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Technical note

Facile dip-coating method to prepare micro-perforated fabric acoustic absorber

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ABSTRACT

Fibrous materials have been extensively used in noise reduction due to its good acoustic absorption properties and artistic appearance. Nevertheless, the acoustic absorption coefficients of woven fabrics are relatively poor in low frequency. In this study, waterborne polyurethane solution was taken to coat the woven fabrics. The results indicated that coated woven fabrics exhibited good acoustic absorption coefficients in low and middle frequency. Furthermore, the experimental values were measured by impedance tube and further compared with *Maa's* model. It has been found that coated woven fabrics exhibited the micro-perforated panel acoustic absorption mechanism. Dip-coating method is effective to improve the acoustic absorption properties of woven fabrics at low frequency range.

1. Introduction

Micro-perforated panels have been widely used in noise reduction for many years. *Maa* has developed both approximate and general theoretical models to predict the sound absorption properties of micro-perforated absorber structures [1,2]. Currently, various algorithms have also been further developed to optimize the calculation process and characterize the acoustic absorption coefficients, such as finite element model, particle swarm optimization, multi-population genetic algorithm, and simulated annealing method [3–6]. The acoustic absorption properties of micro-perforated panels could be accurately designed by altering the structural parameters. According to *Maa's* model, the panel absorber could be made of any materials including cardboard, plastic, epoxy, wood, textiles, and metals. However, it is still a challenge to fabricate such sub-millimeter sized micro-perforated panels efficiently and economically.

In the dozens years ago, drilling and sewing methods were initially taken by *Maa* to fabricate micro-perforated panel, while the preparation process is inefficient and the diameter of the pore is relatively large [2]. Recently, various techniques including infiltration method, laser method, micro-mechanical method and 3D printing process have been presented to fabricate micro-perforated panels [7–10]. For instance, Qian et al. [11,12] has prepared micro-perforated panels with ultra-micro sized pores made of silicon using micro-electro-mechanical systems (MEMS) technology and template method. Liu et al. [13] has successfully fabricated micro-perforated panels with the matrix of polymer materials by using 3D printing technology. Textile techniques such as knitting and weaving were also utilized to make flexible fabric absorber with irregular pores, and the effects of structural parameters were investigated [14–16]. The results indicated that fabric could be analyzed as a micro-perforated panel acoustic absorber, and it has good sound absorption properties in mid-high frequency range while it is poor in the low frequency range.

In the present work, dip-coating method was taken to prepare micro-perforated fabric panel. As it has been demonstrated that such a process is facile and effective to the surface treatment of fibrous materials. Waterborne polyurethane was utilized as the coating solutions, which exhibited the environmental-friendly characteristics, good adhesion and chemical durability. This dip-coating technique with waterborne polyurethane can produce coated fabric with sub-millimeter sized perforations. The purpose of this research is to improve the acoustic absorption properties of woven fabrics in low frequency range via the optimized parameters. In addition, the effects of solution concentrations and fabric structural parameters on the acoustic absorption properties were analyzed, and then compared with *Maa's* model.

2. Materials and methods

Woven fabric used in this study was obtained from DMC Co., Ltd., France. The structural parameters of all the fabric samples are listed in Table 1. Waterborne polyurethane (WPU, solid concentration of 30%, viscosity less than 250 mPa·S) was supplied by Guanzhi Chemical Co.,

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Table 1
Physical parameters of woven fabrics used in this study.

Sample	Thickness (mm)	Diameter (mm)	Perforation (%)	Weight (g/m^2)	Stiffness (mN cm)	Air permeability (mm/s)
C-1	0.773	0.258	1.65	245	49.61	403.3
C-2	0.719	0.553	2.94	301	100.96	630.5
C-3	0.750	0.534	4.51	292	156.23	732.6

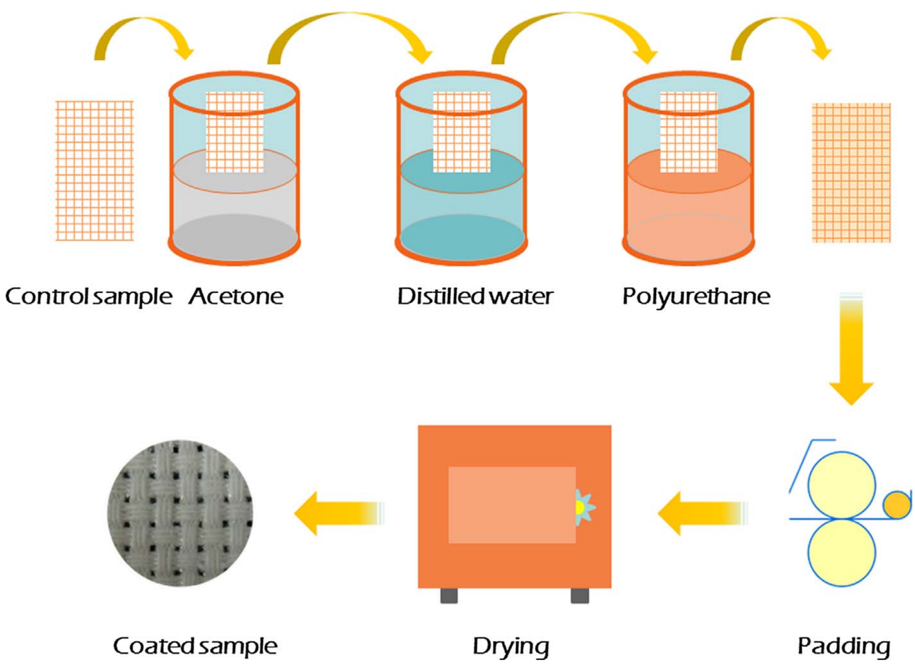

Fig. 1. Fabrication process of coated fabrics via dip-coating method.

Ltd., Guangzhou, China. Distilled water was used to process and rinse all the samples.

The preparation process of waterborne polyurethane woven fabrics could be seen from Fig. 1. All the samples were firstly cleaned with acetone and rinsed with distilled water to remove the impurity. Then the pre-treated woven fabrics were dipped into waterborne polyurethane solutions with different concentrations including 9%, 14%, 20% and 28%. The coating process was therefore designated as #1, #2, #3 and #4 respectively. After 15 min, the specimens were padded to primarily remove redundant aqueous solutions. Subsequently, all the treated samples were cured at 60 °C for 120 min.

The air permeability was measured by YG461E numerical type fabric air permeability instrument based on ASTM D737 standard (Standard Test Method for Air permeability of textile fabrics). SW-260 double-microphones impedance standing wave tube was used to test the acoustic absorption properties. The schematic illustration of acoustic absorption measurement is shown in Fig. 2. The equipment consists of a loudspeaker, a digital frequency analysis system, an impedance tube, a power amplifier and two precision sound level microphones, etc. The test process was according to the method of ASTM E 1050 (Standing Test Method for Impedance and Absorption of Acoustic Properties Using a Tube, Two Microphones and a Digital Frequency Analysis System). Circular test samples with a diameter of 35 mm and 80 mm were used to measure the absorption properties at high and mid-low frequency respectively. The acoustic absorption coefficients at the frequency from 100 to 6300 Hz was calculated by the VA-lab system.

3. Results and discussions

3.1. Structural parameters of woven fabrics

The optical images of control and coated woven fabric processed with different solution conditions are shown in Fig. 3. It could be seen that the fabric has the approximate square perforations. The diameter is gradually decreased with the increasing of waterborne polyurethane concentrations. In details, the structural parameters of three kinds of control and coated fabrics (C-1, C-2 and C-3) are listed in Tables 2–4. The diameter of control C-1, C-2 and C-3 fabric are 0.258 mm, 0.553 mm and 0.534 mm, while the perforation ratio is 1.65%, 2.94% and 4.51% respectively. After the coating of waterborne polyurethane solution, both perforation ratio and perforation diameter are gradually decreased. However, the thickness and areal weight will be gradually increased with the increasing of coating solution concentrations. The thickness of all the samples is ranging from 0.7 mm to 0.9 mm, which is significantly lower than the wavelength of acoustic waves. Therefore, all the control and coated fabrics could be seen as sheet acoustic absorbers. In addition, the areal weight of coated fabrics is also obviously increased with the increasing of waterborne polyurethane solution. The air permeability of control and coated samples was also measured. It has been found that the air permeability will be gradually decreased with the increase of coating solution concentrations.

3.2. Measurement of acoustic absorption properties

The measured acoustic absorption coefficients of C-1, C-2 and C-3 fabric are shown in Figs. 4–6. It could be observed that all the fabric samples exhibited poor acoustic absorption properties when without back air gap, as shown in Fig.4(a), Fig.5(a) and Fig.6(a). As sheet fibrous materials, woven fabric without air gap could not effectively absorb acoustic energy. However, the acoustic absorption properties could be improved by the presence of air gap [17,18]. In this work, the effects of air gap with the distance of 1 cm, 2 cm and 3 cm were studied. As shown in Fig. 4(b), (c) and (d), woven fabrics with air gaps have good acoustic absorption properties. With the increasing of air gap