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 the 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.

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(3) Porosity

Porosity can be determined by

$$\varepsilon = 1 - \frac{m}{AL\rho}, \tag{1}$$

where m is weight of nonwoven sample, A is sample cross-sectional area, L is sample thickness, and ρ 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.

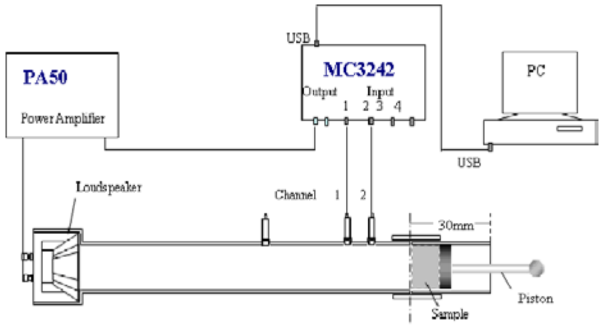

Figure 1 SW260 double-microphones standing wave tube.

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[10]

$$H_{12} = \frac{p_2}{p_1} = \frac{e^{jk_0x_2} + re^{-jk_0x_2}}{e^{jk_0x_1} + re^{-jk_0x_1}} \tag{2}$$

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 $k_0 = 2\pi f/c_0$, 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

$$H_I = e^{-jk_0(x_1 - x_2)} \tag{3}$$

$$H_R = e^{jk_0(x_1 - x_2)} \tag{4}$$

Combining Eqs. (3) and (4), the normal incidence reflection factor, r, can be calculated using

$$r = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_0x_1} \tag{5}$$

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

$$AC = 1 - |r|^2 = 1 - (r_r^2 + r_i^2) \tag{6}$$