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Investigation on Sound Absorbing Performance of the Polyester Fiber for Noise Reduction in Large-scale Equipment

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Abstract. Polyester fiber was attempted to reduce the noise in large-scale equipment. Sound absorbing performance of the polyester fiber with different parameter was investigated based on the standing wave method. Experimental result showed that the sound absorbing coefficients were ameliorated along with the increases of thickness of the polyester fiber. Meanwhile, for the same thickness, the corresponding sound absorbing coefficient of polyester fiber with density of 0.3g/cm^3 was better that of 0.2 g/cm^3. Furthermore, it could be observed that sound absorbing coefficients were almost increasing linearly along with increase of frequency when thickness of the polyester fiber was low. It would be found that there existed peak of the sound absorbing coefficients when the thickness was large. Especially when the thickness reached 24mm, the sound absorbing coefficients in the frequency range of 2000Hz ~ 6000Hz exceeded 90%. The excellent sound absorbing performances of the polyester fiber would be propitious to reduce noise in large-scale equipment.

1. Introduction

Noise reduction is a significant problem in the large-scale equipment, which affects its viability and working efficiency, especially for the submarine and surface warship [1]. For the noise reduction in the cabin, polyester fiber is considered as a promising sound absorbing material [2, 3], because it has the excellent sound absorbing coefficient and can be installed on the inner wall. However, with the different parameters, such as different density or different thickness, sound absorbing performance of the polyester fiber is varied [4]. Meanwhile, sound absorbing coefficient of polyester fiber corresponds to the sound frequency [5]. Therefore, the investigation on sound absorbing performances of the polyester fibers with different parameters is necessary and significative.

Two kinds of polyester fibers with densities of 0.2g/cm^3 and 0.3g/cm^3 were investigated in this study. For each kind of polyester fiber, the investigated thicknesses of the samples were 8mm, 16mm, and 24mm, respectively. Meanwhile, the sound absorbing coefficients of each sample corresponding to the different sound frequencies were achieved according to the standing wave method [6]. Through comparing sound absorbing performances of the polyester fibers with different parameters, the optimal option for the noise reduction in a certain frequency range was achieved.

2. Experimental apparatus

Sound absorbing coefficients of the polyester fibers were detected by the AWA6128A detector, as shown in Figure 1. In order to meet the requirement of the detector, dimensions of the samples were set to ϕ 96mm for the detection in the low sound frequency range and ϕ 30mm for the detection in the high sound frequency range, which were realized by the laser cutting technique [7].

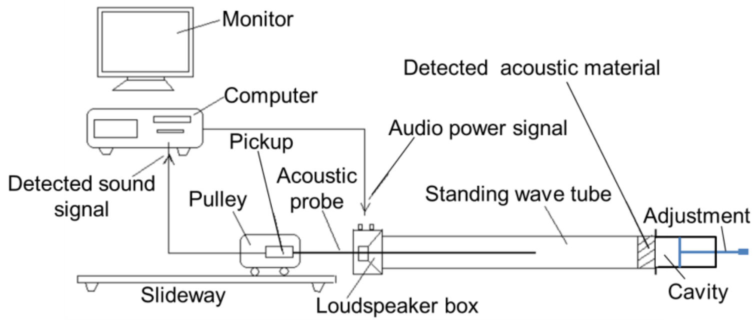

Figure 1. Schematic diagram of the experimental apparatus

The obtained data of the detector were peak sound level L_{max} and the corresponding valley sound level L_{min} of the detected sample for the certain frequency, and the corresponding sound absorbing coefficient α can be calculated by Eq. 1.

$$\alpha = \left(4\times 10^{\left(L_{\max}-L_{\min}\right)/20}\right) \Big/ \left(1+10^{\left(L_{\max}-L_{\min}\right)/20}\right)^2 \tag{1}$$

3. Results and discussions

The summarized data of sound absorbing coefficients for the polyester fibers with different parameters were shown in Table. 1. The detected low frequency of each sample included 100Hz, 200Hz, 300Hz, 400Hz, 500Hz, 600Hz, 700Hz, 800Hz, 950Hz, 1100Hz, 1300Hz, 1500Hz, 1700Hz, and 1900Hz, and the detected high frequency included 2000Hz, 2300Hz, 2600Hz, 2900Hz, 3200Hz, 3500Hz, 3800Hz, 4100Hz, 4400Hz, 4700Hz, 5000Hz, 5300Hz, 5600Hz, and 6000Hz, which were conducted according to instruction of the detector. It could be easily observed that for different densities and thicknesses, distribution of sound absorbing coefficients corresponding to varied sound frequency was distinct.

Table 1. Summarized Data of Sound Absorbing Coefficients.

Density	$0.2g/cm^3$			$0.3g/cm^3$		
Thickness / **Frequency**	8mm	16mm	24mm	8mm	16mm	24mm
100Hz	3.2	3.8	4.5	3	3.6	4.3
200Hz	2.7	4.5	7	2.4	3.9	7.3
300Hz	4	6.5	11.8	3.1	7.5	12.2
400Hz	4.8	9.3	17.7	4.7	11.3	23
500Hz	7.7	12.6	25.5	5.8	15.4	32.4
600Hz	8.3	16.2	30.6	12.4	23.2	40.8
700Hz	9.2	19.4	39	7.8	25.2	50.5
800Hz	9.9	24.2	47	10.3	30.5	59.3
950Hz	12.8	29	56	12.4	37.9	68.8
1100Hz	8.3	30.5	61.9	9.1	47.8	76.3
1300Hz	18.8	43.3	75.7	22.5	59.7	84.5
1500Hz	19.5	51.9	83.2	22	67	89.7
1700Hz	22.5	58.7	89.9	25.8	73.6	93.3
1900Hz	24.5	66.2	94.4	30.2	82	94.4
2000Hz	28.7	74.3	98.7	40.5	82.1	98.7

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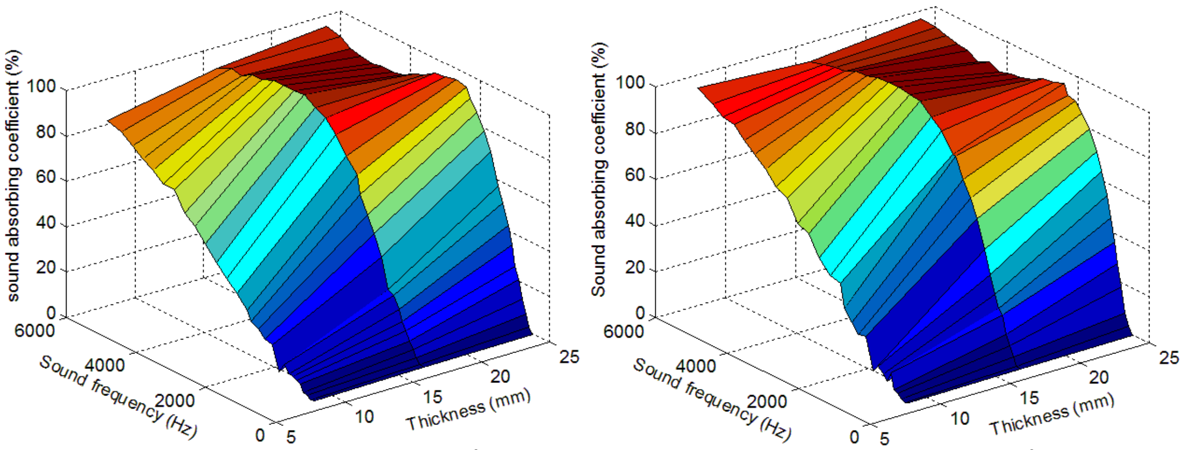
2300Hz	33.6	80	99.7	41.3	90.1	96.9
2600Hz	38.2	87.3	98.8	46.9	93.9	96.3
2900Hz	42.9	92.3	98	55.1	98.2	93.5
3200Hz	48.5	94.7	94.9	57.3	99.1	92.2
3500Hz	54.2	97.9	93.2	65.7	100	91.3
3800Hz	57.6	97.6	90.5	68.4	99.7	90.2
4100Hz	65.5	97.8	89.4	73.7	99.5	92.2
4400Hz	65.7	97.5	89.6	77.9	97.9	90
4700Hz	69.7	95.7	88.3	81.7	97.5	92.6
5000Hz	72.3	95.4	89.6	86.2	95.3	93
5300Hz	75.8	92.6	90.4	87.2	94.7	94.5
5600Hz	79.7	93.6	93.6	90.6	93.4	95.8
6000Hz	81.5	90.6	94.9	94.6	91.6	96.3

In order to intuitionally exhibit the evolution principle of the acoustic performances along with the increase of thicknesses, the sound absorbing coefficients for the three samples with the density of 0.2g/cm^3 and those with the density of 0.2g/cm^3 were shown in Figure. 2. It could be observed that along with the increase of thicknesses of the sample, sound absorbing coefficient for each frequency was entirely improved. However, along with the increase of frequency, sound absorbing coefficient was not increasing by degrees.



(a) with density 0.2g/cm^3 (b) with density 0.3g/cm^3

Figure 2. Sound absorbing coefficients for samples

For the purpose of the further quantitative analysis of the sound absorbing coefficient, the whole data was summarized in Figure 3. It could be found that thicknesses of the polyester fibers had a great influence to sound absorbing coefficients. Along with the increase of thickness, the sound absorbing coefficients in the low frequency range was raised, and that in the high frequency range was steadier, which was suitable for the samples with two densities. It had been considered that the sound wave with a high frequency was primarily absorbed by the surface of the sound absorbent, and that with a low frequency was mainly absorbed by the inner structures of the polyester fiber or porous material [8]. Meanwhile, it could be observed that the sound absorbing coefficient of the polyester fibers with density of 0.3 g/cm^3 was better than that of the polyester fibers with density of 0.2 g/cm^3.

It could be observed that the sound absorbing coefficients of polyester fiber were almost increasing linearly along with increase of frequency when thickness of the polyester fiber was 8mm, no matter the density was 0.2g/cm^3 or 0.3g/cm^3. It would be found that there existed peak value of the sound absorbing coefficients when thickness of the polyester fiber was 16mm or 24mm. Especially when the thickness reached 24mm, sound absorbing coefficients of the polyester fiber in frequency range of 2000Hz ~ 6000Hz exceeded 90%.

For the six series of experimental data, the relationships between sound absorbing coefficients and sound frequencies were investigated by data fitting according to the triple sine function, as shown in Eq. 2, and the related parameters which corresponded to the thickness 8mm with density 0.2g/cm^3, thickness 16mm with density 0.2g/cm^3, thickness 24mm with density 0.2g/cm^3, thickness 8mm with density 0.3g/cm^3, thickness 16mm with density 0.3g/cm^3, and thickness 24mm with density 0.3g/cm^3 were summarized in Table 2.

Comparisons of the data fitting results and the original experimental data were shown in Fig. 5. It could be observed that these fits were fine. The total departure of the regressive average value $R-square$ (R^2) was introduced to quantitative evaluate prediction accuracy of data

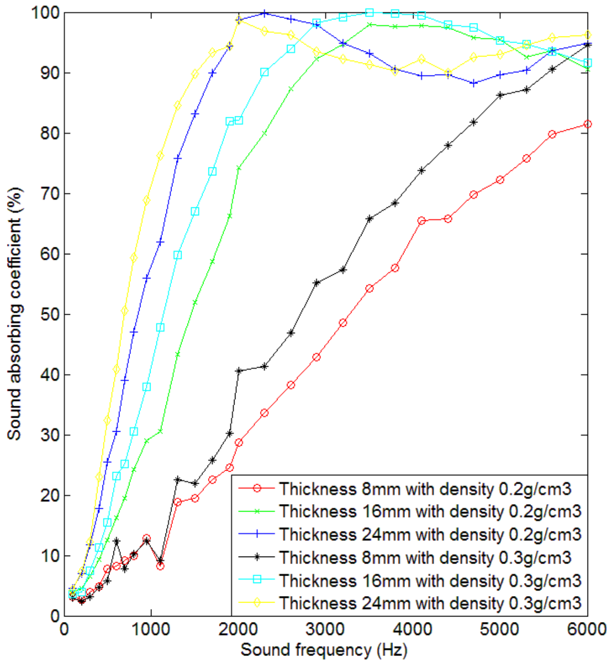


Figure 3. Summarized sound absorbing coefficient

fitting [9], and it could be obtained by Eq. 3. Here α_{ei}, α_{pi}, and N were the actual sound absorbing coefficient obtained by the experiment, the sound absorbing coefficient achieved by data fitting, and the experiment time, respectively. In this study, the detected frequency points were 27.

$$\alpha(\omega)=a_1 \sin(b_1\omega+c_1)+a_2 \sin(b_2\omega+c_2)+a_3 \sin(b_3\omega+c_3) \quad (2)$$

$$R^2 = 1-\frac{\sum_{i=1}^{N}\left(\alpha_{ei}-\alpha_{pi}\right)^2}{\sum_{i=1}^{N}\alpha_{ei}^2} \quad (3)$$

Table 2. The Related Parameters in the Data Fitting.

Density	0.2g/cm^3			0.3g/cm^3		
Thickness / **Parameters**	8mm	16mm	24mm	8mm	16mm	24mm
a_1	128.7	168.5	103.3	10010	106.6	106.3
b_1 **(10^{-4})**	4.558	3.578	3.364	4.592	3.731	3.768
c_1	-0.368	1.241	0.1774	0.0976	0.0138	0.1132

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a_2	92.53	153.7	270.1	9956	8.217	70.46
b_2 **(10^{-4})**	6.927	5.513	14.97	4.604	13.17	16.17
c_2	2.246	4.31	-2.096	3.24	1.765	-1.552
a_3	25.18	32.06	257.1	2.153	17.13	54.94
b_3 **(10^{-4})**	9.588	10.4	15.1	17.03	13.39	17.38
c_3	4.546	5.71	7.249	3.186	5.038	7.413

According to Eq. 3, the calculated R^2 of the six models and the six groups of experimental data was 0.9972, 0.9987, 0.9979, 0.9946, 0.9974, and 0.9967, respectively, which corresponded to the thickness 8mm with density 0.2g/cm^3, thickness 16mm with density 0.2g/cm^3, thickness 24mm with density 0.2g/cm^3, thickness 8mm with density 0.3g/cm^3, thickness 16mm with density 0.3g/cm^3, and thickness 24mm with density 0.3g/cm^3. It was considered that the prediction was reliable when the evaluation index R^2 is larger than 0.99. The larger R^2 is, the more reliable the prediction is. It could be found that all R^2 were larger than 0.99, and the average value reached 0.9971.

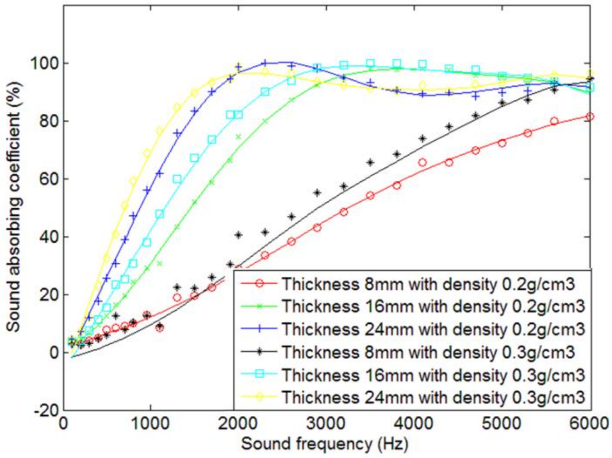

Figure 4. Comparison of theoretical and experimental result.

4. Theoretical analysis

Structure of the inner polyester fiber was a complicated topological structure, which indicated that the absorption of sound in the polyester fiber was a complex dynamic system. The absorption mechanism of sound in the polyester fiber included the following three ways [10]. Firstly, when the sound penetrated into the polyester fiber, air in the interspace among the fibers would be excited vibration and the air could rub wall of the fibers, which resulted in reduction of sound energy by the viscosity resistance. Secondly, there existed temperature gradients among the different particles in the polyester fiber, which would consume some sound energy by thermal conduction [11]. Thirdly, the vibration of fibers also would lead to dissipation of the sound energy. Therefore, the sound absorbing performance of the polyester fiber was influenced by the thickness, density, dimension of the cavity, surface treatment, and other parameters of the polyester fiber.

According to the diffusion characteristics of the sound in the round tubule, the relationship between sound absorbing coefficient α and these parameters of the porosity ϕ, pore tortuosity α_∞, angle frequency ω, glutinous permeability q_0, glutinous characteristic length Λ, thermal permeability q_0', and thermal characteristic length Λ' were shown in Eq. 4 and Eq. 5. The media density and volume bulk modulus could meet the relationships in Eq. 6 and Eq. 7.

$$\alpha(\omega)=\frac{\nu\phi}{j\omega q_0}\left\{\sqrt{\left[1+\left(\frac{2\alpha_\infty q_0}{\varnothing\Lambda}\right)^2\frac{j\omega}{\nu}\right]}\right\}+\alpha_\infty \tag{4}$$

$$\alpha'(\omega)=\frac{\nu'\phi}{j\omega q_0'}\left\{\sqrt{\left[1+(\frac{2q_0'}{\varnothing\Lambda'})^2\frac{j\omega}{\nu'}\right]}\right\}+1 \tag{5}$$

$$\rho=\rho_0\alpha(\omega) \tag{6}$$

$$K=\frac{\gamma P_0}{\gamma-(\gamma-1)\alpha'(\omega)} \tag{7}$$

It could be found that the theoretical expression of the sound absorbing coefficient was extraordinary complicated, which limited its application in predicting sound absorbing coefficient [12]. What's more, establishments of these parameters in Eq. 4 were time-consuming and inefficient [13], which increased the difficulties in practice. Furthermore, it had been reported that accuracy of the model was high in the middle frequency and low in the high or low frequency [14], which meant that novel method was urgently required. In order to promote the application of polyester fiber in the fields of acoustics, development of the practical prediction model would be research focus in future [15, 16].

5. Conclusions

Investigation on the sound absorbing performance of the polyester fiber for noise reduction in large-scale equipment was conducted in this study. Experimental results indicated that the polyester fiber was an excellent acoustic absorption, which could be propitious to reduce the noise in large-scale equipment and improve its acoustic stealth performance.

6. Acknowledgments

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