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Estimating the sound-absorption coefficients of oblique micro-perforated panel absorber by using stepwise multiple linear regression analysis

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ABSTRACT

The oblique micro-perforated panel (OMPP) is distinct from micro-perforated panel (MPP) in terms of structure, such as non-circular form appearance and oblique holes. We employ multiple linear regressions (MLR) to estimate the sound-absorption coefficient of OMPP with various setting of structure factors. The results indicate that the MLR exhibits satisfactory reliability of a correlation between estimation and measured sound absorption coefficients.

INSTRUCTIONS

The oblique micro-perforated panel absorber is distinct from micro-perforated panel absorber in terms of structure, such as non-circular appearance and oblique holes. So the prediction formula on sound absorbing coefficient of MPP derived by Dr. Maa is not applicable to OMPP. In this study, a linear quantitative structure-sound absorbing relationship model (addressed as QSSAR) is presented for modeling and predicting sound absorbing coefficient of OMPP. The model was produced by using the multiple linear regression technique on a database that consists of 48 OMPPs . Stepwise regression as a variable selection method was used to develop a regression equation based on 48 training compounds. Appropriate models with low standard errors and high correlation coefficients were obtained. All of the 48 compounds are built by comparing the diversity of sound absorbing coefficients of OMPP (addressed as α OMPP) measured in the reverberation room, and sound absorbing coefficients of MPP (addressed as α MPP) calculated with the same value of structure descriptors including hole area, hole depth, perforation percentage, cavity depth. The mean effect of descriptors standardized coefficients shows that except perforation percentage and hole area, appearance-index and surface uneven grade also affect the sound absorption coefficients of OMPP.

As a result of MPP can be formed as well sound absorbing structure without using any porous material, it can be used as a means of dealing with architectural acoustics and noise control problems especially in humid environment. According to Dr. Maa's theory, the wide-band sound absorption characterization of MPP was determined by its high acoustic resistance and low acoustic mass reactance, he derived the factors of affecting sound absorption coefficient of MPP, including 1. hole diameter 2.hole depth 3.percentage of perforated area, 4.cavity depth, 5.uneven grade. He also proposed the prediction formula in diffuse field on sound absorbing coefficient of MPP showed as follow：

$$\bar{\alpha} = \int_0^{\pi/2} \alpha_\theta \sin 2\theta d\theta \qquad \text{(Eq.1)}$$

where,αθ：the sound absorbing coefficient with the sound incidence angle θ.

$$\alpha_\theta = \frac{4r\cos\theta}{(1+r\cos\theta)^2 + [\omega m\cos\theta - \cot(\omega D \bullet \cos\theta / c)]^2} \qquad \text{(Eq.2)}$$

r：relative acoustic resistance, calculated by：

$$r = \frac{32\mu}{pc}\frac{t}{d^2}\left[\sqrt{1+\frac{x^2}{32}} + \frac{\sqrt{2}x}{8}\frac{d}{t}\right] \qquad \text{(Eq.3)}$$

m：relative acoustic mass,calculated by：

$$m = \frac{t}{pc}\left[1 + \frac{1}{\sqrt{9+\frac{x^2}{2}}} + 0.85\frac{d}{t}\right] \qquad \text{(Eq.4)}$$

D：cavity depth

p：percentage of perforated area

t：deepness of opening

d：diameter of opening

x：Reynolds number, calculated by：

$$x = \frac{d}{2}\left[\sqrt{\frac{\rho_0\omega}{\mu}}\right] \qquad \text{(Eq.5)}$$

μ：kinematic viscosity of air

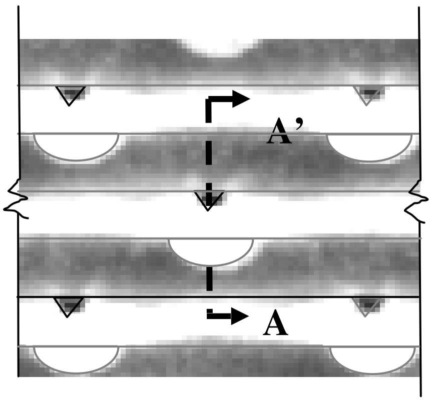
The OMPP is distinct from MPP in terms of structure, such as non-circular form appearance, and oblique holes to the surface of panel, so the prediction formula of MPP is not applicable to OMPP. It has been discussed in the previous work【1】that the inference of hole shape on the sound absorption coefficients of OMPP (α OMPP) is not significant, and the partial correlation between sound absorbing coefficient and structure descriptors of OMPP.

In this study, the quantitative structure-sound absorption relationships (QSSAR) successfully approaches to prediction of sound absorption coefficients of OMPP starting with structure information. A major step in constructing QSSAR models is calculating the sound absorption coefficient of MPP which possess the same hole area, perforated percentage, hole depth and cavity depth as OMPP been measured. The main objective of this work was to develop an accurate, simple, and fast method for calculation of sound absorption coefficients of OMPP using the prediction formula of sound absorption coefficients of MPP. In this work a QSSAR study was performed to develop models that relate the structures of 48 OMPP to their sound absorbing coefficients. The stepwise multiple linear regression (MLR) using SPSS (ver 11.5) as variable selection software was used to model sound absorbing coefficient of OMPP with the structural descriptors.

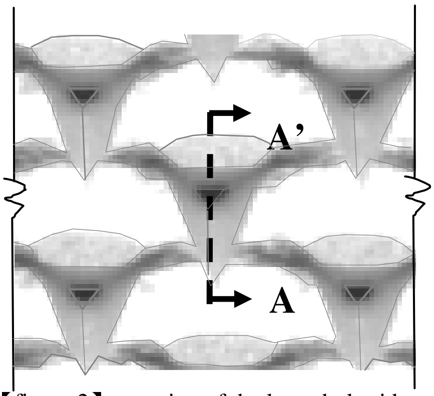
THE SETTING OF STRUCTURAL DESCRIPTORS ON OBLIQUE MICRO-PERFORATED PANEL ABSORBER

The OMPP is made by cutting, expanding and pressing process, so the hole is oblique and it's appearance is not circular, the setting of structure factors on OMPP are showed as follow：

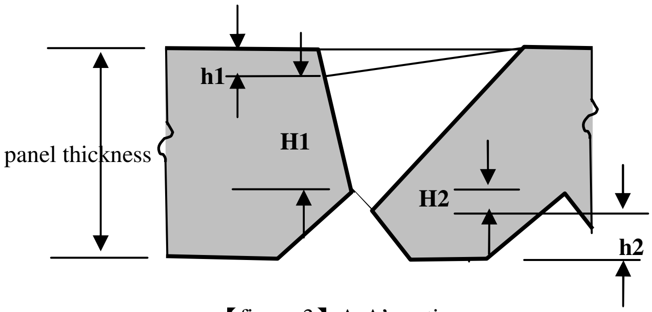
- ✓ Hole shape：The small-hole side facing on back air space is defined as "funnel shape", the large-hole side facing on air space is defined as "anti-funnel shape"
- ✓ Cavity Depth：addressed as D.
- ✓ Hole area：small-hole side area, addressed as As.
- ✓ Hole depth：Defined as the depth of hole which is entirely-enveloped by the wall, addressed as H1and H2. Refer to【figure 3】.
- ✓ Percentage of perforated area：addressed as p.
- ✓ Surface uneven grade：divided into 1. large-hole side surface uneven grade.(addressed as h1) 2. small-hole side surface uneven grade(addressed as h2). Refer to 【figure 3】
- ✓ Hole appearance-index：calculated by the ratio of hole perimeter to perimeter of circular with the equal area. It also divided into two indexes 1. large-hole side appearance-index(addressed as Rl). 2. small-hole side appearance-index(addressed as Rs).
- ✓ hole slope：since the hole is not perpendicular to the surface, so we have the hole slope defined by Inclination of θ.



【figure 1】scanning of the small-hole side



【figure 2】scanning of the large-hole side



【figure 3】A-A' section

EXPERIMENTS FOR SOUND ABSORPTION COEFFICIENTS MEASUREMENT

Realistic sound absorption coefficients measurement data is important for constructing QSSAR models. The sound absorption coefficients measurements carried out in this study fallow the CNS (Chinese National Standards) 9065 "Method for Measurement of Sound Absorption Coefficient in a Reverberation Room". The measurements all were conducted in the reverberation room of the acoustic laboratory located in the Department of Architecture, National Cheng Kung University, Tainan, Taiwan. The floor area of the reverberation room is 32.8 m2, empty volume is 171.6 m3, and interior surface area is 184.3 m2.

The decay of sound pressure level was measured to determine the reverberation time. The cutoff frequency for sound pressure level measurement in the room is 125 Hz. A real time analyzer (B&K 2260) was used to produce signal, measure the decay of sound pressure level and calculate the reverberation time, and the omni-directional loudspeaker (Norsonic Type 229) was used as sound source. The dimension of specimen of the OMPPs is 2.4m (width)$\times$ 3.6m (length), and both the length/width ratio and area are conforming the CNS 9056. The distance from any part of specimen to any wall of reverberation room exceeded 1m. There are 5 microphone positions in the measurement. All the other requirements and parameters in measuring the reverberation time were complied with CNS 9056.

The reverberation times for each frequency (125 Hz ~ 4000Hz, 1/3 Octave) were measured in two situations individually: empty room and after the specimen had been brought in. The sound absorption coefficient was than calculated using the following equation:

$$\alpha = \frac{55.3 \times V}{S \times C}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad \text{(Eq.6)}$$

where α is the sound absorption coefficient; V denotes the volume of reverberation room (m3); S is the area of test specimen (m2); C is speed of sound(m/sec); T1 is the reverberation time on empty room situation (sec); and T2 is the reverberation time after the specimen has been brought in (sec).

RESULTS AND DISCUSSION

The measures used to define the accuracy of prediction of the proposed QSSARs are the square of the correlation coefficient (R2) calculated for the prediction sound absorption coefficients by applying the model developed on the training set, and the root-mean-squared error of prediction (RMSEP). The RMSEP is a measurement of the average difference between predicted and experimental values in the prediction step.

Regression models

Multiple linear regression analysis has been carried out to derive the best QSSAR model. The MLR technique was performed on the training set, and the MLR analysis provide a useful equation (shown as Eq.7) that can be used to predict α OMPP based upon these parameters. The statistical characteristics of the MLR model are shown in Table 1, Table 2 and Table 3.

$$\alpha\,\mathrm{OMPP} - \alpha\,\mathrm{MPP} = 1.207 + 0.476\times Rs + 2.548\times As - 0.828\times h1 - 1.370\times Rl - 0.381\times h2 - 0.024\times p \quad \text{(Eq.7)}$$

Table 1 Model Summary

R	R Square	Adjusted R Square	root-mean-squared error of prediction	Durbin-Watson
.960(f)	.921	.909	.0392254	2.569

Table 2 Coefficients

	Unstandardized Coefficients		Standardized Coefficients
	B	Std. Error	Beta
(Constant)	1.207	.336	
Rs	.476	.027	1.085
As	2.548	.216	.931
h1	-.828	.115	-.445
Rl	-1.370	.244	-.349
h2	-.381	.079	-.311
p	-.024	.005	-.338

Table 3 Residuals Statistics(a)

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-.131375	.272325	.040223	.1250263	48
Residual	-.0797804	.0718479	.0000000	.0366362	48
Std. Predicted Value	-1.372	1.856	.000	1.000	48
Std. Residual	-2.034	1.832	.000	.934	48

The quantitative structure- sound absorbing relationship (QSSAR) model (shown as Eq.8) includes 6 descriptors. The application of QSSAR technology employs statistical methods to derive quantitative mathematical relationships linking structure factors and sound absorption coefficients of OMPPs.

$$\alpha\,\mathrm{OMPP} = \alpha\,\mathrm{MPP} + 1.207 + 0.476\times Rs + 2.548\times As - 0.828\times h1 - 1.370\times Rl - 0.381\times h2 - 0.024\times p \quad \text{(Eq.8)}$$

The MLR analysis provided a useful equation an the most relevant set of descriptors was selected by the stepwise variable selection method. The results obtained indicate that except perforation percentage and hole area, appearance-index and surface uneven grade also play an important role in the sound absorbing coefficients of OMPPs structures. The high correlation coefficients (0.921) and low prediction errors obtained confirm good predictive ability of the model.

REFERENCES

1 Maa, Dahyau, "*Theory and Design of Microperforated Panel Sound-Absorbing Constructions"* Scientia Sinica,(1975), 55-71.
2 Maa, Dahyau, "*Direct and Accurate Measurement of Microperforated Panel"* Inter-Noise 83, 363-366.
3 Maa Dah-You,Chin "*Wide-Band Sound Absorber Based on Microperforated Panels"*,.J.Acoustics,4(3),197-2.8(1985)
4 Maa Dah-You,,"*Microperforated-Panel Wideband Absorbers*", Noise Control Engineering J., 29(3), 77-84(1987)
5 Motoki Yairi,"*Absorption Properties of Microperforated Panel Absorber and its Applications"*, Architectural Acoustics and Noise Control,no.131/Sep.2005