WOOD RESEARCH
63 (4): 2018
559-572

SOUND ABSORPTION PROPERTIES OF WOODEN PERFORATED PLATES

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(Received July 2017)

ABSTRACT

Wooden perforated plates are used to control noise and optimize the indoor sound environment. In the paper, the effects of structure factors on the sound absorption properties, such as the absorption peak, resonant frequencies, and frequency bandwidth, were analyzed using the impedance tube transfer function method and SAS (Data analysis software) significant analysis. Experimental results showed that with the thickness of the medium density fiberboard (MDF) perforated plate increasing from 10 to 20 mm, the resonance absorption frequency shifts to the lower frequency. The depth of hole increased, the absorption peak reinforced. With the pore size increased, the resonance absorption frequency reduced and meanwhile the resonance peak absorption coefficient shrunk. The resonance frequency moves toward the high frequency direction and the sound absorption coefficient decreased when the perforation rate was increased from 3.14% to 7.07%. After increasing the air gap thickness from 25 to 100 mm, the resonance absorption frequency reduced and the sound absorption bandwidth remained relatively constant as the acoustic impedance of the MDF perforated plate did not vary in spite of the variation in the air gap thickness. But the absorption coefficient decreased. This paper may provide a certain theoretical basis for wooden perforated plate design and research.

KEYWORDS: Wooden perforated plate, structure factors, sound absorption, resonance frequency

INTRODUCTION

According to the needs of different occasions for different sound frequencies for selective absorption features, perforated plates having a good sound absorption performance stand out (Zulkifli and Azharim 2011).The research on the perforated plate acoustical structure dates back to 1947, Bolt (1947) first employed perforated plates as the sound absorption plates. In 1952, Callaway et al. (1952) found a perforated plate processing a perforation rate lower than 5%.

Its absorption coefficient increased as the density of the used materials increased, but it decreased with the perforation rate increased. Sullivan and Crocker (1978) measured the sound absorption performance of a perforated plate when the perforation rate was 4.2%. Takahashi (1997) considering the diffraction effect due to perforated plate surface discontinuity constructed a new model. The sound absorption characteristics of the perforated plate resonance sound absorption structure could be predicted via the diffraction effect. Zhong et al. (2008) studied the sound-absorbing structure of a wooden decorative perforated plate experimentally. The results showed that the sound absorption performance could be improved to some extent when a suitable perforated plate cavity depth was used. Hou et al. (2010) discussed the factors linked with the effect of the wooden perforated plate absorption coefficient.

The sound absorption performance of perforated plates mainly depends on the perforation plate structure that can be considered as multiple parallel compositions of Helmholtz resonators (Bolt 1947). When the frequency of incident waves is in accordance with the system resonance frequencies, the perforated plate neck air produces intense vibration friction. At the same time, the absorption peak is formed, the absorption effect is enhanced, and the sound energy attenuates significantly (Cherrier et al. 2012, Tayong et al. 2011). The influencing factors, such as the plate thickness, aperture, perforated rate, and the pore depth, have effects on the sound absorption performance of perforated plates (Zulkifli and Azharim 2011, Lee et al. 2005). Therefore, rationally selecting parameters can effectively improve the sound absorption coefficients of wooden perforated plates.

Currently, noise pollution has negative influence on people health and people need a good indoor acoustical environment (Zhang and Chen 2009, Paul et al. 2013). Thus, it is crucial to improving the sound absorption performance of wooden materials (Zhong et al. 2008, Zhang and Ma 2014, Chang and Zhihui 2011). Meanwhile, suitable perforator material can further heighten the sound absorption performance of materials. However, the early literatures focused on the sound absorption performance of metal perforated plates mainly (Putra et al. 2015), the sound absorption performance of wooden perforated plates has not been investigated systematically yet. Furthermore, the core principles and key technology of woodenplate perforation has not been fully grasped. In this study, MDF was used as the substrate material, and the four structure parameters (plate thickness, aperture, perforation rate, and pore depth) influenced on the absorption peak of the wooden perforated plates were tested. The effect of the resonance frequency and band width was analyzed. This study revealed practicability of wooden perforated plates. Meanwhile, it also offered some theoretical basis for the future processing and production of perforated plates and promotion of their use.

MATERIAL AND METHODS

Materials

The substrate material is MDF, whose moisture content is 8.5%. It was purchased in Beijing Senran wood Co. Ltd. The thicknesses of the plates are 10, 15, and 20 mm, respectively. Their densities are 0.723, 0.719, and 0.717 $g \cdot cm^{-3}$, respectively.

Perforated MDF specimen processing

Aperture: General requirements for the 1-10 mm acoustic perforated plate aperture, but the aperture of 1-2 mm is small and difficult to achieve, the course of drilling cost is high. For the reason that choosing three kinds of pore sizes d_1=3 mm, d_2=6 mm, d_3=9 mm, respectively.

The 3-9 mm represent the range more widely, it is more conducive to explore the optimal process.

The perforation rate: the perforation rate of large orifice acoustic impedance is very small, almost no absorption effect, often used as a protective panel of porous materials. For perforated absorber, it is essential to ensure that the acoustic impedance of the perforation rate should not be too large, generally should not be greater than 10%. The calculation formula of square holes arrangement such as perforation rate type (Eq. 1).

$$p = \frac{\pi}{4}\left(\frac{d}{B}\right)^2 \times 100\% \qquad (1)$$

where: p - perforation rate,
d - aperture (mm),
B - hole spacing (mm).

In known perforation rate cases, type formula of holes spacing through deformation: (Eq. 2)

$$B = \frac{d}{2}\sqrt{\frac{\pi}{p}} \qquad (2)$$

According to the Eq. 2, the perforation rate of p_1=3%, p_2=5%, p_3=8%, combined with aperture type, the calculated B hole spacing, the spacing value is not all integer, difficult to control in processing, convenient processing, the hole spacing roundness correction, by calculating the perforation rate adjustment of P, to get the final results are shown in Tab. 1.

Tab. 1: Perforation rate after corrected hole spacing.

D(mm)	*B*(mm)	*P* (%)
3	15	3.1
3	12	4.9
3	10	7.0
6	30	3.1
6	24	4.9
6	20	7.0
9	45	3.1
9	36	4.9
9	30	7.07

Test methods

Experiments design

The full factorial experiment, which included three factors (thickness, aperture, and perforation rate) and three levels, was designed to investigate how the thickness, aperture, and perforation rate of the plates affect the sound absorption performance and to explore the main effect of the experimental factors, and the size of the interaction between the various factors. The four factors of the cavity, such as thickness, pore diameter, perforation rate, and the depth, were taken three levels of full factorial experiments in Tab. 2.

Tab. 2: Experiment design.

Pore diameter (mm)	Thickness (mm)	Pole distance (mm)	Theoretical perforation rate (%)	Actual perforation rate (%)
3	10	15	2	3.14
6	15	12	5	4.91
9	20	10	8	7.07

Each parameter in the processing of 3 specimens was obtained from 81 specimens. The test specimens corresponding to each cavity are 25 mm, 50 mm and 100 mm, respectively, were measured in 243 groups of experimental data. With 3 groups of different thickness no control group open hole specimens, a total of 270 groups of test data, and then the same parameters under 3 specimen test data obtained by averaging the parameters of the perforation plate final absorption coefficient, a total of 90 groups of data.

Acoustical properties

The sound absorption performance of the perforated MDFs was tested according to the sound absorption coefficient and acoustic impedance measurements (the transfer function method was used for the latter) of ISO 10534-2:1998 acoustic impedance tube. The impedance tube test system of the Beijing reputation company was adopted. Each test specimen was repeatedly measured three times, and the result was the average of these three measurements. The testing conditions were as follows: the temperature was 20.0°C, the relative moisture content was 50.0%, the atmospheric pressure was 101325 Pa, the atmospheric density was 1.2 $kg \cdot m^{-3}$, the sound velocity was 343.237 $m \cdot s^{-1}$, and the characteristic impedance of air was 412.568 $Pa \cdot s \cdot m^{-1}$.

RESULTS AND DISCUSSION

As shown in Fig. 1, the perforated plate structure is multiple parallel compositions of Helmholtz resonators. Hence, a perforated plate is regarded as a resonance system composed of masses and springs. When the frequency of incident waves matches the system resonance frequencies, the air of the perforated plate neck produces intense vibration friction, strengthening the absorption effect, forming the absorption peak, and converting sound energy into heat energy. When the frequency of the incident waves significantly differs from the resonance frequency, the absorption effect decreases (Phong and Papamoschou 2015, Beranek 2005). According to Dah-You (1975) classical theory on the perforated plate absorption peak, the major factors, which affect the sound absorption of perforated plates, are the thickness, aperture, and perforation rate of the plates as well as the pore depth. The relationship between the absorption peak, resonance frequency, frequency bandwidth and plate thickness, hole diameter, perforation rate and cavity depth of perforated plate can be deduced (Andreassen et al. 2015a, Lin et al. 2009).

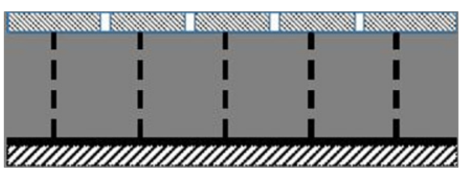

Fig. 1: Diagram of the perforated panel resonance sound absorption structure.

Holes of the wooden perforated plates can be regarded as a cavity, and the air in the cavity waves with sound wave vibration to a certain extent, which also has a certain quality of sound. Air column in the process of vibration constantly produces friction with the holes walls, which contribute to sound energy consumption. This process is equivalent to the acoustic resistance due to viscous damping and the function of the thermal conductivity. The sound energy is continually consumed in the process where vibration turns into the heat energy and dissipation. Acoustic impedance of a perforated plate Z is composed of acoustic resistance R and acoustic impedance Z_k, and the acoustic impedance also includes two parts of acoustic impedance Z_d caused by pores and acoustic impedance Z_v caused by rear cavity of the plates.

$$Z = R + Z_d + Z_v \tag{3}$$

Researchers, such as (Yan-yan 2007, Zhang and Chen 2009), who combined Ma's acoustic absorption theory, calculated the acoustic resistance of the acoustic impedance of perforated plates and obtained the following formula for the acoustic resistance of perforated plates.

$$R=\frac{32\mu t}{pc_0 d^2}\left[\left(1+\frac{k^2}{32}\right)^{1/2}+\frac{\sqrt{2}kd}{32t}\right] \tag{4}$$

$$k=\frac{d}{2}\sqrt{\frac{w\rho_0}{\eta}}=\frac{d}{2}\sqrt{\frac{w}{\mu}}$$

where: t - thickness (mm),
p - perforation rate,
η - air viscous coefficient (Pa·s^{-1}),
ρ_0 - air density (g·cm^{-3}),
k - perforation constant,
w - angular frequency,
η - viscosity coefficient of air (Pa•s^{-1}).

Researchers, such as (Wei-sen 2008, Andreassen et al. (2015b) first calculated the acoustic impedance of a perforated pore of perforated plates. Then, they calculated the total resistance of perforation plates according to the acoustic impedance of a perforated pore. Finally, they obtained formula (Eq. 5).

$$Z_K = Z_{L1} + Z_{v1} = j\omega\frac{\rho\pi\left(\frac{d}{2}\right)^2(t+\delta}{\left[\pi\left(\frac{d}{2}\right)^2\right]^2} - j\frac{1}{\omega\frac{v}{\rho c^2}} \tag{5}$$

Z_K: total acoustic impedance; Z_{L1}: a perforated acoustic impedance; Z_{v1}: cavity acoustic impedance; ω: angular frequency; c: Sound speed, the value is 340 m·s^{-1}; δ: Perforation inlet end correction; v: cavity volume.

Wooden perforated plates are typical resonance sound absorption structures. Combining Eqs. 4 and 5 with Eq. 3 and simplifying the result, we obtain the expression for the acoustic impedance:

$$Z = \frac{32\mu t}{Pc_0 d^2}\left[\left(1+\frac{\omega d^2}{128}\right)^{1/2} + \frac{d^2}{64t}\left(\frac{2\omega^2}{\mu}\right)^{1/2}\right] + j\omega\frac{2\rho\pi(t+0.8d}{\pi d^2} + \frac{\rho c^2}{j\omega v} \quad (6)$$

$j_{\omega w}$ indicates imaginary, μ constant.

When incidence so und waves are vertical, the resonance absorption coefficient is as follows:

$$\partial = 1 - |R|^2 = \frac{4r}{(1+r)^2 + x^2} \quad (7)$$

where: r - the relative acoustic resistance rate of the perforated plate resonance,
x - its relative acoustic impedance rate.

When the resonance of a perforated panel occurs, the acoustic mass of the system as a whole is zero.

And the resonance absorption coefficient is

$$\partial_r = \frac{4r}{(1+r)^2} \quad (8)$$

As demonstrated in Eq. 8, when *r* is less than 1, the absorption coefficient increases with the resonance, and when *r* is more than 1, the resonance absorption coefficient decreases with the increase in *r*. According to Eq. 6 combined with the parameters chosen in this paper, acoustic resistance R can be calculated to be less than 1, so the relative acoustic resistance rate is less than 1, and the resonance absorption coefficient increases with the acoustic resistance. Simplified Eq. 6 shows that the acoustic resistance is proportional to the thickness and is inversely proportional to the perforated rate and aperture.

The resonance frequencies of perforated plates: Owing to a certain air layer at the back side of the plates, when sound waves enter holes of the perforated plates, variation of the sound pressure caused by fluctuations stimulates reciprocating motion of the air column inside the holes, making the air inside the cavity compressed repeatedly. When the frequency of incident sound waves equals the inherent frequency of the perforated plate structure, the resonance occurs in the system composed of the air column inside the holes and the air inside the cavity. When the system achieves the resonance, the resonance frequency is (Andreassen et al. 2015a, Yuan et al. 2006):

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{P}{(t+0.8d)L}} \quad (9)$$

where: 0 -resonance frequency (Hz),
L - air depth (m)in the rear cavity of the plate,
t - thickness (m),
d - aperture (m),
c - sound velocity ($m\cdot s^{-1}$) in air,
P - perforation rate.

According to Eq. 9, the resonance frequency is proportional to the rate of perforation and is inversely proportional to the thickness, aperture, and pore depth. The resonance absorption acoustic band width: f_1 and f_2 separately stand for the absorption coefficients of the absorption peak in high- and low-frequency bands, respectively, reducing to the frequency of the alpha r/2.

The number of octaves between f_2 and f_1 is called the resonance acoustic band width, Ω, of absorption, so it can be obtained from the theory

$$\Omega = 6.6\lg\left[\sqrt{1+\left[\frac{1}{2Q}\right]^2}+\frac{1}{2Q}\right] \quad (10)$$

Where Q is the quality factor:

$$Q = \frac{\lambda r}{2\pi L(1 + r)} \quad (11)$$

where: λr - resonance when the acoustic wavelength,
L - pore depth (mm),
r - relative acoustic resistance rate (a dimensionless quantity).

Effect of the pore diameter on the sound absorption properties

Wooden perforated plates meet general sound absorption characteristics of perforated plates, that is, their absorption range is greatly varied. The absorption peaks mainly concentrate in the low- and middle-frequency range. As shown in Fig. 2, the three curve stand for the absorption coefficients of the wooden perforated plates, whose apertures are 3, 6, and 9 mm, thicknesses are 20 mm, perforation rates are 3.14%, and rear pore depths are 50 mm. The resonance frequency of an aperture of 3 mm is 630 Hz, and the resonant frequency of an aperture of 9 mm is 400 Hz. As the resonance frequency is decreased (from 630 Hz to 400 Hz), the resonance absorption coefficient decreases (from 0.49 to 0.34). According to the results of the significant test shown in Tabs. 3 - 6, the aperture has a significant effect on the resonance absorption peak and resonance frequency of the perforated plates. In accordance with Eq. 6 and the experimental parameters selected in this paper, when the acoustic resistance is less than 1, the sound resistance rate is less than 1.

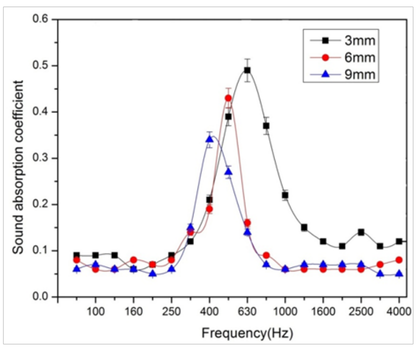

Fig. 2: Normal incidence sound absorption coefficients of three 3.14% perforation rates, with 20mm thick perforated panels, backed by a 50 mm air cavity, each with different diameter pores.

According to Eq. 8, the resonance absorption coefficient α increases with the increase with r. Owing to the fact that the acoustic resistance is inversely proportional to the aperture, the acoustic resistance, acoustic impedance, and acoustic resistance rate decreaseas the apertureis increased. The resonance absorption peak decreases (Tab. 4) with r. According to the formula of the resonance frequency (Eq. 9) of the perforated plates, when the perforated plate thickness, rear cavity, and perforated rate are given, only the change in the aperture needs to be taken into account. As the aperture is inversely proportional to the resonant frequencies of the perforated plates, when the aperture is increased from 3 mm to 9 mm, the resonance absorption frequency reduces from 630 Hz to 400 Hz and the resonant frequency moves to a lower frequency (Tab. 6). According to Eq. 10, the quality factor is inversely proportional to the relative acoustic resistance rate. As mentioned above, when the aperture is increased, the acoustic resistance decreases, the relative acoustic resistance rate decreases, and the quality factor increases. The width of the frequency band is inversely proportional to the quality factor, and the band width becomes narrower.

1) The analysis of the significance of the absorption peak compared with the thickness, aperture, perforated rate, and the rear cavity of the plates.

Tab. 3: Max sound absorption coefficient square error analysis and F test.

Source	DF	Type I SS	Mean square	F value	Pr> F
Pore diameter	2	1.22635638	0.61317819	74.85	< 0.0001
Thickness	2	0.01091687	0.231545844	78.853	< 0.0001
Perforation rate	2	0.85106255	0.42553128	51.95	< 0.0001
Air gap	2	1.21860329	0.60930165	74.38	< 0.0001

Tab. 4: The max-sound absorption coefficient of different factor levels and their significant difference.

Independent variables	**Levels**	**N**	**Max-sound absorption coefficient**
Pore diameter	3	81	0.617A(0.131)
	6	81	0.519B(0.136)
	9	81	0.443C(0.120)
Thickness	10	81	0.519A(0.126)
	15	81	0.525A(0.140)
	20	81	0.535A(0.172)
Perforation rate	7.07%	81	0.450A(0.134)
	4.91%	81	0.534B(0.134)
	3.14%	81	0.595C (0.137)
Air gap	25	81	0.616A(0.141)
	50	81	0.520B(0.123)
	100	81	0.443C(0.123)

2) The thickness, aperture, perforated rate, and pore depth of the perforated plate analysis of the significance of the resonance frequency.

Tab. 5: Resonant frequency square error analysis and F test.

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr> F**
Pore diameter	2	184027.366	92013.683	19.02	< 0.0001
Thickness	2	451061.934	225530.967	46.61	< 0.0001
Perforation rate	2	1878432.305	939216.152	194.11	< 0.0001
Air gap	2	3724261.934	1862130.967	384.86	< 0.0001

Tab. 6: Resonance frequency of different factor levels and their significant difference.

Independent variables	Levels	N	Resonant frequency
Pore diameter	3	81	461A(195)
	6	81	427B(165)
	9	81	393C(158)
Thickness	10	81	487A(181)
	15	81	407B(154)
	20	81	388C(173)
Perforation rate	7.07%	81	543A(189)
	4.91%	81	408B(142)
	3.14%	81	330C(114)
Air gap	25	81	585A(156)
	50	81	413B(112)
	100	81	283C(92)

The effect of the thickness on the sound absorption properties

Fig. 3 shows the absorption coefficients of the wooden perforated plates, whose thicknesses of wooden perforated plates are 15, 20, and 10 mm, apertures are 3 mm, distances between the two plates are 10 mm, perforation rates are 7.07%, and rear pore depths are 50 mm. The resonance sound absorption coefficients of the 10-mm-thick plates and 20 mm thick plates are 0.55 and 0.95, respectively.

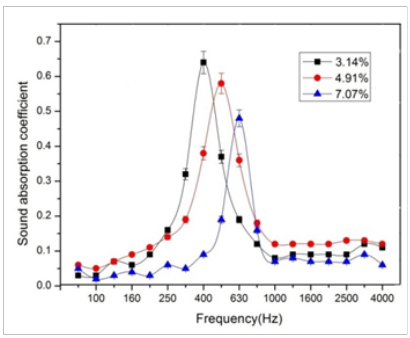

Fig. 3: Normal incidence sound absorption coefficients of three 7.07% perforation rates, with 3 mm diameter pores, backed by a 50 mm air cavity, each with different thick perforated.

The resonant frequencies of the 10 mm thick plates and 20 mm thick plates are 620 Hz and 400 Hz, respectively. According to the significance test results demonstrated in Tab. 3 - 6, the thickness of the plates has a significant effect on the resonance frequency size of the perforated plates (Tab. 5). Tab. 3 shows that the thickness of the plates does not have a significant effect on the absorption peak value. This can be attributed to the fact that the interaction of the aperture, perforation rate, and thickness are considered. If only the influence of the thickness is considered, the resonance sound absorption coefficient of the perforated panels (the sound resistance is 0) is only related to the resonance acoustic resistance rate under the resonance of the perforated plates. According to Rao's theory on the acoustic impedance of perforated plates, the acoustic resistance rate is less than 1 within the experimental design range of the pore size and thickness. According to Eq. 6 and 8, the acoustic resistance is proportional to the thickness; with the increase in the thickness (*t* is the hole depth), the acoustic resistance, acoustic impedance, and acoustic resistance rate increase. According to Eq. 8, *r* is less than 1. Therefore, with the increase with *r*, the resonance absorption peak increases (Tab. 4). According to the formula for the resonance frequency of the perforated plates (Eq. 9), the rear pore depth, aperture, and perforation rate are constant, and the thickness of the plates is inversely proportional to the resonant frequencies of the perforated plates (only the change in the thickness is considered). If the plate thickness is increased (from 10 mm to 20 mm), the frequency of resonance absorption decreases from 620 Hz to 400 Hz, and the resonance frequency moves in the low-frequency direction (Tab. 6). Eq. 10 shows that the quality factor is inversely proportional to the relative acoustic resistance rate. As mentioned above, with increase of the thickness, the acoustic resistance and the relative acoustic resistance rate were increased that caused the quality factor decreases. The band width is inversely proportional to the quality factor, so the decrease in the quality factor makes the band width narrower.

Effect of the perforation rate on the sound absorption properties

As shown in Fig. 4, the three curves exhibit the absorption coefficients of the wooden perforated plates, whose perforation rates are 7.07, 4.91, and 7.07%, thicknesses are 15 mm, apertures are 3 mm, and rear pore depths are 50 mm. The resonance frequencies of the perforated panels, whose perforation rates are 3.14%, 4.91%, and 7.07%, are 400, 500, and 630 Hz, respectively. The sound absorption coefficient decreases from 0.64 to 0.49. According to the significance test results shown in Tabs. 3-6, the perforation rate has a significant influence on the resonance absorption peak of the perforated plates and the size of the resonant frequency (Tabs. 3 and 5). According to Eq. 6 and 8, the acoustic resistance is inversely proportional to the perforation rate; with the increase in the perforation rate, the sound resistance and the acoustic resistance.

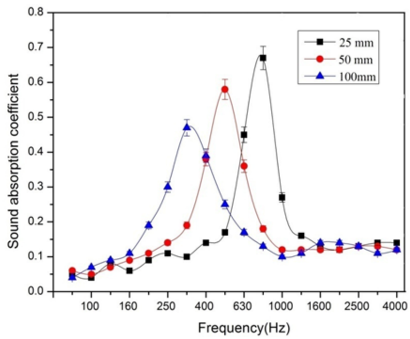

Fig. 4: Normal incidence sound absorption coefficients of three 10 mm thick perforated panels, with 3 mm diameter pores, backed by a 50 mm air cavity, each with different perforation rates.

According to Eq. 8, *r* is less than 1, so with the decrease in *r*, the resonance absorption peak decreases (Tab. 4). According to the formula for the perforated plate resonance frequencies (Eq. 9), when the rear pore depth, pore diameter, and thickness are constant, the perforation rate is proportional to the resonance frequencies of the perforated plates (only the changes in the perforation rate are considered).When the perforated rate is increased from 3.14% to 7.07%, the resonance absorption frequency increases from 400 Hz to 630 Hz, and the resonant frequency moves in the direction of a higher frequency (Tab .6). When the aperture is changeless, an increase in the perforation rate leads to a decrease in the hole spacing and an increase in the number of holes on the specimens of the same area. If the depth of the rear cavity is given, the number of holes per unit area increases, air holes in each column with their viscosity additional lengths is certain, and the frictional resistance in vibration is constant. Thus, the total frictional resistance in unit area of the specimen increases, and the greater the perforation rate is, the greater the original quality (equal to an equivalent mechanical spring vibration system).As the vibration damping effect increases, the quality factor of the system reduces. According to Eq. 10, the quality factor reduces, so the effective frequency band broadens (Lin et al. 2009a, Lin et al. 2009b).

Effect of the air gap on the sound absorption properties

As shown in Fig. 5, the three curves stand for the absorption coefficients of the wooden perforated plates, whose rear cavities are 25, 50, and 100 mm, thicknesses are 15 mm, pores diameters are 3 mm, and perforation rates are 7.07%. The resonance frequencies of the perforated plate structures, whose air cavities are 25 mm and 50 mm, are 800 Hz and 500 Hz, respectively, and the resonance frequency of the perforated plate, whose pore depth is 100mm, is 315 Hz.

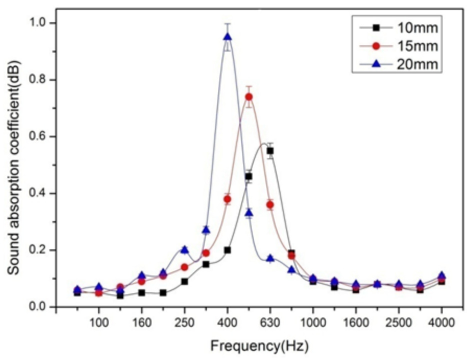

Fig. 5: Normal incidence sound absorption coefficients of three 10 mm thick perforated panels, with 3 mm diameter pores, 7.07% perforation rates, each with different backed air cavity.

According to the significance test results shown in Tabs. 3-6, the pore depth has a significant influence on the size of the resonance absorption peak and the resonant frequency of the perforated plates. In accordance with Eqs. 6 and 8, when the pore depth is increased, the acoustic resistance is constant, the loss of the sound waves in and out the perforated plates reduces, the peak of the sound absorption coefficient becomes smaller (Tab. 4), and the absorption coefficient decreases from 0.68 to 0.47. According to Eq. 9, when the other parameters are constant (only the influence of the rear cavities on the acoustic properties of the perforated plates is considered); the rear cavity is inversely proportional to the resonance frequency. Therefore, when the cavity depth is increased, the resonance frequency reduces from 800 Hz to 315 Hz, and the resonance frequency moves in the direction of a lower-frequency position (Tab. 6). The absorption coefficient curve of the large-cavity structure takes up a large span on the axis, whose abscissa equally distributes in the form of the centre frequency of the 1/3 frequency range/Low-frequency spacing stands for a narrow frequency range, so the acoustic absorption bandwidth of the perforated plate structure with different cavities mainly remains unchanged.

CONCLUSIONS

1) If the aperture, perforation ratio and pore depth are the same, with the increase in the thickness, the absorption peak becomes larger, the resonance frequency moves in the direction of a lower frequency, and the acoustic band width slightly narrows.
2) If the thickness of the plates, perforation ratio, and pore depth are the same, the smaller the aperture is, the larger the peak value of the absorption coefficient of the perforated plates is, the resonance frequency moves in the direction of a lower frequency, and the sound absorption band width becomes narrower.
3) If the thickness of the plates, aperture, and pore depth are the same, the increase in the perforation rate causes the absorption peak to decrease, the location of the resonance frequency to move towards the direction of a higher frequency, and the acoustic absorption band width to widen.
4) If the thickness, aperture, and perforation rat eare the same, the increase in the pore depth causes the absorption peak to decrease and the location of the resonance frequency to move towards the direction of a higher frequency. The acoustic absorption bandwidth is invariant.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support of 948 project "High performance wood composite sound-absorbing material manufacture technology import" (2013-4-15)

REFERENCES

1. Andreassen, et al, 2015: Directional bending wave propagation in periodically perforated plates, Journal of Sound & Vibration 335(335): 187-203.
2. Beranek, L., 2005: Noise and vibration control engineering: Principles and Applications, Second Edition. John Wiley & Sons, 976 pp.
3. Bolt, R. H.,1947: On the design of perforated facings for acoustic materials, Journal of the Acoustical Society of America 19(5): 917-921.
4. Callaway, D. B., Ramer, L.G., 1952: The use of perforated facings in designing low frequency resonant absorbers, Journal of the Acoustical Society of America 24(3): 309-312.
5. Chang, L., W. U., Zhihui, W.U., 2011: Study on sound absorption performance of extruded tubular particleboard used in indoor wooden products, Journal of Nanjing Forestry University 35(2): 56-60.
6. Cherrier, V., Pommier-Budinger, V., F. Simon, V., 2012: Panel of resonators with variable resonance frequency for noise control, Applied Acoustics 73(8): 781-790.
7. Hou, Q., Q., et al. 2010: Research on influence factors of absorption performance for wooden perforated panels, Advanced Materials Research 113-116(1): 959-1963.
8. Lee, Y.Y., et al, 2005: Sound absorption of a finite flexible micro-perforated panel backed by an air cavity, Journal of Sound & Vibration 287(1): 227-243.
9. Lin, M.D., Tsai K.T., Su B.S., 2009: Estimating the sound absorption coefficients of perforated wooden panels by using artificial neural networks, Applied Acoustics 70(1): 31-40.
10. Dah-You, M.,1975: Theory and design of microperforated panel sound-absorbing constructions, Scientia Sinica 18(1): 55-71.

11. Zhang, B, Chen T. 2009: Calculation of sound absorption characteristics of porous sintered fiber metal, Applied Acoustics 70(2): 337-346.
12. Paul, S., et al. 2013: Noise pollution in Porto Velho, a typical state capital in Western Amazonia, and a combined approach to cope with, Proceedings of Meetings on Acoustics Acoustical Society of America19(1): 5644-5649.
13. Putra, A., et al. 2015: Utilizing hollow-structured bamboo as natural sound absorber, Archives of Acoustics 40(4): 601-608.
14. Phong, V., Papamoschou,D., 2015: Normal incidence acoustic insertion loss of perforated plates with bias flow, Journal of the Acoustical Society of America 138(6): 3907.
15. Zulkifli, R., Azharim,C.H., 2011: Perforated plate backing with coconut fiber as sound absorber for low and mid range frequencies, Key Engineering Materials 462-463: 1284-1289.
16. Sullivan, J, W., Crocker, M. J., 1997: Analysis of concentric-tube resonators having unpartitioned cavities, Journal of the Acoustical Society of America 64(1): 207-215.
17. Takahashi, D., 1997: A new method for predicting the sound absorption of perforated absorber systems, Applied Acoustics 51(1): 71-84.
18. Tayong, R., Dupont, T., Leclaire, P., 2011: Experimental investigation of holes interaction effect on the sound absorption coefficient of micro-perforated panels under high and medium sound levels, Applied Acoustics 72(10): 777-784.
19. Wei-sen L. et al., 2008: Perforated plate of sound absorption principle and application, World Professional Audio and Lighting 6(6): 42–47.
20. Zuo, Y.Y.,et al, 2007: Sound absorption performance of the perforated plate absorption structure and its application, China mechanical engineering 18(7): 778–780.
21. Yuan, Xian Cheng, et al., 2006: The experiment of research sound absorption performance of perforated plate was improved, Journal of engineering in Tianjin normal university 16(2): 31–34.
22. Zhang, B., T., Chen, T., 2009: Calculation of sound absorption characteristics of porous sintered fiber metal, Applied Acoustics 70(2): 337-346.
23. Zhang, F., et al., 2014: Effect of spinning process on the absorption performance of wooden activated carbon fiber for methylene blue, Applied Mechanics & Materials 469:117-120.
24. Zhong X., Z., et al., 2008: Wood perforated decorative sound absorption plate and its application, Journal of sound technology and equipment and application(8): 27–30.

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