Sound Absorption Characteristics of Polymer Microparticles

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ABSTRACT: A sound absorption material composed of polymer microparticles and polyurethane (PU) foam with certain geometry cavum has been developed. Its sound-absorbing characteristic was investigated in the impedance tube, according to transfer function method. Measurements show that polymer microparticles have remarkable effect on the absorption performance of the composite material because of their microstructures and features. Several models established for acoustic properties have been adopted to fit the experimental data. The results show that these models fail to predict accurately the acoustic properties of the materials. The sound energy attenuation in polymer microparticles material may most likely consist of two parts, viscous attenuation of air inside the pores and the friction energy caused by the oscillation of polymer particles. © 2006 Wiley Periodicals, Inc. J Appl Polym Sci 101: 2675–2679, 2006

Key words: acoustic property; modeling; polymer microparticle; sound absorption material

INTRODUCTION

Recently, polymer has been extensively applied for absorption of sound and reduction of noise, whose attractive characteristics include its excellent viscoelasticity, relatively simple processing, and commercial availability.[1–6] Through design of molecular and structure for polymer and combination of damping effect with conventional visco-thermal mechanism as well as resonating principle, the sound absorption ability of polymer sound absorbing materials can be greatly improved.

Many researches have focused on studying and developing polymer sound absorption materials, among which polyurethane (PU), polyacrylic ester, polystyrene, and polyvinyl chloride have been used to prepare sound absorption materials. Falke et al. and Zaschk et al.[3–4] studied sound absorbing PUR foams with an adhesive surface by introducing multifunctional polyetherol. In general, sound absorption coefficients of foam materials are large in high frequency regions but small in low frequency regions of several hundred Hertz. Granular porous materials are suggested to serve as an alternative to many existing fibrous and foam absorption materials. 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 between loose and consolidated rubber granular mixes and pointed out that the overall absorption is reduced by the consolidation, which partly results in the change of flow resistivity and first resonant frequency (touristy). Moreover, their applications are difficult in many cases because of the practical problems in consolidation process as well as the fact that the width of the frequency region will be restricted.

Since the noise problem 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. Accordingly, the authors have paid much attention to the sound absorbing features of polymer microparticles.

In this article, a novel conception of a composite sound absorbing material is presented; the sound absorbing material is prepared by enclosing polymer microparticles in PU foam. The evaluation of the sound absorbing characteristics and understanding of the influence of some structure parameters of polymer microparticles on its acoustic properties are presented.

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EXPERIMENTAL

Materials

Polymer microparticles with different structures, size, and size distributions were synthesized by suspension, dispersion, and emulsion polymerization. And then the sound absorption materials were prepared by enclosing various polymer microparticles in polyurethane (PU) foam with certain geometry cavum. It is suggested that samples of 20 and 30 mm thickness were suitable in investigation, since they allow of good comparisons to be made and were considered technologically viable to manufacture.

Instruments

Two-microphone impedance Tube (type 4206) of Bruel and Kjaer (B and 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.

RESULTS AND DISCUSSION

Impedance and incident sound absorption coefficients of material

Sound absorption performance is influenced by physical parameters of materials such as flow resistivity, porosity, structure factor, viscoelasticity, density, and thickness. In general, these parameters can be characterized synthetically through acoustic impedance z, which is the ratio of the sound pressure on the sample surface to the normal component of the vibration speed on the sample surface. When the sound wave is incident form air (characteristic impedance $z_0 = \rho \cdot c$) into material of z, the reflection coefficient of the sound pressure at the interface, r, is defined from the following equation[1]:

$$r = (z - z_0)/(z + z_0) \qquad (1)$$

Obviously, for sound absorption material, its acoustic impedance z should match the characteristic impedance z_0 of air as possible. On the other hand, larger dissipation factor is required to attenuate sound energy. Theory analysis for homogeneous elastic sound absorption material with infinite thickness reveals that, when $z \approx z_0$, the reflection coefficient r at the interface is as follows[7]:

$$|r| = \sqrt{(\eta^2/4)/(4 + \eta^2/4)} = \eta/4 \qquad (2)$$

Here η is the dissipation factor. Apparently, there is inconsistency between the impedance match and requirement of dissipation factor. So, it is necessary to investigate experimentally the fundamental acoustic properties of the composite materials and the influence of structure parameters of polymer microparticles on acoustic performance of polymer particles.

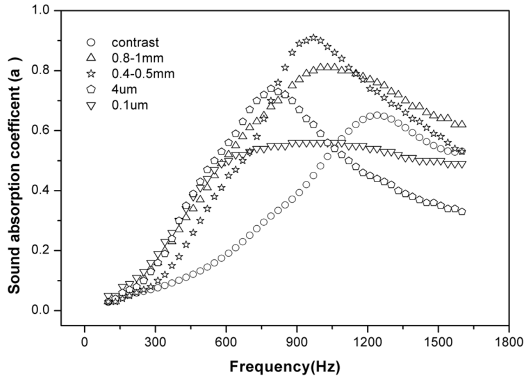

Figure 1 Sound absorption coefficient of varied polymer microparticles.

Figure 1 shows the absorption coefficients of several samples of polymer microparticles sound absorption materials, which are 20-mm thick. In broad frequency range from 400 to 1600 Hz, the sound absorption coefficients are generally above 0.4, with the maximum of 0.9. It reveals that PU foam enclosing polymer particles have good sound absorption ability in low and medium frequency range. The PU foam and polymer particles contribute to impedance matching and acoustic absorption, respectively. Furthermore, the absorption peak frequency varies with the size of polymer microparticles. When sound waves are incident normally on powder layers composed of polymer microparticles, sound energy is dissipated by viscous attenuation of air inside pores and interactions between vibrating particles in different sizes, which allows of an increased attenuation of the low frequency sound.

When the sound wave is incident at angle θ, the relation between sound absorption coefficient and specific acoustic resistance r_s and specific acoustic reactance x_s of material can be expressed as the following equation[8]:

$$\alpha_\theta = \frac{4r_s\cos\theta}{(r_s\cos\theta + 1)^2 + (x_s\cos\theta)^2} \qquad (3)$$

If the acoustic impedance z of material is pure imaginary number (specific acoustic reactance), the composite material absorbed no energy. If it is pure real number, then the reflection coefficient is less than 1, and materials dissipate sound energy. So as shown in eq. (3), the more r_s approaches to a constant and x_s verges on zero, the higher the sound absorption coefficient is.

As Figure 2 shows, polymer microparticles play an important role in modifying the impedance of composite material. The size and vibration (interaction) of polymer particles are partly determined by the impedance change of sound absorbing materials. With the

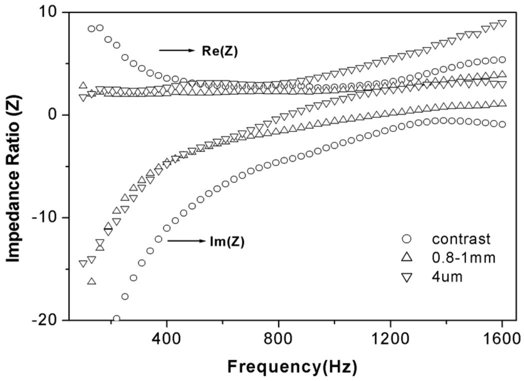

Figure 2 Impedance ratio of various polymer microparticles.

decrease of particle sizes, the sound absorption peak shift toward lower frequency region in the spectrum.

Experiments show that bulk properties of polymer microparticles would affect the acoustic performance of composite material. As shown in Figure 3, polymer particles prepared by various monomer mixtures with different ratios lead to apparently different impedance and sound absorption performance. The glass-transition temperature of polymer is descended accordingly as the monomer mixture ratio (MMA/BA) decreases. It means more polymer segmers are activated and

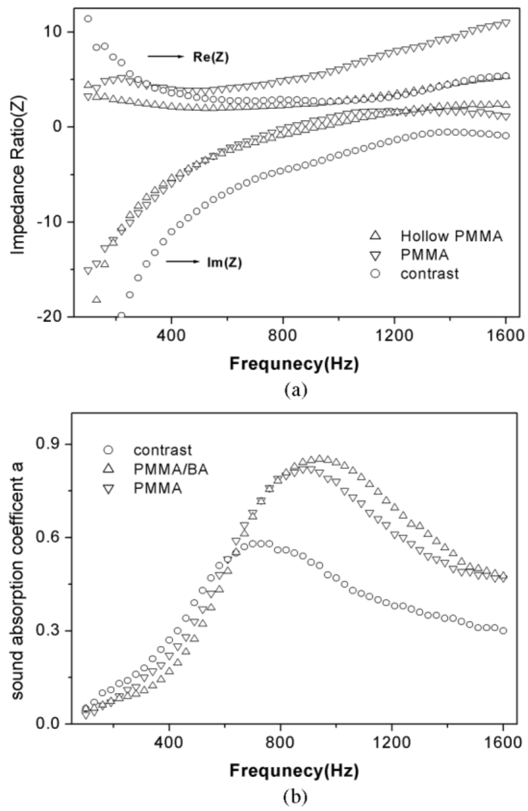

Figure 4 Sound absorption coefficient and impedance ratio of polymer hollow microparticles.

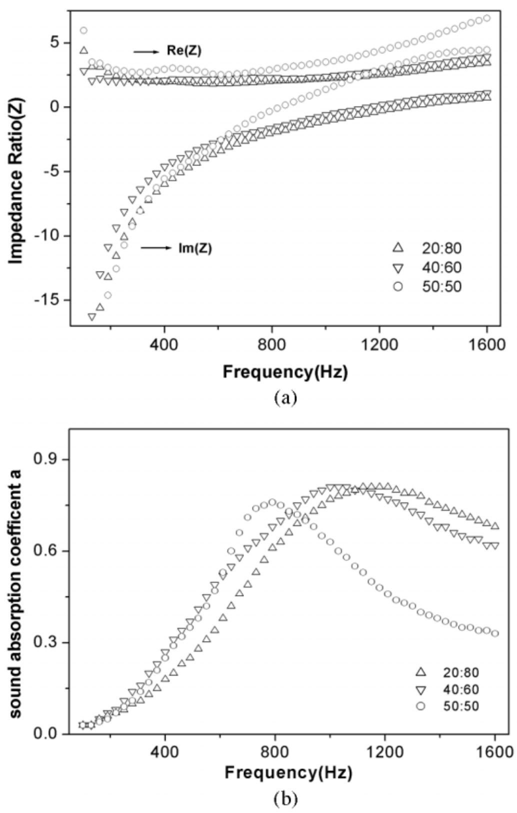

Figure 3 Sound absorption coefficient and impedance ratio of PMMA/BA microparticles.

some move or resonances under sound wave are generated. In this case, sound absorption ability of material is improved. The effect of bulk properties of polymer on acoustic performance have been identified by Yu et al.[9]

The most interesting phenomenon is that acoustic performance of material varied with the microstructure changes of polymer microparticles. In this work, hollow and nonhollow polymer particles are used to prepare sound absorption materials. The absorption and impedance spectra shown in Figure 4 suggest that hollow polymer particles greatly affect the impedance of composites, which results in the improvement of sound absorption. It indicates clearly the combination of the conventional viscous attenuation of air inside the pores with the longitudinal vibration of particles by the hollow structure.

Modeling prediction of sound absorption characteristics of polymer particles

In addition to the research on measurement of acoustic surface impedance and normal incidence absorption coefficient, it is necessary to obtain a keen insight into the physical mechanisms of the acoustic absorption. In many cases, an empirical or theoretical model is applied to or developed for the

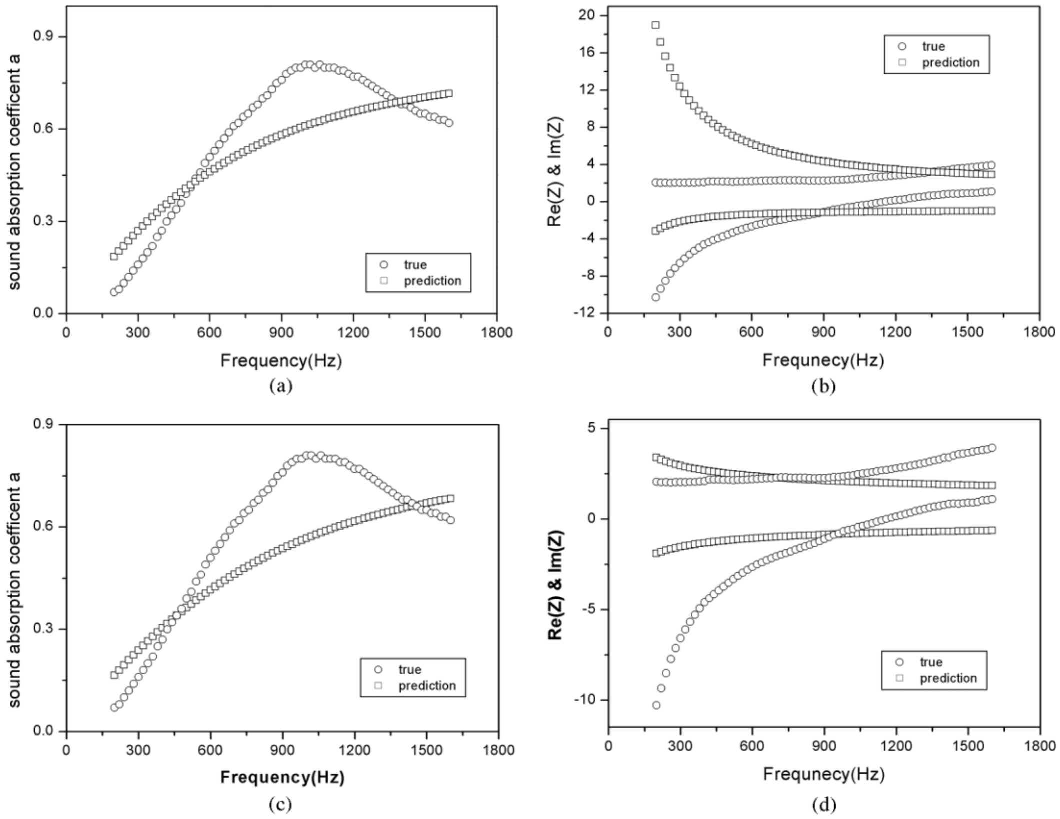

Figure 5 Sound absorption coefficient and impedance ratio from model prediction: (a,b) Delaney–Bazley model; (c,d) Voronina model.

prediction of the acoustic properties. There are many existing models for acoustic properties of porous materials, such as empirical models using linear and nonlinear regressions and theoretical models based on phenomenological or microstructure material parameters.[1] To make out whether sound absorption mechanism is consistent with the assumption above, two empirical approaches, Delaney and Bazley model for fibrous material[10] and Voronina and Horoshenkov model for granular porous material,[11] which, to some extent, are similar to polymer microparticles material, are selected here to fit the sound absorbing data of polymer microparticles. Although polymer microparticles sound absorption material is more complicated than the traditional porous materials, the experimental results can be used to test those established models for the acoustic properties.

The comparisons between the experimental results and predictions show that in some cases these models can produce distinct errors, as in Figure 5. Although the Delaney–Bazley and Voronina models cannot illuminate the absorbing features of the polymer particles materials, it gives information that the sound absorption mechanism of the polymer particles materials is not entirely similar to the granular porous materials. The results suggest that the sound energy attenuation in polymer particles material probably includes two parts, viscous attenuation of air inside the pores and the energy loss form friction caused by the oscillation of polymer particles.

Attempting to overcome the difficulties caused by the complexity of polymer microparticles, an artificial neural network model with an appropriate set of acoustic parameters is employed in this work. As shown in Figure 6, the prediction of ANN can be compatible with the experimental data, especially at higher frequencies. But they are inaccurate at lower frequencies (450–900 Hz). Glenn et al.[12] found that the static flow resistivity and frequency are sufficient to predict the normal surface impedance and the normal incidence absorption coefficient for a class of foams. The results also indicate that the absorption mechanism of polymer microparticles material differ from that of normal porous material such as PU foams, granular porous materials, and so on. The contribution of polymer microparticles to lower-frequency sound absorption is reasonable as it is assumed before.

In this respect, more studies are required to develop a new model, which will provide the basis for prediction of the polymer microparticles acoustic properties and further validation of this conception. And these works will be discussed later.

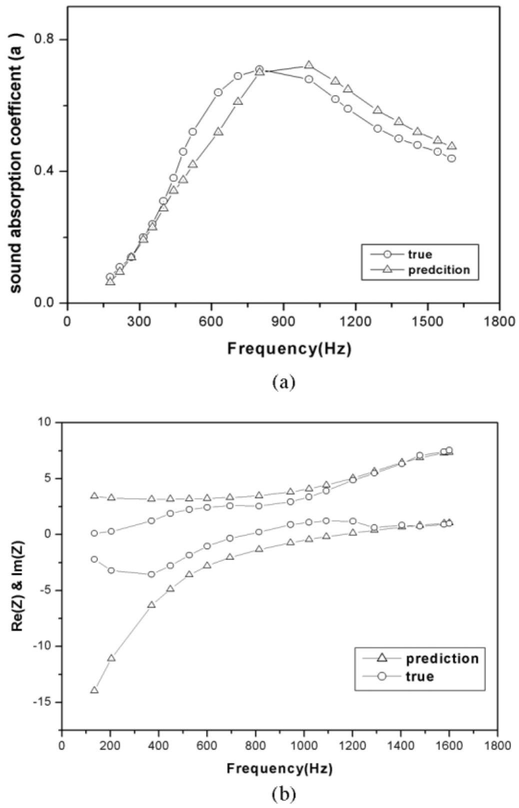

Figure 6 Sound absorption coefficient and impedance ratio from ANN model.

CONCLUSIONS

It has been found that the composite material of polymer microparticles possesses a characteristic frequency band where the average sound absorption coefficient of the material is 0.4 and the maximum is up to 0.92. In the low-frequency region, it has a higher sound absorption coefficient than porous sound absorption materials such as PU foam with the same thickness.

In a word, the results show that the acoustic behavior of the material and farther the sound absorption ability is apparently to be influenced by the multilevel microstructures of the materials and properties of polymer microparticles. It suggests that the combined effect of the vibration of the polymer particles and sound absorption of visco-thermal loss between the particles and inside the urethane foam contributes to sound absorption.

Although more tests are required to verify the effect of various polymer particles, the results can be used as guidance for future design of thin low-frequency sound-absorption materials and development of the model for polymer particles sound absorption materials.

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