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Study of the Sound Absorption Performance of Ethylene-Vinyl Acetate Foam Materials

Wei GONG [1, 2], Yu Long MA [1, 2], Da Ming BAN [1], Xiao Gang YIN [1], Li HE [1, 2] *, Hai FU [1]

[1] *College of and Architectural Engineering, Guizhou Normal University, Guiyang 550025, Guizhou, China*
[2] *National Engineering Research Center for Compounding and Modification of Polymer, Guiyang 550014, Guizhou, China*

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Ethylene-Vinyl Acetate (EVA) polymer foam was prepared using a mold for this investigation. The effect of the cell structure parameters and pore filling gas type on the sound absorption performance of the EVA foam materials were analyzed in terms of their sound absorption capability. The results show that the cell size, cell wall thickness and pore filling gas type have significant influence on the sound absorption performance. When the cell size is 71.3 μm, at low frequency (1000 Hz) the absorption coefficient was the largest at 0.487 and the absorption effect was good. With the increase of the cell wall thickness, the peak value of the sound absorption coefficient first increased and then decreased, and gradually transferred to the low frequency area. When the cell wall thicknesses were 14.3 μm, the foam material had optimal sound absorption properties. The cell filling gas was hydrogen, the EVA foam material had optimal sound absorption effect, and the sound absorption peak value was 0.553 at 800 Hz in the low frequency range (I), the sound absorption performance of the foamed materials was ideal.

Keywords: EVA foam materials, sound absorption mechanism, pore structure, sound absorption coefficient.

1. INTRODUCTION

As the times progress, there is more and more significant environmental noise, leading to adverse influence on communication, health and living quality, mainly in industrial noise, which accounts for 27 %, traffic noise (33 %) and live noise (40 %). For this reason, efficient sound absorption will work as a “quick capsule” [1, 2].

At present, high porosity materials often are adopted for sound absorption and heat insulation. According to research on the influence of different foam sizes on sound absorption property of titanium/nickel alloy foam by Liu et al [3], when the foam size is 60 μm, the first resonance frequency occurs at the frequency of 2000 Hz, with the sound absorption coefficient larger than 0.6. Li et al. [4] investigated the influences of material thickness and back cavity thickness on the sound absorption effect of aluminum foam materials. They found that the flow resistance gradually increased with increase in the thickness and the back-cavity width, which increased the effectiveness of sound absorption. Additionally, the sound absorption peak value was gradually transferred to lower frequencies. Lisi et al. [5] prepared closed-cell aluminum alloy foam materials by the melt foaming method and discussed the influence of materials density, thickness and back cavity width on the sound absorption characteristics of closed-cell aluminum alloy foam. The results showed that the peak value of the sound absorption coefficient decreased with increase in cell density. With increasing thickness and a wider back cavity, the peak value of the sound absorption coefficient decreased, and when the thickness was 20 mm, the sound absorption characteristic was ideal. Xiu et al. [6] prepared a polyvinyl chloride composite foam material using the molded foaming method, to study the effects of inorganic content on sound absorption characteristics. The results showed that the sound absorption performance of the composite foaming material decreased with the increase in the inorganic content, due to the poor compatibility of the inorganic material with the polyvinyl chloride material, which interfered with the foaming process and resulted in a deterioration of the cell structure. Ao et al. [7] have investigated the effect of gradient structure on the sound absorption characteristics of Fe-Cr-Al fiber porous materials. The results show: because of the multilayered fibrous porous material of the complicated internal structure, it is beneficial to the viscous and thermal loss of the acoustic energy, so that the sound absorption characteristics of the multi-layer gradient Fe-Cr-Al fiber porous material is better than the single frequency in the frequency range of more than 2000 Hz, up to about 0.9. Liu et al. [8] have prepared foaming polycarbonate using 3D printing technology and artificial perforation, they have studied the effect of different perforation angles on sound absorption performance of foaming polycarbonate. The results showed that the sound absorption peak of the porous polycarbonate material fluctuates in the range of 2000 Hz to 4000 Hz in 0°, and as the perforation angle increases, the sound absorption characteristics decrease. When the perforation angle is 45°, the sound absorption coefficient is the smallest, the sound absorption worst.

The above research improved the high frequency sound absorption property of foam materials to certain extent. However, the low frequency sound absorption characteristics were poor. More importantly, the alloy foam material was expensive. PVC foam products easily produce "white pollution" and other environmental problems. Therefore, the development of a cost-effective

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* Corresponding author. Tel.: +8-685-183227439; fax: +8685183227439.
E-mail address: *prcheli@163.com* (L. He)

material to replace the traditional materials as sound absorption and insulation materials has become a key technical issue to be solved.

As an environmentally-friendly polymer material with abundant raw material sources, low cost and ideal comprehensive properties, which is easy for machine shaping, ethylene vinyl acetate (EVA) can be applied for sound absorption. Although scientists at home and abroad have undertaken research on the sound absorption properties of polymer foams, no systematic researches have been reported, especially into the influence of cell structure parameters. Therefore, by preparing EVA foam materials using a mold/pressing method, and in combination with the mechanisms of sound absorption, the present study investigated the influence of foam size, foam wall thickness and foam filling gas on foam sound absorption properties. The findings produced theoretical guidance that broadened researches into sound absorption and heat insulation.

2. EXPERIMENTAL

Ethylene-Vinyl Acetate copolymer (EVA), grade 40W, was obtained from the DuPont Company, USA. Azodicarbonamide (AC) as the chemical blowing agent (CBA) was obtained from Kekotite Co., Ltd., Guizhou Province. Dicumyl peroxide (DCP) was obtained from Shanghai China Chemical Reagent Co., Ltd., ZnO (zinc oxide) was sourced from the Jiangsu Branch of a zinc industry group, and $ZnSt_2$ (zinc stearate) as CBA activators were commercially available and used as masterbatches.

In order to obtain different sizes of EVA foam material,the temperature of the plastic mixing mill (SK-100, Shanghai Branch of the Rubber and Plastics Machinery Co., Ltd.) was adjusted to 90 °C, with the roller space of 0.5 mm. The EVA material was added for 15 minutes, and then the foaming agent, AC, was mixed in, together with the cross-linking agent DCP and the assister $ZnO/SnSt_2$(Expanding the decomposition temperature range of foaming agent AC), In this study, the CBA and activator masterbatches were used at 15 wt.% and 5 wt.% levels, respectively. The roller space of the plastic mixing mill was increased and slices were cut as per the mold shape. The slices then were pressed in the mold and foaming on the vulcanizing machine (XLB-D350×350×2) to prepare the EVA foam material. It was then cooled down and cut in readiness for the property tests.

3. CHARACTERIZATION

3.1. Scanning electron microscopy (SEM)

The samples were placed in liquid nitrogen for 3 h, brittle fractured, the cross-section sprayed with gold, before being examined and photographed in the scanning electron microscope (KYKY-2800B, Beijing China Branch Instrument Co., Ltd.). Image-pro software was used to count the cell density and the cell size and cell wall thickness were calculated according to Eq. 1 – Eq. 3 [9]:

$$\overline{D_n} = \frac{1}{n}\sum_{i}^{n} D_i \ ; \tag{1}$$

$$D_{mean} = 1.273\overline{D_n} \ ; \tag{2}$$

$$\delta = D_{mean}\left(\frac{1}{\sqrt[3]{1-\rho_f/\rho}} - 1\right). \tag{3}$$

In these equations: $\overline{D_n}$ is the cell size, μm; n is the number of cells; ρ_f is the foam sample density in g/cm^3; ρ is the density in g/cm^3; D_{mean} is the average cell volume diameter in μm; δ is the cell wall thickness, μm.

3.2. Sound absorption testing

The sound absorption coefficient (α) and noise reduction coefficient (NRC) were tested according to ISO13472.2-2010 in a standing wave tube tester (AWA6128A, Hangzhou Aihua Instrument Co. Ltd.).

3.3. Tortuosity

When the material was not conductive, it was immersed in $CaSO_4$ solution for evaluation using the Montejano method. The resistivity (R_c) of the materials and the current between the two poles are measured by voltage. The tortuosity (T) is calculated using the following equation [10]:

$$T = V_f\left(\frac{R_c}{R_f}\right), \tag{4}$$

where R_f is the measured resistivity of the fluid, the measured voltage is 0 – 1.5 V; V_f is the porosity, %.

3.4. Density

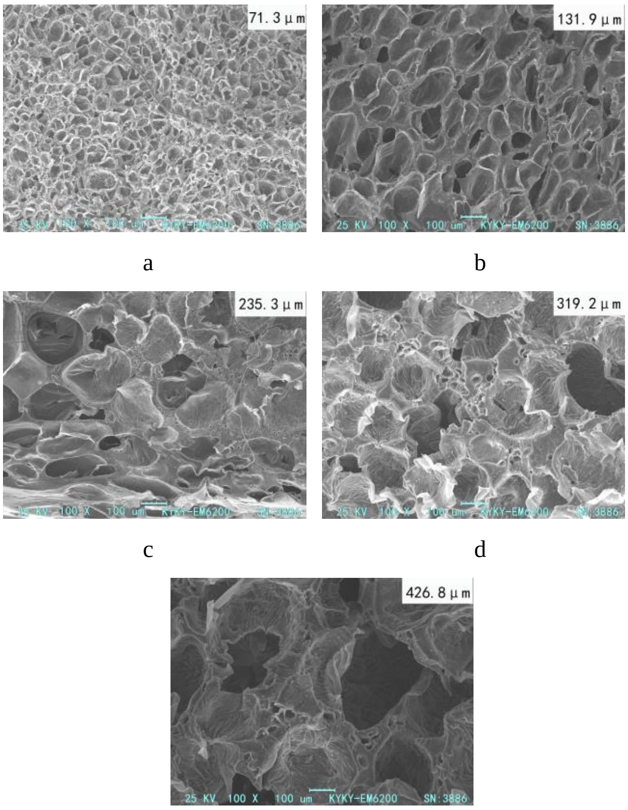
The density of the sample was evaluated according to ISO845-2006 using an XS electronic balance (XS-205, METTLER TOLEDO Instruments, Shanghai China Co., Ltd.).

4. RESULTS AND DISCUSSION

4.1. Effect of cell size on sound absorption properties of EVA foam materials

The foamed EVA materials with different cell sizes were prepared by different processes. The microstructures are shown in Fig. 1. The sound absorption performance test results for foamed EVA materials with different cell sizes are shown in Fig. 2.

According to Fig.2 a and b, foam cell size has a significant influence on the sound absorption coefficient and the noise reduction coefficient of the different EVA foam materials. The sound absorption coefficient decreased with increase in the foam cell size at low frequencies (I). However, it increased at higher frequencies (II). When the foam cell size was 71.3 μm, the sound absorption coefficient at the low frequency of 1000 Hz was maximum, at 0.487. However, it was less than 0.45 at high frequency area, where the noise reduction coefficient was as large as 0.358. When the foam cell size was increased to 426.8 μm, the sound absorption coefficient at low frequency was significantly decreased, but increased at high frequency, to 0.357 at the maximum. The noise reduction coefficient was small, i.e. 0.203, which was 43.3 % lower than that for 71.3 μm cells.



a b

c d

e

Fig. 1. Microstructure of different cell size. Note: The dimension given in the upper right corner of each micrograph represents the average cell size

The sound absorption property of the foam materials is mainly expressed on the viscous loss, the frictional loss and the heat loss in the materials. The viscous loss is expressed by characteristic length (Λ); the heat loss is expressed by characteristic length (Λ') and resonant frequency (f) And is calculated as per the following equation [11, 13]:

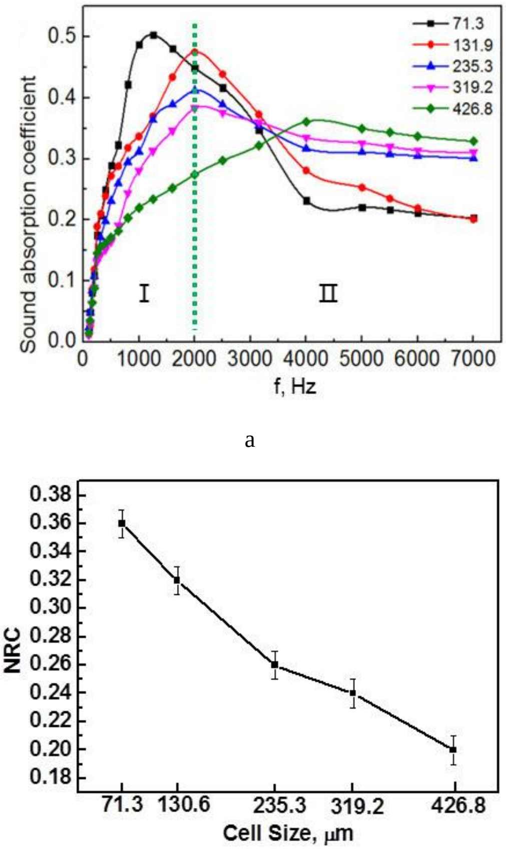
$$\Lambda = \frac{D}{c}\sqrt{T}\ ; \tag{5}$$

$$\Lambda' = \sqrt{\frac{8}{7}}D\ ; \tag{6}$$

$$f = \frac{\Gamma}{2\pi}\sqrt{\frac{V_f}{PD}}\ . \tag{7}$$

In these equations: c is the geometric parameter associated with the cell section, and the value is 1.07; P is the cavity thickness (P = 10 mm); D is the effective length of the hole (cell size), μm; T is the tortuosity; Γ is the speed of sound, ($\Gamma = 3 \times 10^{11}$mm/s). The results are shown in Table 1 by taking different cell sizes into Eq. 5, Eq. 6, Eq. 7.

It can be observed from Table 1 that with the increase of the foam cell size, the characteristic length of the viscous loss and the heat loss of sound waves in the materials increases.



a

b

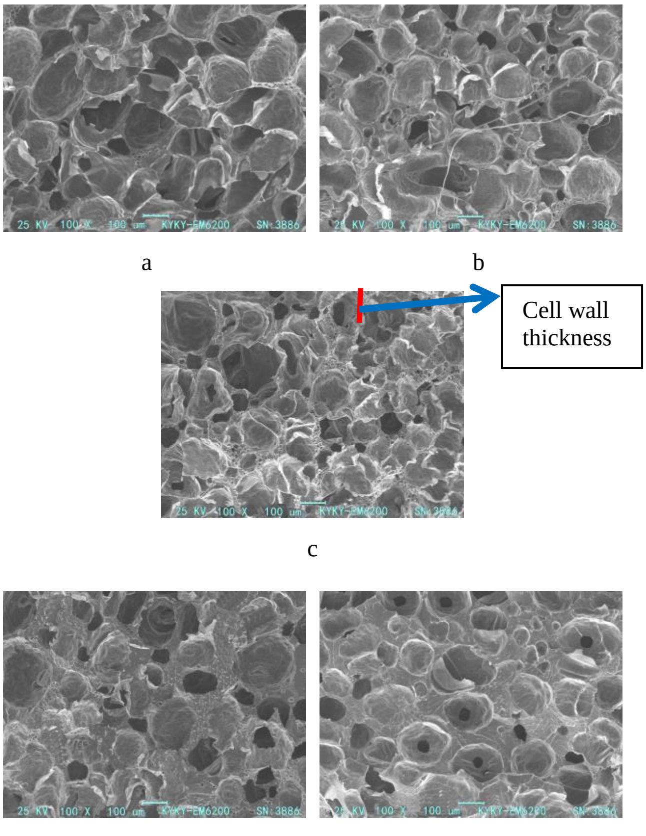
Fig. 2. a – sound absorption coefficients; b – noise reduction coefficients of foams with different cell sizes

Table 1. Different characteristics of foaming materials with different cell sizes

Cell size, μm	Porosity, %	Λ, μm	Λ', μm	T	Resonance frequency, Hz
71.3	79.1	73.33	76.2	1.211	5.05×10^{10}
131.9		133.17	139.6	1.167	3.72×10^{10}
235.3		233.25	251.5	1.125	2.78×10^{10}
319.2		314.01	341.2	1.108	2.39×10^{10}
426.8		354.76	456.3	0.791	2.07×10^{10}

In general, an increase in the characteristic length of viscous loss and heat loss increases the sound absorption property of foam materials [14]. However, with the increase of the foam cell size, the tortuosity value decreases (see Table 1), leading to the decrease of the sound absorption property. When the cell size is 71.3 μm, the tortuosity of the foam material is large, (1.211). When cell size was gradually increased to 426.8 μm, the tortuosity was small (0.791), which was 53 % less than for the condition of 71.3 μm. Thus, with an increase of the foam cell size, the propagation path of sound waves in the foam materials gradually tends to a linear type, significantly decreasing the propagation time of sound waves in the materials; i.e., the time for viscous loss, frictional loss and heat lost decreases, which leads to a reduction in the sound absorption property of the foam material.

In addition, the low-frequency sound waves are absorbed mainly inside the material, and high frequency sound waves are absorbed on surface of the material [15]. When sound waves enter into the foam material, if the foam size of the material is much too small (i.e. ~ 71.3 μm), the materials is compact and the sound waves may generate friction and reflection in the foam materials. As the resonant frequency is as large as 5.05×10^{10} Hz, it is easier for this to cause vibration of the foam wall, leading to an increase in the dissipation of low frequency sound energy and an increase in the low frequency sound absorption property. When the foam cell size is much too large (e.g. 426.8 μm), high frequency sound waves can penetrate the interior of the materials, significantly increasing the absorption of high frequency sound waves. However, too large a cell size and the resulting loose structure, as well as the small resonant frequency of 2.07×10^{10}Hz, means very little effective damping friction is generated between sound waves and foam and the reflection effects are small, which results in only a small loss of low frequency sound energy.



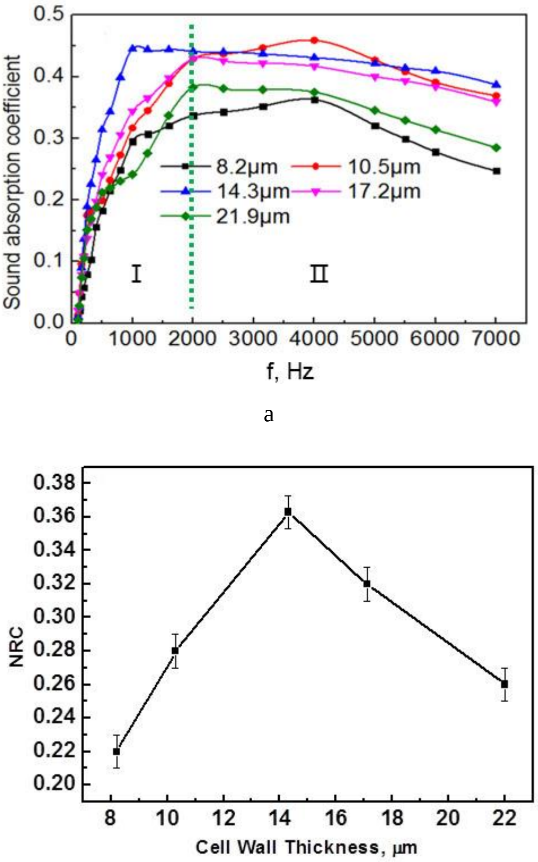
a b

c

d e

Fig. 3. Microstructures of different cell wall thicknesses.note: the dimension shown in the upper right corner of the photo represents the thicknesses of the cell wall (cell wall thicknesses: a – 8.2 μm; b – 10.5 μm; c – 14.3 μm; d – 17.2 μm; e – 21.9 μm)

The influence of different foam wall thicknesses (as shown by the red arrow in Fig. 3 a) on figure a the sound absorption coefficient and Fig. 3 b noise reduction coefficient of foam are shown in Fig. 4.



a

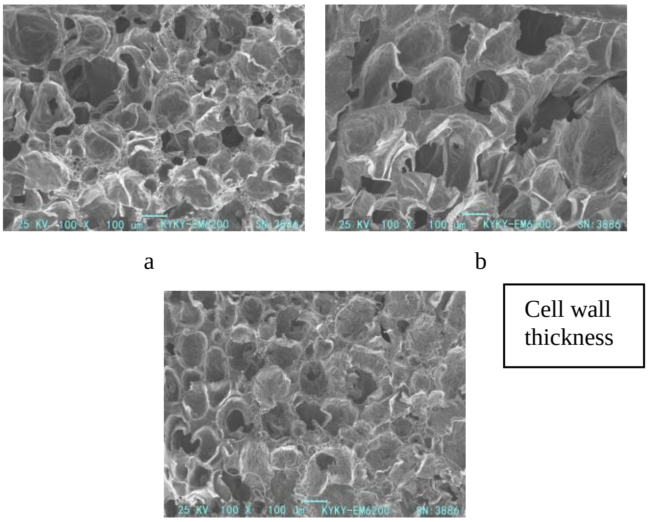
b

Fig. 4. a – sound absorption coefficients; b – noise reduction coefficients of foams with different cell sizes

It is evident, the sound absorption property of foam materials increases at first and then decreases with the increase of the foam wall thickness. When the foam wall is as thin as 8.2 μm, the foam has poor sound absorption properties. The sound absorption coefficient at 4000 Hz in high frequency area (II) is the maximum at 0.363, and the noise reduction coefficient is 0.224. When the foam wall thickness is increased to 14.3 μm, the sound absorption coefficient is larger than 0.45 within the frequency scope of 1000 Hz – 6000 Hz, i.e. 19 % larger than that of the foam wall thickness of 8.2 μm. The noise reduction coefficient is large, at 0.372, which is a 1.02 times increase. However, when the foam wall thickness is increased to 21.9 μm, the sound absorption property reduces. This is mainly because that the foam wall is easy to overcome, due to the impact and the compressing effects of sound waves. The reduction on the sound absorption surface area in the materials leads to the reduction in Helmholtz resonation, weakening the viscous loss and the heat loss effects of the foams, leading to a reduction of the sound absorption property of the foam materials. However, a foam wall that is much too thick seriously weakens the resonance effect between sound waves in the materials and the gas solid phase, leading to a reduction in the loss effects of the viscous loss and the heat loss on sound waves, which results in a reduction in the sound absorption property [16].

4.3. Effect of filling gas on sound absorption properties of EVA foam materials

EVA foam materials were prepared with different filling gases by different foaming agents and the microstructures are shown in Fig. 5. Their sound absorption performance was tested and the results are shown in Fig. 6.



a b

c

Fig. 5. Microstructures with different filling gases: a – N_2; b – N_2+H_2; c – H_2

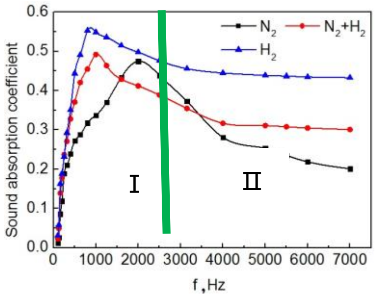


Fig. 6. Sound absorption coefficient of EVA foam with different filling gases

Table 2. Propagation velocity of sound waves at different filling gases [16, 17]

Filling gases	Propagation velocity, m/s
Nitrogen	334
Hydrogen	259
Nitrogen + Hydrogen	> 593

It can be observed from Fig. 6 that, different filling gases, including (for example) hydrogen (blowing agent is CH4), mixed gas of nitrogen and hydrogen (blowing agent is AC + CH4) and nitrogen (blowing agent is AC), the sound absorption coefficient follows a roughly declining trend within the whole frequency range, with the resonant frequency transferring to the high frequency area (II). When the filling gas is hydrogen, the foam material has a large sound absorption coefficient of 0.553 at the first resonance frequency (800 Hz). When the filling gas is a mixture of nitrogen and hydrogen, the sound absorption coefficient peak value was 0.492 at the resonance frequency (1000 Hz), an 11 % decrease from that of the hydrogen environment. However, when the filling gas was nitrogen, the maximum sound absorption coefficient was 0.475 at 1000 Hz, which was 14.1 % lower than that in the hydrogen atmosphere. Thus, when the filling gas was nitrogen, the sound absorption property was optimal. The sound absorption mechanism is caused mainly by the different propagation speeds of the sound waves in the different filling gases, as shown in Table 2 [16, 17]. Sound waves have large propagation speed in nitrogen + hydrogen, which significantly decreases the dissipation time of sound waves in the foam materials, there is a decrease of the sound absorption property, which gives a small sound absorption coefficient. When the filling gas is hydrogen, the sound wave propagation speed is small, delaying the loss of sound energy caused by viscous drag, friction and heat conduction, thereby improving sound absorption effect.

5. CONCLUSIONS

1. Foam cell size has a significant influence on the sound absorption property of EVA foam materials. With an increase of the foam cell size, the peak value of the sound absorption property decreases in the low frequency area and gradually increases in high frequency area. When the foam cell size was 71.3 µm, the sound absorption coefficient was the maximum of 0.487 at the low frequency of 1000 Hz.
2. With the increase of the cell wall thickness, the peak value of the sound absorption coefficient first increased and then decreased, and gradually transferred to the low frequency area. When the cell wall thicknesses were 14.3 µm, the foam material had optimal sound absorption properties.
3. When the cell filling gas was hydrogen, the EVA foam material had optimal sound absorption effect, and the sound absorption peak value was 0.553 at 800 Hz in the low frequency range (I).

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