SOUND ABSORPTION PROPERTIES OF COMPOSITES MADE OF DISCARDED DUCK FEATHERS

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ABSTRACT

A novel composite with good sound absorption properties was prepared by discarded duck feathers and Ethylene vinyl acetate copolymer (EVA) non-woven fabrics by using lay-up and hot-pressing method. The effects of discarded duck feather concentration, composite density, composite thickness and air cavity depth on sound absorption performance were studied. When the composites with proportion (w/w) of the discarded duck feathers to EVA non-woven fabrics of 300/100, density of 1400g/m2, thickness of 20mm, the noise reduction coefficient (NRC) was 0.54. By adding the 30mm air cavity depth, the NRC of the composite increased from 0.54 to 0.76. Theoretical models for the prediction of sound absorption coefficients of composites made of discarded duck feathers were presented. The good agreement was obtained by the comparison of measured and calculated absorption coefficient curves. The theoretical models were therefore suitable for the design of discarded duck feather composites with an excellent sound absorption performance.

Keywords: Discarded duck feathers, composites, sound absorption, theoretical model

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1. INTRODUCTION

Feather resources are very rich in China, and the annual output was about 800 thousand tons in 2008 [1]. At present, feathers are mainly used for feed additives, keratin membrane materials, filling and decoration materials. However, 80% feathers are regarded as garbage, which not only wastes resource but also pollutes the environment. Hence, more effective and efficient methods are needed to reuse the feathers. The work of Li et al. [2] achieved a compound amino acid using acid or alkali to hydrolyze duck feathers. Zhou et al. [3] prepared regeneration protein solution using peracetic acid to oxidize duck feather, then mixed the regeneration protein solution with polyvinyl alcohol and achieved regenerated feathers protein/PVA fiber. Yao et al. [4] reported the preparation of feather peptide powder in the method of alkaline hydrolysis. It was found that feather peptide powder contains little keratin, more kinds of amino acid that can be used as feed additives. Carrillo [5] prepared a composite with light weight and good mechanical properties using chicken feathers as reinforced material and PP, HDPE and PLA as matrix material.

The duck feather is a green protein fiber material with density 0.8g/cm^3 and thermal conductivity 0.024w/m^2 ℃[6]. The skin region and core region can be observed on the cross section of duck feather. The structure of skin region is denser and the structure of core region is very loose and exist some voids or cavities [7-8]. Because of the unique skin-core structure, duck feathers have good sound absorbing property. Therefore, it is a good choice that using discarded duck feathers to manufacture sound absorption composites.

Reddy et al. [9] prepared light- weight composite with chicken feather as reinforced material and PP non-woven fabric as matrix material and investigated its mechanical and sound absorption properties. Huda et al. [10] made detail discussions about mechanical and acoustic performance of composites, which were made of chicken feather fibers and HDPE and PP fibers. Yang et al. [11] studied the mechanical and sound absorption performance of composites with discarded chicken feathers and discarded plastic bags (HDPE).

In this study, discarded duck feathers were used as reinforced material and EVA non-woven fabrics were used as matrix material. The composites were fabricated by lay-up and hot –processing method. Sound absorption properties were studied by changing duck feather concentration, composite density, composite thickness and air cavity depth. The theoretical models for the prediction of sound absorption coefficients of composites made of discarded duck feathers were presented. It was found that they had good agreement with the measured results. The theoretical models provided theory support for the development of sound absorption composites.

2. MATERIALS AND METHODS

2.1. Materials

Duck feathers were supplied by Hangzhou Xinfeng feather product Co., Ltd., China. The duck feathers were fluffy and had a white color. EVA non-woven fabrics were procured from Shanghai hot melt adhesive corporation, China, with a melting temperature of 80 °C.

2.2. Fabrication of the composite

Barb discarded duck feathers were cut with scissors, removing the quill, and discarded impurities in duck feathers. On the basis of the proportion of feather to EVA non-woven fabrics, the required EVA non-woven fabrics and feathers were divided into dozens of parts. The feathers and EVA non-woven fabrics had been laid to the specified thickness alternately. The composites were fabricated by hot-pressing method for 15 min at a particular temperature and pressure(14□,2Mpa). After compression, the composites were cooled and the samples were removed.

2.3 Testing of the Composites

SW422/SW477 impedance tube sound absorption test system was used under the atmospheric condition of 22 °C and 68% relative humidity, according to transfer function method (GB/T 18696. 2-2002). Each sample was tested 3 times and the average values were taken.

3. RESULTS AND DISCUSSION

3.1. Effect of discarded duck feather concentration on sound absorption properties

The effect of discarded duck feather concentration on sound absorption properties is shown in Fig.1. The proportion(w/w) of discarded duck feathers to EVA non-woven fabrics was varied from 100/100, 200/100, 300/100. The thickness of the composite was 6mm and the density was 1600g/m^2.

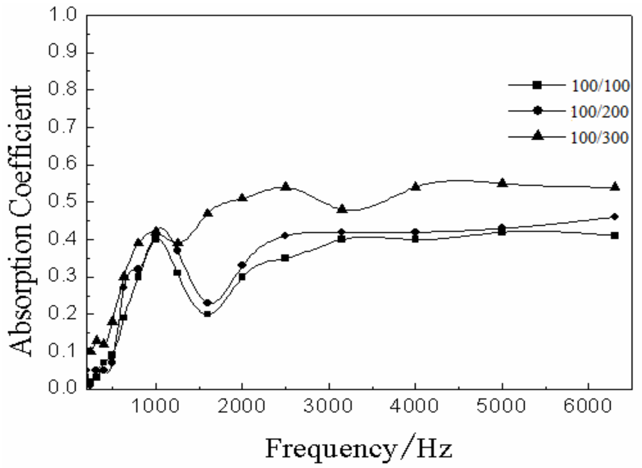

Fig.1. Effect of discarded duck feather concentration on sound absorption properties

As shown in Figure 1, with the increase of discarded duck feather concentration, the peak of sound absorption coefficient increased and it shifted to low frequency range. With the increase of frequency, the sound absorption property of the composite became better. The possible reason may be that duck feathers had inherent void structures in barbs part and feathers surface had vertical arrangement texture and orientation arrangement subprime barbules. The micro void structures were formed between feather and feather, also feather and EVA. Therefore, entrapped air existed in micro void of composites. With the concentration of feathers increase, more micro void and volume of entrapped air existed in composites. This resulted in a tortuous sound wave travel path and higher airflow resistance in the composites, hence the peak of sound absorption coefficient increased[12]. Additionally, at high frequencies, friction of the feather fibers and vibration of the entrapped air within micro void can be accelerated [13].

3.2. Effect of composites density on the sound absorption properties

Figure 2 showed the sound absorption coefficient curve of composites with thickness 6mm, the proportion (w/w) of the feathers to EVA non-woven fabrics 200/100,when the density of composites was 1400,1600,1800g/m^2 .

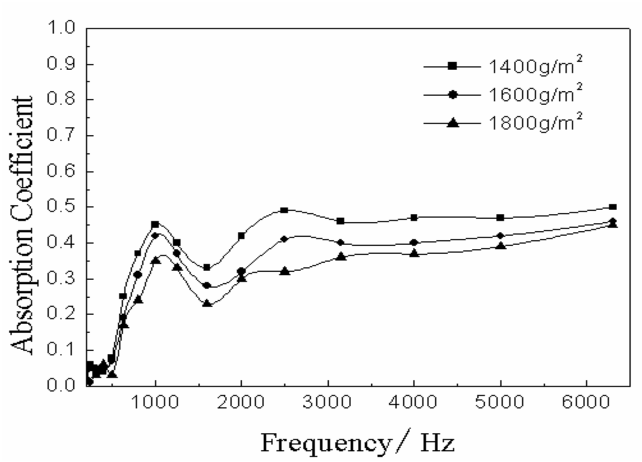

Fig.2. Effect of density on sound absorption properties

As shown in Figure 2, the absorption coefficient curves had some fluctuations in the whole frequencies range. The sound absorption performance of the composite with density of 1400 g/m^2 was better than composites with density of 1600 and 1800g/m^2. With the frequency increased, sound absorption performance of composites became better. The feathers became compactness in composites with increasing density, but without changing the thickness and proportion of feathers to EVA non-woven fabrics [14]. Due to the compact surface of composite, it prevented transmission of sound wave through the composite, and a great proportion of incident sound waves were reflected. Then, this decreased sound absorption.

3.3. Effect of composites thickness on sound absorption properties

Figure 3 showed the sound absorption coefficient curve of composites with density 1600g/m^2, proportion (w/w) of the feathers to EVA non-woven fabrics 200/100,when the thickness of composites were 2, 6 and 10 mm .

The Figure 3 shows that, with the composite thickness increasing, the sound absorption coefficient increased at each frequency. The sound absorption performance of the composite with thickness 10mm was better than the samples with thickness 2 and 6 mm, in the frequencies range of 400 to 6300Hz.

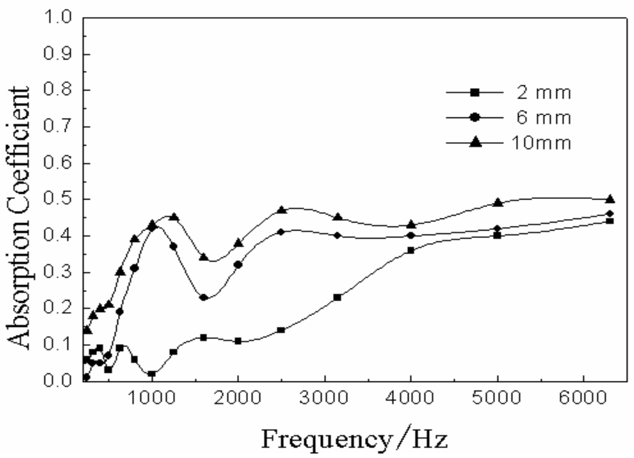

Fig. 3. Effect of thickness on sound absorption properties

Increasing thickness without changing the density of the composites, it had more micro voids structure in the composite. That is to say, more entrapped air, which used to damping sound waves existed in the micro voids. It also increased the travel time and distance of sound waves in composite with increasing the composites thickness. And it made the more interaction chance of sound waves and air in the voids structure [15]. More sound energy were consumed by the friction of air and voids wall when incident sound waves passed through the composite. Thus the absorption coefficient of composites increased and sound absorption property improved significantly.

3.4. Effect of air cavity depth on sound absorption properties

Air cavity depth is some distance between composite and a rigid wall. Figure 4 showed the sound absorption coefficient curve of composite with density 1400g/m^2, proportion (w/w) of the feathers to EVA non-woven fabrics 300/100, thickness 20 mm, when the air cavity depth was 0, and 30mm.

Figure 4 shows that, sound absorption coefficient curves of composite had small fluctuations, the composite had a stable and better sound absorption performance, and the noise reduction coefficient (NRC) was 0.54. By adding the 30mm air cavity depth, the NRC of the composite increased from 0.54 to 0.76. The NRC was obtained as the mean of absorption coefficient values at frequencies of 250, 500, 1000, 2000 and 4000Hz[16].

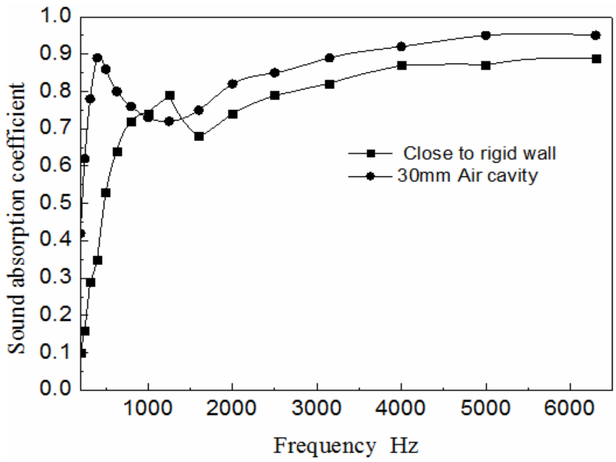

Fig.4. Effect of air cavity depth on sound absorption properties

As seen from the figure 4, with the increase in air cavity depth, the peak of sound absorption coefficient shifted to low frequency. So, the sound absorption properties improved under low frequency. But the air cavity depth cannot increase unlimited, otherwise, it will reduce sound absorption in high frequency range and take up too much space. Thus, a suitable air cavity depth is very necessary.

4. THEORETICAL CALCULATION OF ABSORPTION COEFICIENT

There were a lot of complex interconnected macro voids and continuous air channel structure existed in composites. Therefore, this was an ideal porous sound absorbing composite. In order to deduce the formula of sound absorption coefficient in an easy way, the macro voids were modeled by randomly arranged thin tubes [17].

When the composite thickness was l and the air cavity depth with a rigid wall was 0, surface acoustic impedance Z of the composites could be deduced by acoustic impedance transfer method. The surface acoustic impedance of the composite could be written as [18].

$$Z = -j \cdot \rho c \cot kl \tag{1}$$

Where j was the imaginary unit, ρ was the effective density of composite, c was the speed of sound in composite, and$k$was the wave number in composite.

The effective density ρ of composite could be written as [19]

$$\rho = \frac{k^2 \rho_0}{k_0^2 \gamma \sigma} \tag{2}$$

Where ρ_0 was the density of air, k_0 was the wave number in air with $k_0 = \omega / c_0$, c_0 was the speed of sound in air, γ was the specific heat ratio of air with $\gamma = C_p / C_\upsilon$, C_p was the specific heat of air at constant pressure, C_υ was the specific heat of air at constant volume, σ was the porosity of composite with $\sigma = 1 - \rho_m (W_r / \rho_r + W_s / \rho_s)$, ρ_m was the density of composite, W_γ was the mass fraction of the EVA, W_S was the mass fraction of duck feathers, ρ_γ was the density of EVA, ρ_S was the density of duck feather fiber.

The speed of sound in composites could be calculated by [20-22].

$$c = \sqrt{\frac{K_e}{\rho_e}} \tag{3}$$

The dynamic density ρ_e, which took into account the inertial and the viscous force per unit volume of the air in the composite, was given by

$$\frac{\rho_e}{\rho_0} = 1 + \frac{\rho_m}{\rho_s} \cdot \frac{\frac{\delta^2}{a^2}}{A + jB} \tag{4}$$

$$\delta = \sqrt{\frac{2\eta}{\omega \rho_0}} \tag{5}$$

$$A = \frac{\pi}{4} + \frac{\rho_0}{\rho_s} \cdot \frac{\delta^2}{a^2} \tag{6}$$

$$B = \ln \frac{\delta}{a} + \frac{1}{2} \ln 2 - E \tag{7}$$

Where a was the feather fiber radius, η was the dynamic viscosity of air and $\omega = 2\pi f$ was the angular frequency with frequency f, E was the Euler's constant.

The dynamic bulk modulus K_e, which related the divergence of the averaged molecular displacement of the air in the composite to the averaged variation of the pressure, was given by

$$\frac{K_e}{K_0} = 1 - \frac{\gamma - 1}{A' + jB' \left(\frac{R}{\delta'} \right)^2} \tag{8}$$

$$A' = \gamma - b + \frac{\pi}{4} \left(\frac{R}{\delta'} \right)^2 \tag{9}$$

$$b = \frac{\rho_0 C_p}{\rho_m C_s} \tag{10}$$

$$\frac{a^2}{R^2} = \frac{\rho_m}{\rho_s} \tag{11}$$

$$B' = \ln \frac{\delta'}{a} + \frac{1}{2} \ln 2 - E \tag{12}$$

$$\delta' = \delta \Big/ \sqrt{C_p / \Lambda} \tag{13}$$

Where Λ was the heat conductivity, C_s was the specific heat of feather fiber. The equation of the k was chosen according to Champoux and Allard as [23-25].

$$k = 2\pi f \sqrt{\frac{\rho_e}{K_e}} \tag{14}$$

Acoustic impedance ratio of the composite could be written as

$$\frac{Z}{\rho_0 c_0} = x_s + j y_s \tag{15}$$

When the air cavity depth with a rigid wall is 0, the installation method is shown in Figure 5. The normal incidence sound absorption coefficient is given by [26]

$$\alpha = \frac{4 x_s}{\left(1 + x_s^2\right) + y_s^2} \tag{16}$$

The other installation method is shown in Figure 6, which an air cavity between the composite and the rigid wall existe. When normal incidence wave is perpendicular to the composites surface, the sound absorption coefficient can be written as follows [27]

$$\alpha = 1 - \left| \frac{z - Z_0}{z + Z_0} \right|^2 \tag{17}$$

$$z = Z \frac{jZ + Z_c \cot\left(\omega l / c\right)}{Z \cot\left(\omega l / c\right) + jZ_c} \tag{18}$$

$$Z_c = -j \rho_0 c_0 \cot\left(\omega D / c_0\right) \tag{19}$$

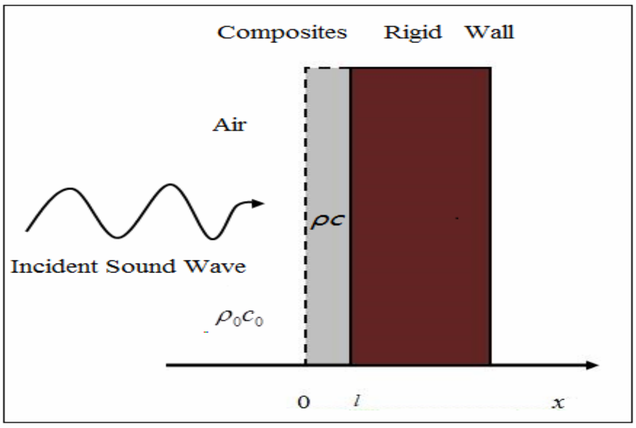

Fig.5 Illustration of the composites installation method (Ⅰ).

Where D is the air cavity depth, Z_c is the acoustic impedance of air cavity, Z_0 is the characteristic impedance of air with $Z_0 = \rho_0 c_0$, z is the surface acoustic impedance of sound absorption structure of Figure 6.

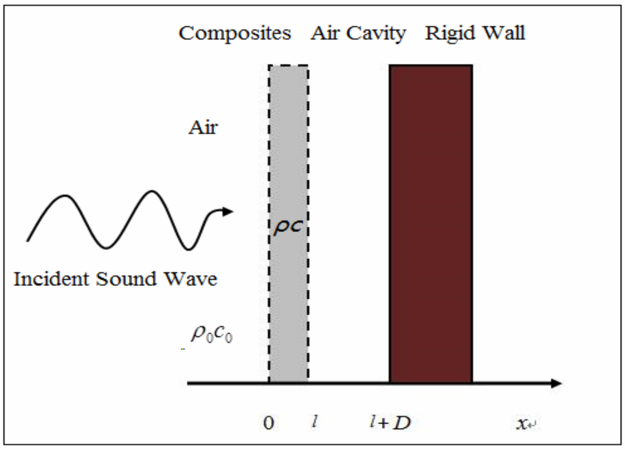

Fig.6. Illustration of the composites installation method (Ⅱ).

5. COMPARISON OF ABSORPTION COEFFICIENT CURVES

According to the existing model, measured and calculated absorption coefficient curves had been compared. The specific parameters for installations I and II were seen in the table1.

Table 1. The specific parameters for installations I and II

Installation	Density /(g/m²)	Thickness of composites /(mm)	Air cavity depth /(mm)	Thickness of rigid wall /(mm)
I	1400	20	0	1000
II	1400	20	30	500

The measured and calculated sound absorption coefficient curves of composites are shown in Figure 7 and Figure 8 with two different installation methods.

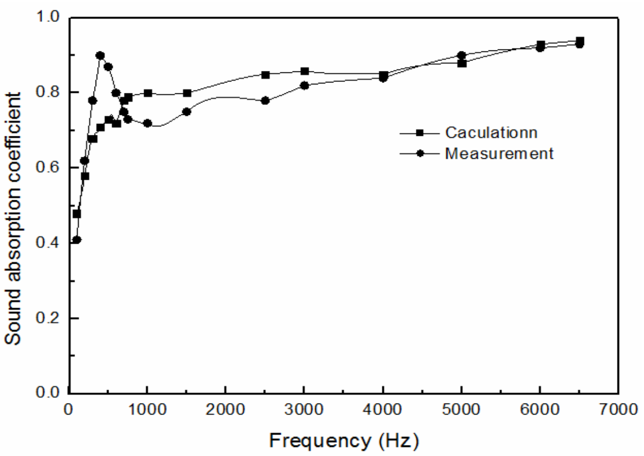

Fig. 7. Measurement and calculation of normal incidence sound absorption coefficients (Ⅰ).

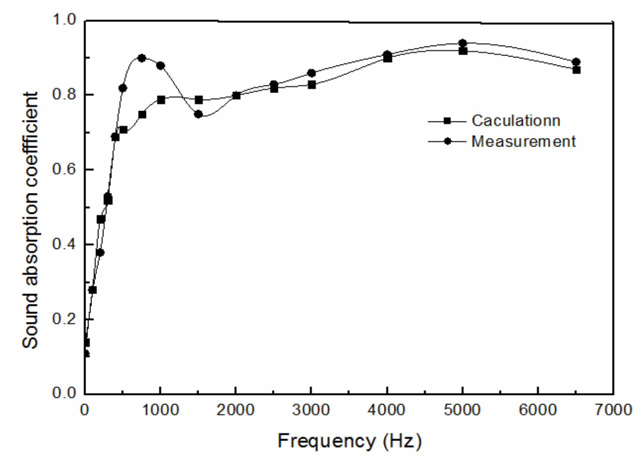

Fig. 8. Measurement and calculation of normal incidence sound absorption coefficients (α).

From Fig.7 and Fig.8, it was seen that they had good agreement with the measured results and calculation results. It suggested that the theatrical models were suitable to describe the sound absorption characteristic of composite with discarded duck feathers in the whole frequency range. Slight deviations only occured at the local minima of the sound absorption coefficients curves. The reason could be explained that the calculated absorption coefficient by the theoretical models were an ideal case. Whereas, the preparation of the composites was affected by the fabrication conditions, and the sizes of pores in the composites were different.

6. CONCLUSIONS

The discarded duck feathers were used as reinforced material and EVA non-woven fabrics were used as matrix material. The composites with good sound absorption properties were fabricated by lay-up and hot-processing method. The effects of duck feather concentration, composite density, composite thickness and air cavity depth on sound absorption performance had been fully studied. When the composites with proportion (w/w) of the feathers to EVA non-woven fabrics of 300/100, density of 1400g/m^2, thickness of 20mm, the noise reduction coefficient (NRC) was 0.54. By adding the 30mm air cavity depth, the NRC of the composite increased from 0.54 to 0.76. Theoretical models for the prediction of sound absorption coefficients of composites made of discarded duck feathers were presented. By the comparison of measured and calculated absorption coefficient curves, they had good agreement with the measured results. It suggested that the theatrical models were suitable to describe the sound absorption characteristic of composite with discarded duck feathers in the whole frequency range.

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