Air Permeability and Acoustic Absorbing Behavior of Nonwovens

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Abstract: Several nonwovens were studied to explore the relationship between their structural characteristics, permeability and acoustic absorbing behavior. Fundamental structural parameters including thickness, gram square meter and porosity were considered. Results show that the permeability is not just linear to porosity, but also related to many other complex and difficult-to-measure parameters. Further in this paper we compared absorption coefficient of nonwovens with and without air permeability back, the sound absorption principles of those are completely different. For nonwovens with rigid back, the absorption coefficient increases with increasing thickness. For samples tested with air gap, the increasing air permeability moves the absorption curve towards lower frequency, and enhances the initial slopes of the curves. And also the absorption coefficients over the whole frequency range were found to increase with air permeability. This finding also indicates that the capillary effect alone cannot sufficiently explain the acoustic absorbing behaviour of nonwovens. Accurate theories which can illustrate sound absorption property of nonwovens still need to be improved and more precise model is still to be developed to explain the acoustic absorbing behaviour of nonwovens.

Keywords: Nonwovens, porosity, permeability, acoustic absorption, peak shift.

1. Introduction

Acoustical absorbing materials are often used in automotive and building industries. At present, the most common materials being used are fibrous materials, foam, glass, perlite and concrete. Fibrous materials are considered to be the most ideal ones because of their low-cost, light-weight, no pollution and high-efficient absorbing ability.

Sound absorption behavior of nonwovens are studied by many researchers [1-3]. C. Zwikker and C. W. Kosten who provided the first monumental work on this subject [4], looked at the porous medium as a mixture of two phases, air and solid material, which react differently with the sound wave. Yakir Shoshani and Yakov Yakubov [5] used Zwikker and Kosten’s theory to do numerical calculations of some intrinsic characteristics of nonwoven fiberwebs yielding the highest sound absorption coefficients in the audible frequency range. For nonwoven fiber-based materials, acoustical insulation is mostly related to the geometry of the fabric. The fiber denier, shape and length in nonwoven fabrics are very important factors in sound absorption and insulation [6,7]. Mevlut Tascan and Edward A. Vaughn [8] studied the effects of total surface area and fabric density on acoustical behavior of needle punched nonwoven fabrics. N. Voronina [9] investigated experimentally and derived a model which can be used to predict values of the acoustic impedance and the sound absorption coefficient of material layers, provided the fiber diameter and density are known.

In this research, we studied several nonwovens to explore the relationship between their structural characteristics, permeability and acoustic absorbing behaviour. Fundamental structural parameters have been considered including thickness, gram square meter and porosity. Furthermore, in this paper we have compared the sound absorption coefficient of nonwovens with and without air gap behind.

2. Experiment

Six nonwoven samples are involved in this study.

2.1 Fundamental parameters measurement

(1) Thickness

The thickness of the nonwoven samples is measured by YG141N digital fabric thickness gauge, which complies with the standard ISO5084. The paper chose press weight as 50cN and press time as 10s.

(2) Gram square meter

Using electronic balance, small round samples with radius of 15mm are measured, further their gram square meters are calculated.
(3) Porosity

Porosity can be determined by

\[ \varepsilon = 1 - \frac{m}{A L \rho}, \]  

where \( m \) is weight of nonwoven sample, \( A \) is sample cross-sectional area, \( L \) is sample thickness, and \( \rho \) is density of the fiber.

2.2 Permeability measurement

The permeability of samples is measured by numerical type fabric air permeability instrument (YG461E), which complies with the standard GB/T5453-1997. Pressure is set as 200Pa, test area as 20cm\(^2\), and the diameter of nozzle is determined by permeability, larger permeability needs bigger nozzle to match with.

2.3 Sound absorption measurement

There are two types of methods to obtain acoustic absorption coefficient: the reverberation room technique (ASTM C 423-84a) and the impedance tube technique (ASTM C 384-85). The latter one is adopted here since it requires rather small sample, just 100 or 30mm in diameter. For normal incident sound waves, this method is faster and more accurate. There are also two options available with the standing wave tube: standing wave ratio method and transfer-function method. The only difference between them is that in the latter one two microphones are fixed on the wall of tube in place of one slipping microphone in the former one. Compared with the standing wave ratio method, the transfer function method has a wider testing range. Thus in this study the transfer function method is used.

The instrument adopts SW260 double-microphones standing wave tube, which is made in BSWA Technology Co., Ltd, complying with a standard GB/T18696.2-2002 and ISO 10534-2:2001. It is composed of a signal generator, a loudspeaker, an impedance tube, a portable dual-channel fast Fourier transform (FFT), a power amplifier and a precision sound level meter as shown in Fig.1. The generator transmits a broadband signal which is collected and processed at the location of two microphones, where the incident sound energy is separated from the reflected one, therefore the acoustic absorption coefficient and impedance at different frequencies can be determined.

Figure 1 SW260 double-microphones standing wave tube.

The measuring process must use a plain wave, whose wavelength is longer than the tube diameter. For this reason, in this work we chose the narrowest tube (30 mm in diameters) to obtain widest extent of working frequency. During the measurement, the two microphones must be carefully matched.

The transfer function technique is based on the fact that the sound reflection factor at normal incidence, \( r \), can be determined from the measured transfer function, \( H_{12} \), between two microphone positions in front of the material being tested. The complex acoustic transfer function, \( H_{12} \), is normally defined as

\[ H_{12} = \frac{p_2}{p_1} = \frac{e^{j k_0 x_1} + re^{-j k_0 x_2}}{e^{j k_0 x_1} + re^{-j k_0 x_2}}. \]  

where \( p_1 \) and \( p_2 \) are the complex sound pressures at the two microphone positions; \( x_1 \) and \( x_2 \) are the distances between the two microphone positions from the reference plane \( x = 0 \); and \( k_0 \) is the wave number defined as \( k_0 = \frac{2\pi f}{c_0} \), where \( f \) is the frequency and \( c_0 \) the speed of sound.

The transfer functions for the incident wave, \( H_i \), and for the reflected wave, \( H_r \), can be calculated by

\[ H_i = e^{-j k_0 (x_1 - x_2)} \]  
\[ H_r = e^{j k_0 (x_1 - x_2)} \]  

Comparing Eqs. (3) and (4), the normal incidence reflection factor, \( r_i \), can be calculated using

\[ r = \frac{H_{12} - H_i}{H_{12} - H_i} e^{2j k_0 x_1} \]  

Further the sound absorption coefficient, \( AC \), can be determined in terms of \( r \) by the following equation

\[ AC = 1 - |r|^2 = 1 - (r_i^2 + r_r^2) \]
3. Results

3.1 Fundamental parameters

The results of fundamental parameters of nonwovens involved are listed in Table 1. These parameters include raw material, thickness, gram square meter, porosity and mean pore diameter.

3.2 Permeability properties

The permeability properties of six nonwovens are shown in Fig. 2. Based on Kozeny Equation, the permeability coefficient is [11-13]

\[ K_{sp} = \frac{\varepsilon^3}{\eta s^2 \kappa}, \]  

(7)

where \( \kappa \), the Kozeny constant, is

\[ \kappa = k_0 t_f, \]  

(8)

and \( t_f \), the tortuosity, is

\[ t_f = \frac{L_e}{L}, \]  

(9)

where \( \varepsilon \) is porosity of the sample, \( \eta \) is viscosity of the flow, \( s \) is channel wetted surface, \( k_0 \) is shape factor, and \( L_e \) is effective channel length, or effective sample thickness.

Mohammadi [14] has modified Kozeny Equation using Davies’ permeability coefficient equation \( k_D \) [11], and derived the theoretical permeability \( q_{sp} \) for fibrous structures with porosities ranging from 0.94 to 0.994

\[ q_{sp} = \frac{d^3 \varepsilon^3 \Delta p}{16 k_D \eta (1-\varepsilon)^2 L} \text{ cm/s} \]  

(10)

where \( d \) is fiber diameter, \( \Delta p \) is the pressure difference besides sample, and \( L \) is the thickness of the sample.

From Eq. (10) it can be seen that the permeability is not just linear to porosity, but also relates to many other complex and difficult-to-measured parameters such as tortuosity, shape factor etc.

3.3 Sound absorption properties

The paper measures the sound absorption properties of the six samples without air gap, with 15mm air gap, and with 30mm air gap behind, respectively. The results are shown in Fig.3. It indicates that, the sound absorbing results of samples with and without air gap behind are completely different. Introducing air gap can enhance the absorbing effect of nonwovens greatly, especially at the frequency range of 1000-4000Hz.

Fig.3 (a) shows the result of samples tested with rigid back. It can be seen that the sound absorption coefficient is improved by the increasing thickness. From Table 1 it can be seen that the order of thickness of samples is 5>6>3>2>4>1, whereas the thickness of samples 1-4 are nearly the same.

While Fig.3 (b) shows the sound absorbing result of samples tested with 15mm air gap, and Fig.3 (c) shows that of 30mm air gap behind. From these two figures, we can see that the increasing air gap makes the absorption curve shift towards lower frequency, and enhances the initial slopes of the curves.

<table>
<thead>
<tr>
<th>No.</th>
<th>Raw material</th>
<th>Thickness (mm)</th>
<th>Gram square meter (g/m²)</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PET</td>
<td>0.523</td>
<td>42.46</td>
<td>0.941</td>
</tr>
<tr>
<td>2</td>
<td>PET/VS 70/30</td>
<td>0.779</td>
<td>84.50</td>
<td>0.923</td>
</tr>
<tr>
<td>3</td>
<td>PET</td>
<td>0.828</td>
<td>123.14</td>
<td>0.892</td>
</tr>
<tr>
<td>4</td>
<td>Superfine Fiber</td>
<td>0.673</td>
<td>141.12</td>
<td>0.850</td>
</tr>
<tr>
<td>5</td>
<td>Fiberglass</td>
<td>5.275</td>
<td>505.02</td>
<td>0.963</td>
</tr>
<tr>
<td>6</td>
<td>Basalt Fiber</td>
<td>3.490</td>
<td>581.03</td>
<td>0.937</td>
</tr>
</tbody>
</table>
4. Discussion

The theory of capillary effect of porous materials[15] has been used to explain the sound absorption property for a long time. It indicates that the sound absorbing properties are related to thickness, pore size and porosity. The sound impedance can be calculated by

\[ z = \frac{8\eta L}{\rho_s c_l \varepsilon a^2}, \]  

where \( z \) is sound impedance, \( L \) is thickness, \( \eta = 1.85 \times 10^{-5} \) is viscosity of air, \( a \) is pore radius, \( \varepsilon \) is porosity, and \( \rho_s c_l = 415s \) characteristic impedance of air.

It can be seen that Eq. (11) does not consider the issue of frequency \( f \); however, the sound impedance is changing with frequency. For the reason sound absorption coefficient is proportional to sound impedance, in this work we have compared the calculated sound impedance with the two series of experimental sound absorption coefficients of samples with air gap behind. One is average coefficient on the whole testing frequency, the other is peak value of coefficient. The results are plotted in Fig. 4. It can be understood from the figure that, the peak value of coefficient approximately has the same trend with that of the calculated impedance.

5. Conclusion

From modified Kozeny Equation and the permeability experiment, it can be seen that air permeability is not just linear to porosity, but also relates to many other complex and difficult-to-be-measured parameters such as tortuosity, shape factor etc.
Furthermore, in this work we compared the absorption coefficient of nonwovens with and without air gap behind, the sound absorption principles of these are completely different. For nonwovens with rigid back, the absorption coefficient increases with the increasing thickness. For samples tested with air gap, the increasing air permeability moves the absorption curve towards lower frequency, and enhances the initial slopes of the curves. And also the absorption coefficients over the whole frequency range are found to increase with air.

Theory of capillary effect explains the absorption coefficient values very well. However, it ignores the issue of frequency. So the accurate theories which can illustrate sound absorption property of nonwovens still need to be improved.

Acknowledgements

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References: