SIMULATION AND VALIDATION OF METAL PERFORATED PANELS FOR ARCHITECTURAL ACOUSTICS

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Usage of Metal Perforated Panels (MPPs) is increasing in India, as they are durable and environmental friendly. These MPPs are used with a thin resistive layer of fabric scrims with very high airflow resistivity glued to MPPs. The acoustical performance of these MPPs is governed by NRC values. The sound absorption coefficient of MPPs is measured in reverberation chamber as per international standards like ISO 354 / ASTM C423 with optimised air gap. The sound absorption coefficient of metal perforated panel depends upon hole diameter, distance between two consecutive holes and thickness of the MPP and mainly on airflow resistivity of resistive fabric scrim and air-gap. In this paper, the measurement methodology is presented in detail. Also the MPPs along with the resistive layer are modelled using theoretical models for each layer and used to predict sound absorption values at random incidence. The optimised sound absorption coefficient can be achieved using modelling techniques by varying airflow resistivity and thickness of resistive fabric. This modelling technique can also be used to get targeted NRC values by multiple iterations of design parameters. In this paper, the theory behind mathematical modelling has been discussed in detail. Also theory has been used to optimise the sound absorption coefficient at customised frequencies and NRC values. At the end, predicted results are compared with experimental results to validate the modelling techniques.

1. Introduction

Metal Perforated Panels (MPPs) along with a high resistivity scrim and air cavity backed by hard wall are widely used in Architectural acoustics for interior noise reduction. These panels are made up of galvanised steel and are resilient in nature. Earlier MPPs were used with thick backing of Glasswool or Rockwool covered with a polyethylene film bags and lot of literature is available on prediction of sound absorption coefficient of such systems at random incidence. A pioneering work was made by Bolt in 1947 [1]. Recently a more detailed theory is presented by so many authors [2]. A more useful theory is presented by Uno Ingard in his book []. As the mineral wools are health hazardous, now a day these wools are replaced with thin layer of resistive fabrics with very high airflow resistivity. Airflow resistivity is nothing but the resistance to flow air when air passes through the fabric and is an important acoustic parameter. Higher the airflow resistivity better is the performance of system. In this paper, a methodology has been developed to simulate sound absorption of the MPP panels along with the high resistive scrim and air cavity backed with hard wall. Form the initial study; it has been observed that airflow resistivity of resistive fabrics plays a crucial role in sound absorption coefficient of metal perforated panels backed with thin scrim layer and air cavity. Effect of other parameters like hole diameter, spacing between the holes, MPP thickness and air-gap thickness can also be optimised using modelling techniques. In the present paper, theoretical models used of multilayer MPP system are discussed in detail. Then the predicted results are validated with experimental random incidence sound absorption coefficient measured inside a reverberation room.

2. THEORY FOR METAL PERFORATED PANELS

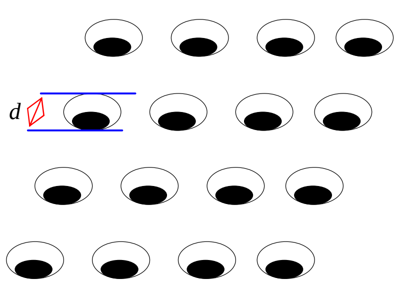
Today's MPP system consists of a metal perforated panel with 10 -20% open area, backed with thin layer of resistive scrims of 60-150 GSM. These scrims are glued to the metal panels using water based glue. These MPP with scrims are mounted with different air-gaps of 300- 600 mm. This Multilayer MPPs then provide very sound absorption at low frequencies with mounted with air-gaps.

2.1 Model for Perforated Panel

Metal Perforated Panels have perforations of millimeters or even centimeter size. Theory and design was established by D.Y.Maa [3]. The normalized impedance for a micro-perforated absorber is given by

$$\zeta = \left[7.37\times10^{-3}\left(1+72.23M\right)+j2.2245\times10^{-5}\left(1+51t\right)\left(1+204d\right)f\right]/\sigma \tag{1}$$

where
σ is the porosity, d is the perforation diameter in mm,
t is panel thickness in mm, f is the frequency in Hz
M is the Mach number.



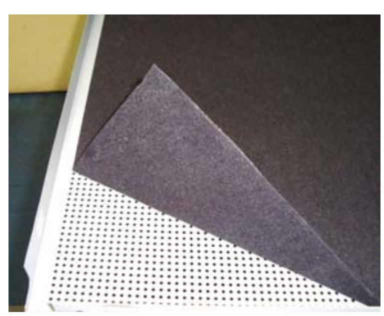


Figure 1: Geometry and Schematic of Metal Perforated Panel with Resistive Scrim

2.2 Model for Resistive Scrim

In case of resistive scrim, the surface impedance is given by

$$Z_f = j\,2\pi\, f\, \sigma^{'} \tag{2}$$

where
f is frequency of incident sound
$\sigma^{'}$ is mass per unit area

2.3 Transfer Matrix Method for single and multilayer porous materials

A simple Transfer Matrix Method (TMM) is used to model the design configurations. The general representation for a Transfer matrix of a single layer acoustic system (fig.2) is.

$$\begin{bmatrix} P_r \\ V_r \end{bmatrix} = \left[T_1\right] \begin{bmatrix} P_{r+1} \\ V_{r+1} \end{bmatrix} \tag{3}$$

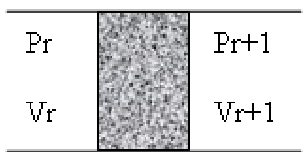


Figure 2: Schematic of a Transfer Matrix

Where P_r is sound pressure and V_r is sound velocity and T_{11}, T_{12}, T_{21} and T_{22} are four pole parameters or transfer matrix elements.

For a porous acoustic material of thickness d , the transfer matrix for a resistive scrim is given as

$$T_1 = \begin{bmatrix} 1 & Z_f \\ 0 & 1 \end{bmatrix} \tag{4}$$

where Z_f is given by eqn. (2)
For a perforated panel the transfer matrix is given by

$$T_2 = \begin{bmatrix} 1 & \zeta \\ 0 & 1 \end{bmatrix} \tag{5}$$

For an air space of depth *d*, the transfer matrix is given by

$$T_3 = \begin{bmatrix} \cos(k_c.d_3) & {}^{j}\!/_{z_c}.\sin(k_c.d_3) \\ j\,z_c.\sin(k_c.d_3) & \cos(k_c.d_3) \end{bmatrix} \tag{6}$$

where, ρ_0 is density of air
c_0 is velocity of sound

For multilayer configuration, the overall Transfer Matrix T is obtained by multiplying the above matrices for required configuration.

$$[T] = [T_1][T_2].......[T_n] \tag{7}$$

The total impedance Z_s is given by

$$Z_s = jZ_\omega \coth(\Gamma_\omega d) \tag{8}$$

The normal incidence sound absorption α for an absorbing material with rigid backing is given by

$$\alpha = 1 - \left| \frac{Z_s - \rho_0 c}{Z_s + \rho_0 c} \right|^2 \tag{9}$$

The random incidence sound absorption coefficient can be evaluated by considering random incidence and integrating over angles 0^0 to 90^0 using Paris's formula as follows.

$$\alpha_{random} = \int_{\theta_{min}}^{\theta_{max}} \alpha(\theta).\cos\theta.\sin\theta\, d\theta \tag{10}$$

where θ is the limiting angle varying between θ_{min} and θ_{max} . Generally the limiting angle is between 70^0 to85^0.

3. EXPERIMENTAL TECHNIQUES

In this section, experimental techniques used to measure intrinsic physical parameters and acoustic parameters are discussed. The performance of resistive scrim can be predicted with prior measurement of intrinsic physical parameters such as porosity, flow resistivity. The experimental measurement of these parameters requires specialized test rigs like; porosity is measured using an air porosity meter based on Boyle's law [4]. Flow resistivity is measured using flow resistivity test rig based on ASTM C522 standard [5]. Porosity of the MPP was calculated from hole diameter and spacing between the holes. Airflow resistivity values measured experimentally for resistive scrim are given in table 2.

Table 1. Physical Parameters of MPP

Physical Parameters	MPP
Density[kg/m^3]	7850
Thickness [mm]	0.5
Hole Diameter	2.3
Perforation Ratio [%]	16

The random incidence sound absorption coefficient was measured using a reverberation room with an air cavity as per ISO 354. The air cavity was maintained by using a wooden frame as shown in figure 3. The periphery of the wooden frame was sealed using silicone sealant to make air cavity. In reverberation room an Omni-directional source was placed to create diffused field inside the reverberation room as shown in figure 3.

Table 2. Physical Parameters of Resistive Scrim

Physical Parameters	Cloth based Resistive Scrim	Fiberglass Tissue Paper	
		With Adhesive	Without Adhesive
Surface Density [GSM]	150	90	90
Flow Resistivity [Ns/m^4]	370000	520778	1429002
Thickness [mm]	0.75	0.45	0.45

Figure X: Experimental Test setup for measurement of sound absorption coefficient in a Reverberation Room

A large sample of size 5.76 m^2 is used to measure random incidence sound absorption coefficient. The method is based on the calculation of two reverberation times T_1 and T_2 with and without the sample. The equivalent sound absorption area A_1 of the empty reverberation room and with sample of area A_2 is calculated as

$$A_1 = \frac{55.3V}{c_0 T_1} - 4Vm_1, \quad A_2 = \frac{55.3V}{c_0 T_2} - 4Vm_2 \tag{11}$$

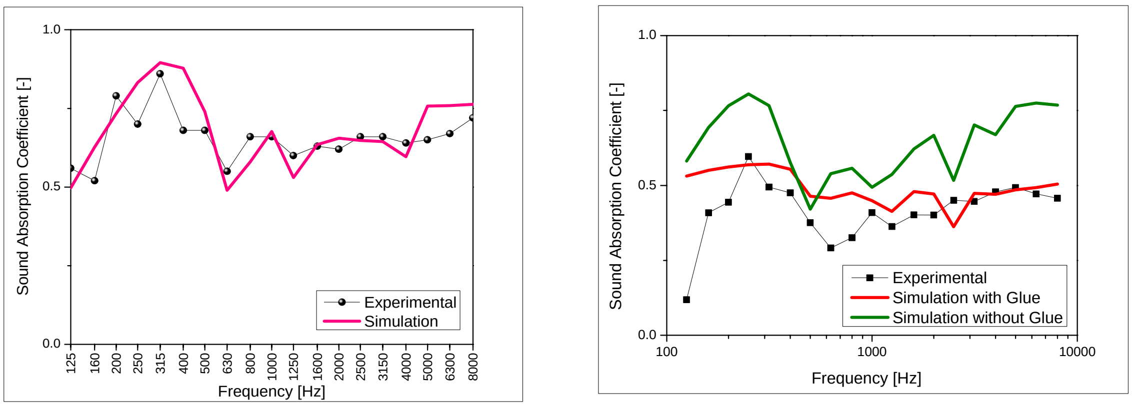
where, V is the volume of the empty reverberation room in cubic meters, c_0 is the speed of sound in meters per second, T_1 is the reverberation time in seconds of the empty reverberation room, T_2 is the reverberation time in seconds of the reverberation room with specimen placed inside the room and m is the power attenuation coefficient in reciprocal meters calculated according to ISO 9613-1. The sound absorption coefficient α_s of a plane absorber can be calculated as follows [6]

$$\alpha_s = \left(A_2 - A_1\right)/S \tag{12}$$

where, S is the surface area of the test specimen.

3. RESULTS AND DISCUSSIONS

The physical intrinsic properties measured using specialized test rigs of tested samples are given in table 1 and 2. These parameters were used for simulation of metal perforated panel with cloth based resistive scrim and air cavity backed by hard wall as shown in Figure 2. Figure 4(a) shows good correlation of predicted sound absorption coefficient with the experimental results and NRC in both the cases is 0.56. This study inspired the authors for improving the sound absorption coefficient and NRC of such multilayer systems to higher NRC 0.7 – 0.75.



4(a) 4(b)

Figure 4: Comparison of predicted sound absorption coefficient with experimental sound absorption coefficient in a Reverberation Room

To achieve a NRC of 0.7 to 0.75, a resistive scrim made of fiberglass tissue paper with higher air-flow resistivity was used to predict random incidence sound absorption coefficient. In actual test, this tissue paper was pasted to the perforated panels using water based adhesive. In the test, it was observed that experimental random incidence sound absorption coefficient was lower than the predicted random incidence sound absorption coefficient as shown in figure 4(b).

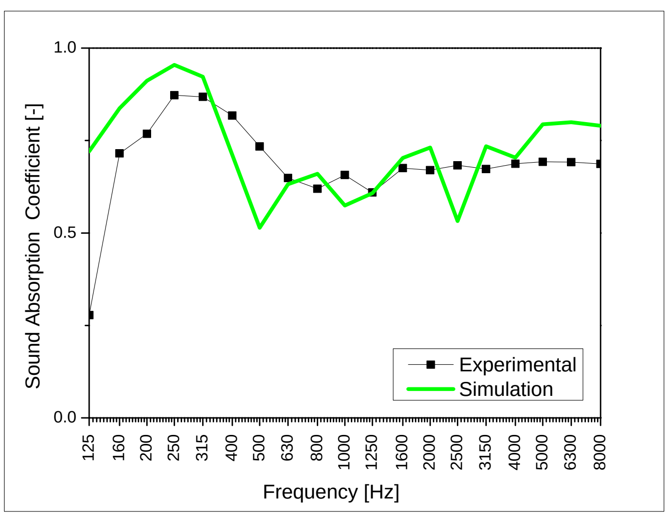


Figure 5: Comparison of predicted sound absorption coefficient with experimental sound absorption coefficient in a Reverberation Room

This result was not logical as same MPPs and wooden frame were also used for this test. So airflow resistivity was measured again of the pasted sample and it was surprising to see that airflow resistivity of the pasted sample was lower than the original sample. The reason behind this was the water solvable adhesive which was used to paste the samples on MPPs. When this adhesive was used to paste the fiberglass tissue paper on MPPs, that time, it changed the acoustic characteristics of the fiberglass tissue paper. So again a new test carried out using new samples and results are compared in figure 5. From this figure, it has been observed that, a prediction carried out using airflow resistivity of pasted sample correlates well with experimental results very well with NRC values more than 0.70. Some deviation in results is observed at low frequencies. This might be due to variation of airflow resistivity of the pasted sample. As only small samples of pasted resistive scrim were cut from the complete area and it was not feasible to check airflow resistivity of more samples.

CONCLUSION

In this study, a methodology has been developed using simulation techniques to design and improve acoustic performance of metal perforated panels. Using this technique, it is possible to predict performance of multilayer systems including MPPs before manufacturing and testing actual component. It has been observed that, if designed resistive scrim along with optimum air-gap is used then the sound absorption coefficient improves significantly.

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