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Study on wooden micro-perforated panel and its application

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ABSTRACT

A wooden micro-perforated panel (W-MPP) with dual function of acoustics and decoration is presented in this paper. Sound absorption characteristics of W-MPP are theoretically predicted and compared with the measurement results in impedance tube. This paper further discusses the effect of slot depth and stripe width on absorption characteristics. The manufacturing process of W-MPP is simple and easy to operate. Finally, an actual example of cinema acoustic design shows the capability of interior decoration of W-MPP besides its acoustical properties.

INTRODUCTION

Micro-perforated panel (MPP) structures have been widely used in architectural acoustics and noise control engineering design. However, there are still some problems both from the production and application viewpoints. Firstly, it is still relatively difficult to manufacture because the pore size generally can only be achieved with roughly the same to thickness of panel by using the ordinary drilling method, so it is difficult to further reduce the aperture for the wood panel. The other hand, MPP commonly is a lack of decoration, whether it is metal or plastic. Therefore, it obstructs the application of MPP in the auditorium acoustics and architectural acoustics design as a sound absorption structure.

In this paper, a kind of wooden micro-perforated panel (W-MPP) with dual function of acoustics and decoration is presented. The manufacture of W-MPP is simple and easy to operate. Based on the mature theory of micro-perforated panel, the acoustic characteristic of W-MPP is theoretically predicted. The relation between the sound absorption and the structural parameters of W-MPP is derived. The experimental data by the standing wave method are compared with the calculated results. A good agreement is revealed. The article also analyses the influence of slot depth and stripe width, stripe intervals on absorption characteristics. Finally, an actual example of cinema acoustic design demonstrates the capability of architectural interior decoration of W-MPP besides its acoustical properties.

CONSTRUCTION OF WOODEN MICRO-PERFORATED PANEL

The Structural sketch of W-MPP is shown in Figure 1. Manufacture process of W-MPP is simple and easy to operate. Along the two mutually perpendicular directions, we can cut a lot of slots in the positive and negative sides of an ordinary wooden panel. The cross-section of slot appears an inverted triangle. The slots on the positive and negative sides are deeper than the neutral surface of panel, therefore a series of pores arranged in a rectangle are formed after processing.（see Fig.2）The surface of wooden panel appears the stripes with trapezoid cross-section.

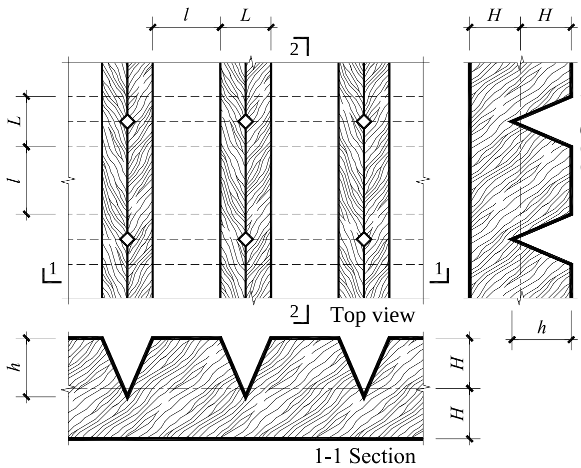

Fig.1 Structural sketch of W-MPP

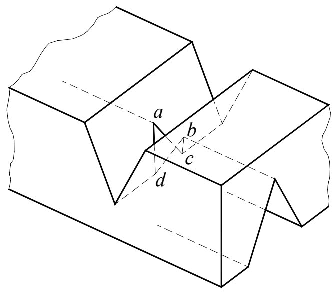

Fig.2 Schematic diagram of pore shape

According to the thickness of panel, while properly selecting the depth and width of the slot, the micro-perforated structure with good sound absorption can be created. Furthermore the wooden micro-perforated panel exhibits the straight stripe pattern which is suitable for interior decoration of auditorium in modern theatre and concert halls.

SOUND ABSORPTION PROPERTIES OF WOODEN MICRO-PERFORATED PANEL

For a typical W-MPP (panel thickness $2H$ = 6mm, slot depth h = 3.2mm, stripe width l = 2.5mm, and stripe interval L = 2.5mm), acoustic impedance and absorption coefficient can be determined by the impedance tube measurement[1].The normal incidence absorption coefficients of W-MPP mounted on the wall with 5cm air cavity behind for that with and without the woven closely pasted on the back of panel are shown in Fig.3. It is shown from figure that this kind of W-MPP has the high sound absorption characteristic in certain frequency band, which is consistent with that of the sound resonating structure; its resonance frequency depends on the cavity depth. The relative specific acoustic resistances of W-MPP for above mounted condition are shown in Fig.4. It is shown from figure that the relative specific acoustic resistance of such a structure without woven is around 0.5. When a layer of woven is pasted on the back of panel the relative specific acoustic resistance can be controlled nearby 1 and the best sound absorption of W-MPP will be achieved.

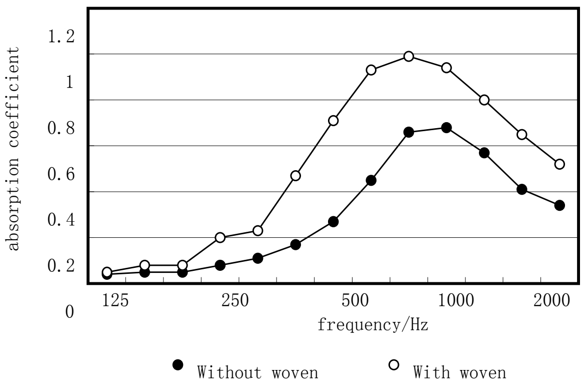

Fig.3 Sound absorption characteristics of W-MPP

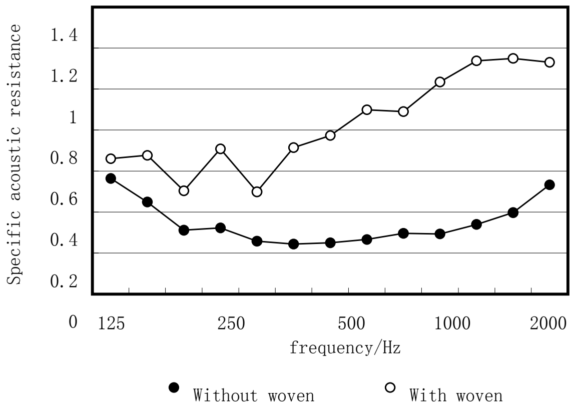

Fig.4 Relative specific acoustic resistance of W-MPP

PREDICTION OF ABSORPTION CHARACTERISTICS OF W-MPP

In order to further optimize the sound absorbing structure of W-MPP, the authors explore the prediction of quantifying the sound absorptive effect of W-MPP. As sound absorption mechanism of micro-perforated panel comes mainly from viscous losses of wall when sound waves go through the perforations, so its acoustic properties are closely related to the pore diameter and the perforation depth.

Estimate of equivalent diameter of W-MPP

It is shown from Fig.1 that the thickness of panel is $2H$, the depth of slot is h, and width and interval of stripe are l and L respectively. As the slot depth is slightly larger than half of the panel thickness and the slotting direction along the positive and negative of the surface is mutual perpendicular, a square arrangement of the microporous is formed. The shape of the pore shown in Fig. 2 seems to be irregular, so the accurate calculation of sound attenuation along the pore is quite complex. Here, roughly estimated as the circular channel, its equivalent pore diameter is given by

$$d = Q\frac{L(h-H)}{h} \qquad (1)$$

Where Q, an average value of the pore diameters on different cross-section along sound propagation, can be fitted from experimented data.

The depth t of pore and the perforation rate p of micro-perforated panel can respectively denoted by

$$t = 2(h-H) \qquad (2)$$

$$p = \frac{\pi}{4}\left(\frac{d}{l+L}\right)^2 \qquad (3)$$

Resonance frequency and specific acoustic impedance of W-MPP

By setting W-MPP mounted on the wall with an air cavity D, the resonance frequency of this acoustic structure is

$$f_r = \frac{c_0}{2\pi}\sqrt{\frac{p}{D(t+\beta_0 d)}} \qquad (4)$$

where c_0 is sound velocity, $\beta_0 = \frac{8}{3\pi}(1-\frac{5}{4}\sqrt{p}+\frac{p^2}{4})$ is the terminal correction factor of circular pore, which depends on the perforation rate p [2].

Based on the mature theory of micro-perforated panel, the relative specific acoustic resistance and acoustic mass of W-MPP are respectively determined by[3]

$$r = \frac{0.147t}{pd^2}\left[(1+\frac{k^2}{32})^{\frac{1}{2}} + \frac{\sqrt{2}}{8}\frac{d}{t}k\right] \qquad (5)$$

$$m = \frac{0.294\times10^{-3}t}{p}\left[1+(9+\frac{k^2}{2})^{-\frac{1}{2}} + 0.85\frac{d}{t}\right] \qquad (6)$$

where d, t, p are respectively determined by formula (1), (2), (3) and the quantity k relates to frequency which can expressed as

$$k = d\sqrt{\frac{f}{10}} \qquad (7)$$

The normal incidence absorption coefficient α is

$$\alpha = \frac{4r}{(1+r)^2 + [\omega m - ctg(\omega D/c)]^2} \qquad (8)$$

where ω is circular frequency.

When a layer of woven is closely pasted on the back of W-MPP an additional acoustic resistance would be provided, whereas acoustic mass has not significant increase. For a more detailed of the calculation of acoustic impedance of perforated panel closely pasted on the back, the reader is referred to Ref. 4

Comparison with experimental results

The experiment of normal incidence sound absorption coefficient by impedance tube for typical W-MPP structure has been conducted. The test results were compared with the above theoretical predictions. The specimen measured is of panel thickness of 6mm, with slot depth of 3.2mm, stripe width of 2.5mm, and stripe interval of 2.5mm and with an air cavity of 4cm. Fig. 5 is the comparison of the measured normal incident absorption coefficient with the calculated values, which indicates that both are in good agreement. According to the above theoretical prediction, the acoustic characteristics of W-MPP can be further optimized.

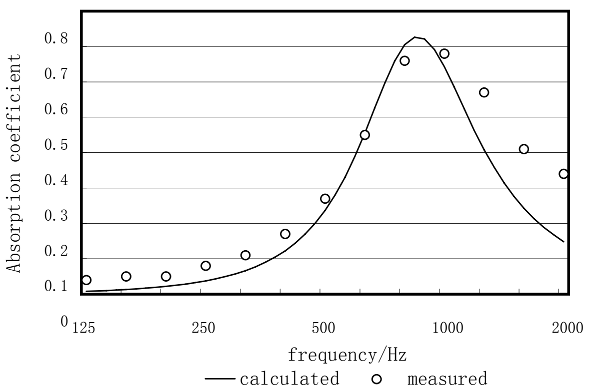

Fig. 5 Comparison of calculated values with measured data

INFLUENCE OF STRUCTURAL PARAMETERS OF W-MPP ON ACOUSTIC CHARACTERISTICS

For certain thickness of wood panel, the acoustic characteristics of W-MPP depends on slot depth, width and interval of stripe. Fig.6 indicates the change of the relative specific acoustic resistance with depth of slot, where the panel thickness is 6mm; the width and interval of stripe are 2.5mm, and with an air cavity of 4cm. The depths of slot are 3.2mm, 3.3mm and 3.4mm respectively. The figure shows that the relative specific acoustic resistance has a significant change with slot depth for a fixed width and interval of stripe. When depth of slot is 3.2mm the relative specific acoustic resistance approximates 1 and then W-MPP has higher absorption coefficient. Fig.7 indicates the change of the relative specific acoustic resistance with width and interval of stripe（from 0.5mm to 5mm）, while the thickness of panel and the air cavity maintain unchanging. The figure shows that relative specific acoustic resistance also changes with the width and interval of stripe. When they were chosen as 1 mm or 2.5 mm the relative specific acoustic resistance approximates 1.

Fig.8 and Fig.9 indicate the change of the normal incidence absorption coefficient with depth of slot (from 3.1mm to 3.4mm) and width of stripe (from 0.5mm to 5mm). For different depths of slot and widths and intervals of stripe the absorption characteristics of W-MPP has evident change. To adjust the structure parameters of W-MPP can meet the requirements of room acoustics. Therefore the optimization of design of W-MPP can be implemented by above theoretical prediction to achieve the best acoustic effects.

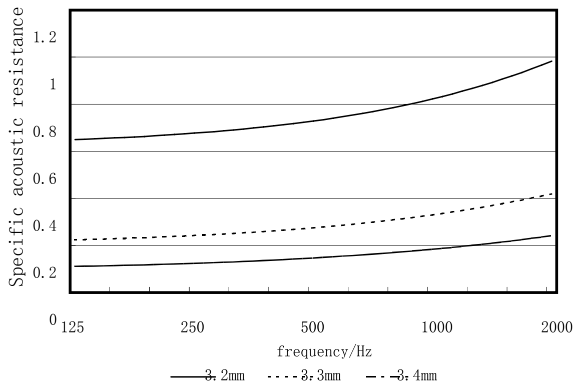

Fig.6 Change of the relative specific acoustic resistance with depth of slot

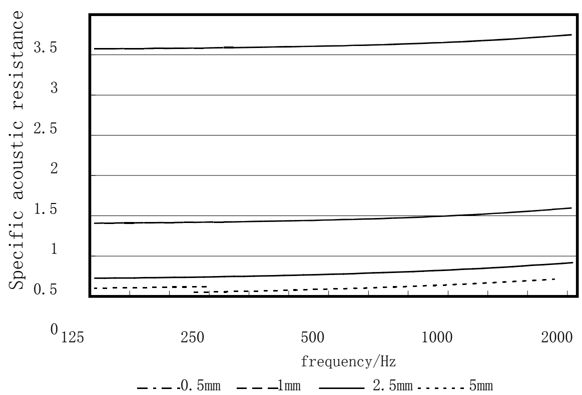

Fig.7 Change of the relative specific acoustic resistance with width and interval of stripe

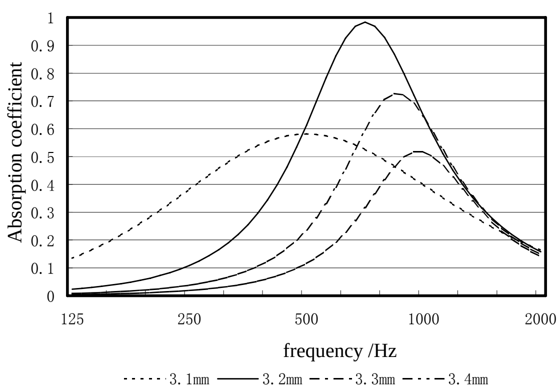

Fig.8 Change of the normal incidence absorption coefficient with depth of slot

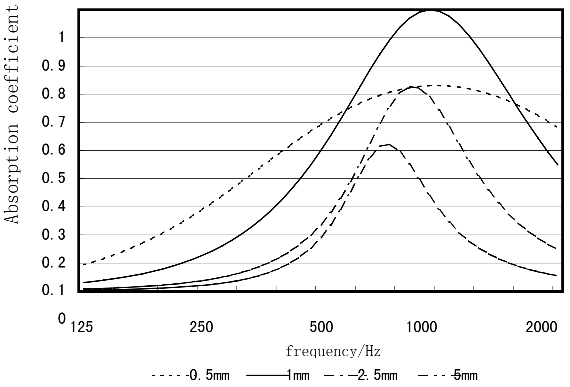

Fig.9 Change of the normal incidence absorption coefficient with width of stripe

EXAMPLE OF APPLICATION

Architectural acousticians have been particularly interested in hall that utilizes W-MPP because of their potential for creating an art and technology space. An actual example of cinema design is shown in Fig.10. In the auditorium of this cinema, W-MPP is laid on the ceiling and the walls as sound absorption structure, which also presents an exciting pattern.

Fig.10 Photograph of cinema auditorium utilizing W-MPP

CONCLUSION

In this paper, a wooden micro-perforated panel (W-MPP) with dual function of acoustics and decoration is presented. The acoustic characteristics of W-MPP were theoretically predicted. The relationship between the acoustic impedance and the absorption characteristics and the structural parameters of W-MPP was derived. The experimental results by the impedance tube method agree well with theoretical predictions. Based on theoretical prediction the influence of slot depth, width and interval of stripe of W-MPP on acoustic characteristics was analysed. It reveals that this kind of wooden micro-perforated panel possesses excellent sound absorption characteristics. For the demands of different projects, selecting different structure parameters of W-MPP, the best optimization of the structure can be obtained. Because of this W-MPP structure has a good decorative effect; it is expected to play a greater role in the architectural and the acoustical design.

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