer composed by PU foam and rubber particles.

Then the acoustic absorption coefficient α of the composite absorber can be obtained from the resultant acoustic impedance as [10]

$$\begin{aligned}\alpha_n &= \frac{4(R_P + R_1)\rho_0 c_0}{(\rho_0 c_0 + R_P + R_1)^2 + (\omega M_P + M_1)^2} \\ &= \frac{4(r_P + r_1)}{(1 + r_P + r_1)^2 + (\omega m_P + m_1)^2},\end{aligned} \tag{2}$$

where

$$r_P = \frac{32\eta t}{\sigma \rho_0 c_0 d^2}\sqrt{1 + \frac{k^2}{32}}, \tag{3}$$

$$\omega m_P = \frac{\omega t}{\sigma c_0}\left(1 + \left(3^2 + \frac{k^2}{2}\right)^{-1/2}\right), \tag{4}$$

$$k = d\sqrt{\omega \rho_0 / 4\eta}. \tag{5}$$

The $\rho_0 c_0$ is characteristic impedance of air; k is the constant of perforated panel, $\rho_0 = 1.2\,\mathrm{kg/m^3}$, $c_0 = 340\,\mathrm{m/s}$, $\eta = 1.85 \times 10^{-5}\,\mathrm{kg/s/m}$. As the porosity of perforated panel σ (%), the thickness of panel t (mm), pore size d (mm) and sound frequency f are known, and the surface impedance Z_1 of the compartment composed by PU foam with rubber particles can be predicted by the useful empirical relations of porous materials or the two-thickness method [9,11,12], the sound absorption of composite absorber is attained.

To validate the acoustic transmission analysis model, the sound absorption of composite absorber CP21 is discussed. In this case, the porosity of perforated panel $\sigma = 4.75\%$, the thickness of panel $t = 2\,\mathrm{mm}$, pore diameter $d = 5\,\mathrm{mm}$, thickness of PU foam is 10 mm, the thickness of rubber particle layer (150 μm) is 20 mm. Fig. 8 shows that the result obtained by the model well expresses the trend in measured frequency characteristic. It is valuable that the sound absorption at lower frequency is shown clearly though at higher frequency the difference increases because of perforated panel which needs further investigation.

By the acoustic transmission analysis, the acoustic impedance and acoustic absorption coefficients for composite absorber can be calculated. This provides a reliable guidance for the design and optimization of composite absorbers with recycled rubber particles.

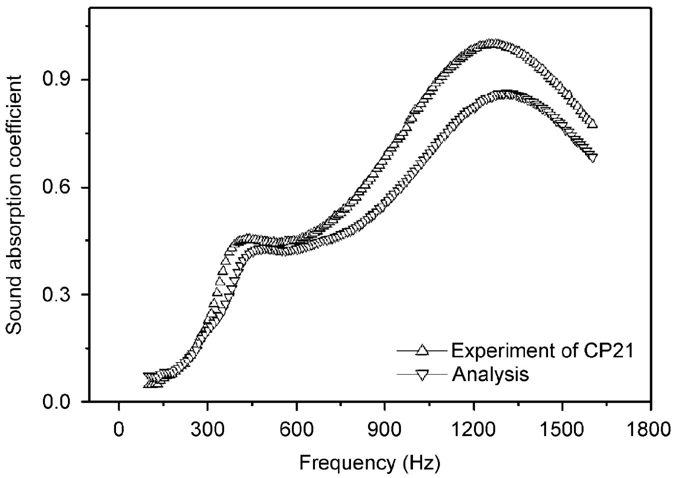

Fig. 8. Comparison of the acoustic absorption coefficient for the composite absorber CP21.

4. Conclusions

In this work, a kind of sound absorber with recycled rubber particles is presented and the sound absorption ability of the absorber is greatly enhanced through impedance matching design of structure and combination of damping effect with conventional visco-thermal mechanism as well as resonating principle. By the acoustic transmission analysis model, the acoustic impedance and acoustic absorption coefficients for composite absorber can be evaluated and contribution of recycled rubber on low-frequency sound absorption is confirmed. Although more work is required to verify the effect of different rubber particles and composite structure, the results can lead to a novel kind of sound absorption materials with high performance.

Acknowledgements

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References

[1] C. Zwikker, C.W. Kosten, *Sound Absorption Materials*, Elsevier, New York, 1949.
[2] H. Zhou, G.S. Huang, X.R. Chen, X.R. He, Advances in sound absorption polymers, *Progress in Chemistry* 16 (2004) 450–455.
[3] P. Falke, I. Rotermund, K. Schmutzer, K. Schmaler, Production of sound-damping and energy-absorbing polyurethane foams. US Patent No. 6, 316, 514, 2001.
[4] B. Zaschk, K. Schmutzer, P. Falke, Production of sound-absorbing polyurethane foams having an adhesive surface, US Patent No. 6, 337, 356, 2002.
[5] K. Ootsuta, T. Shuichi, The application of sound-absorbent plastic to acoustic paneling, *Mitsubishi Electric Advance* 174 (1996) 18–20.
[6] M.J. Swift, K.V. Horoshenkov, Acoustic absorption in recycled rubber granulate, *Applied Acoustics* 57 (1999) 203–212.
[7] H. Zhou, B. Li, G.S. Huang, Sound absorption characteristics of polymer microparticles, *Journal of Applied Polymer Science* 101 (2006) 2675–2879.
[8] Y. Okudaira, Y. Kurihara, H. Ando, et al., Sound absorption measurements for evaluating dynamic physical properties of a powder bed, *Powder Technology* 77 (1993) 39–48.
[9] F.C. Lee, W.H. Chen, Acoustic transmission analysis of multi-layer absorbers, *Journal of Sound and Vibration* 248 (2001) 621–634.
[10] P.M. Morse, K.U. Ingard, *Theoretical Acoustics*, McGraw-Hill, New York, 1986.
[11] M.E. Delany, E.N. Bazley, Acoustic properties of fibrous absorbent material, *Applied Acoustics* 3 (1970) 105–116.
[12] C.D. Smith, T.L. Parrott, Comparison of three methods for measuring acoustic properties of bulk materials, *Journal of the Acoustical Society of America* 74 (5) (1983) 1577–1582.