ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

On some problems Related to the Fabrication of a Metallic Micro-Perforated Panel for Noise Control Applications

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Abstract*— Micro-Perforated Panels (MPP) are widely used nowadays as a noise control solution. Such materials present many interesting advantages and are considered to be among the latest innovative sound absorbing materials. For these reasons, many models are proposed in the literature to predict their acoustic behavior. However, the accuracy of these models depends on the assumptions under which they are derived and more often on the MPP samples built for their validation. Rigorous attention is therefore needed to insure convenient fabrication of samples for the MPP. This paper investigates some important problems related to the fabrication of metallic MPP samples used for noise control applications. Particular emphasis is given to the hole drilling effects. It is shown for instance that the presence of shavings inside the perforation may alter or change the MPP acoustic response. This work supports the design of optimum MPP for noise control applications such as duct mufflers, room acoustics, and transport domain and environment noise abatement.

***Index Terms*—Metallic MPP design, Micro-perforated panels, MPP, problems and constraints.**

I. INTRODUCTION

The use of Micro-Perforated Panels (MPP) to attenuate sound has been widely spread for some decades now. If perforated plates and screens were formerly used as protective layers of porous materials, it is now known that they can alone afford very interesting sound absorption when the perforations are reduced to the sub millimeter size [1] (the term micro-perforated panel is rather used for sub millimetric radius).

The study of MPP as dissipative silencers may be related to the studies of resonators with orifices [2] which date back to the middle of the last century. An extensive work was originally done by Sivian [3] and Ingard [4] basically on the radiation and the end corrections for a single aperture. Their works were then reviewed by Melling [5] who did a notably work for the cases of medium and high sound excitations. As soon as the case of low sound excitations studies [1],[2],[6] (linear regime) was relatively mastered, a certain number of works were devoted to the case of high sound excitations [5],[7]-[9] (nonlinear regime). The aspect of interacting pores (concerning relatively high open area ratio) was also considered in some studies [10], [11].

The modeling of the acoustic behavior of MPP usually requires the plate thickness, the diameter of the holes and the open area ratio (implicitly the distance between two consecutive pores) as input entries. Among all these entry parameters, the open area ratio plays an important role. In fact, Maa [1] clearly states that the value of the open area ratio (also known as the porosity) is important, mentioning that while a small change of its value is usually allowed, the exact value is necessary for very good prediction of the models. The open area ratio can simply be defined as the ratio of the air space size in a material to the entire material size. Theoretical and experimental methods for estimating the porosity of classical porous materials are well known and mastered [12],[13]. Despite the fact that the theory for micro-perforated plates have been well developed, a particular attention has not yet been given in proper evaluation of the entry parameters for metallic MPP sample and their influence on the acoustic response. In evaluating the open area ratio, it is common using some classical well known formulas [1],[14],[15]. These formulas strictly depend on the holes configuration and may lead to some slight errors in the modeling if they are not properly estimated.

The purpose of the present paper is to investigate some important problems related to the fabrication of metallic MPP such as the holes drilling effect. These problems are presented and their cause is explained. Some solutions are also proposed backed by a rigorous measurement to prove their effectiveness. In the first step of this study, Maa's model [1] is briefly presented and both the open area ratio and holes diameter variations are discussed. The next section deals with the holes drilling effects on the open area ratio, the holes diameter and the plate thickness. An experimental setup is then described and the obtained results are discussed in details. The theoretical and experimental results are also compared and discussed. The important results are summarized in the conclusion of this study.

II. THE THEORETICAL CONSIDERATIONS

A. The Acoustic Absorption Model

The most commonly used model in the literature for MPP is the analytical model of Maa [1] derived after Crandall’s work [16] on acoustic propagation inside small and thin tubes. According to Maa's work [1], the impedance of a single

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ISO 9001:2008 Certified
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perforation can be expressed in terms of real (*Re*) and imaginary (*Im*) parts as [1]:

$$z = \mathrm{Re} + j\,\mathrm{Im}, \tag{1}$$

with

$$\mathrm{Re} = \frac{32\eta h}{d^2}\left(\sqrt{1+\frac{K_p^2}{32}} + \frac{\sqrt{2}}{32}K_p\frac{d}{h}\right), \tag{2}$$

and

$$\mathrm{Im} = \omega h \rho_0\left(1 + \frac{1}{\sqrt{1+\frac{K_p^2}{2}}} + 0.85\frac{d}{h}\right), \tag{3}$$

Where η is the air viscosity, h is the plate thickness, d is the diameter of the perforations and K_p is the perforation constant expressed as [1]:

$$K_p = d\sqrt{\omega\rho_0 / 4\eta}, \tag{4}$$

with ω the pulsation, ρ_0 the air density. It is worth mentioning that the real part (equation (2)) accounts for the resistive phenomena taking place inside and around the perforation whereas the imaginary part (equation (3)) accounts for the reactive phenomena.

In order to create a sound absorbing effect, the MPP is normally coupled to an air cavity gap or a classical porous material such as fiber or glass wool. It is considered in this work the case of a coupling with an air cavity gap. The air cavity impedance z_{cav} before rigid backing wall is given by [6], [10]

$$z_{cav} = -j\cot\left(\frac{\omega}{c_0}D_{cav}\right), \tag{5}$$

with D_{cav} is the air cavity depth and c_0 is the speed of sound. The surface impedance z_{MPP} of the MPP is obtained thanks to the open area ratio (ϕ) and given by [6], [10]

$$z_{MPP} = \frac{z}{\phi\rho_0 c_0} + z_{cav}. \tag{6}$$

The sound absorption coefficient α is calculated using the well known expression given by [6]

$$\alpha = 1 - \left|\frac{z_{MPP}-1}{z_{MPP}+1}\right|^2 \tag{7}$$

B. Some Simulation Results

Fig.1 presents the simulated sound absorption coefficient as a function of the frequency with a variation of the MPP porosity (Fig.1a) and the hole diameter (Fig.1b). In Fig.1a, it is observed that for a given frequency of resonance, the band for an optimum open area ratio is very limited even more for the low frequency range. For low frequency range, even a small variation of the open area ratio (porosity) can considerably alter the absorption characteristic of the air cavity backed MPP. In Fig.1b, one can observe that for a given resonance frequency, the band for an optimum perforation diameter is also relatively small. As for the latter case of porosity, a small change of the perforation diameter may cause a degradation of the absorption coefficient. For a designed frequency, the variation of the porosity (so as for the perforation diameter) will mainly affect the absorption amplitude although in practice it will also affect the frequency of resonance (frequency for which the absorption coefficient is maximal).

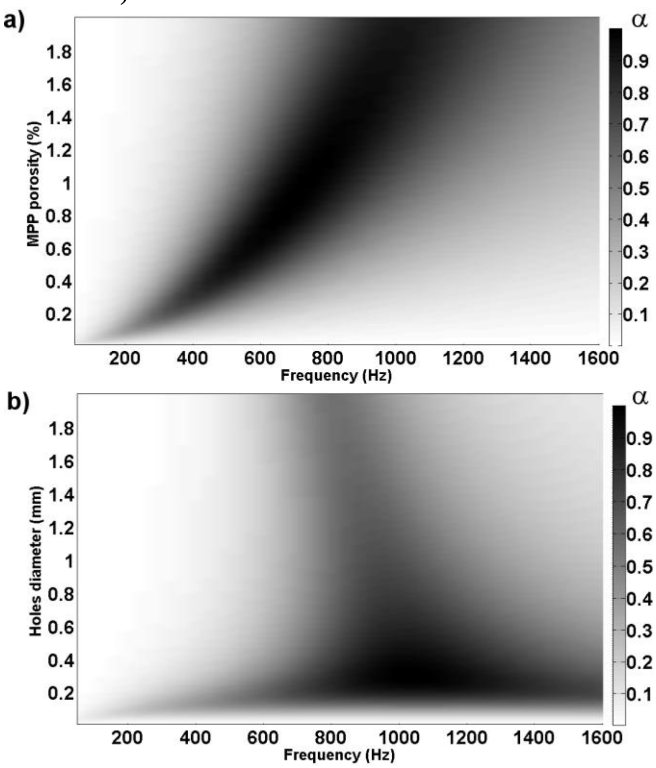

Fig.1 Simulated sound absorption coefficient as a function of the frequency. (a) Variation of MPP porosity (plate thickness of 1 mm, holes diameter of 0.5 mm and air cavity depth of 50 mm); (b) Variation of holes diameter (plate thickness of 1 mm, porosity of 1.94 % and air cavity depth of 50 mm).

III. HOLES DRILLING EFFECTS

A. Effect on the effective open area ratio

Among the parameters necessary in predicting the acoustical behavior of a multi-perforated plate, the open area ratio is of a great importance. The open area ratio ϕ, also known as the perforation ratio or the porosity, is the ratio of the air volume V_a contained in the perforates for a given material to the total volume V_t of the material [6].

$$\phi = \frac{V_a}{V_t}. \tag{8}$$

For MPP, assuming identical holes (same size and length), ϕ is given by [6]

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ISO 9001:2008 Certified
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$$\phi = \frac{nV_p}{V_t}, \tag{9}$$

Where V_p is the volume of air contained in one pore and n is the total number of holes. Considering this latter equation, one can deduce that an obstruction (partially or complete) of a certain number of holes can change the value of ϕ. Now, despite the fact that n is an integer and does not account for fractions of holes on the sample, it is possible to avoid using n in calculating ϕ. In the case of very great number of pores on the sample for instance, it is not necessary knowing the number of pores on the plates. Assuming a regular spacing between the pores, the diameter d of holes and the distance b between two consecutive holes are sufficient in determining ϕ. For instance, Maa [1] and Miasa and Al. [15] in their works make the use of the following expression

$$\phi = 0.785\,\xi^2, \tag{10}$$

Where $\xi = d/b$ (ratio of the pore diameter d to the holes distance b). Although Miasa and Al. [15] do not distinguish the pores arrangements in their work, Maa [1] clearly mentioned that this latter expression of ϕ is to be used for the case of square lattice arrangements of perforates. This can easily be mathematically proved.

In Everest and Pohlmann [14] work, it is noted that expression (10) is for the square lattice arrangement. The open area ratio for a triangular (equilateral) lattice arrangement of the holes is given by [14]

$$\phi = 0.906\,\xi^2, \tag{11}$$

Both latter expressions of ϕ are the classical formulas used in evaluating the open area ratio.

The laser drilling process is a technological method that uses energy from a laser beam to drill a metallic plate. This process creates some defaults around and inside the perforations which are not easily observable for very small perforations (micro-perforations). In fact, once the drilling is done, there are shavings remains inside and sometimes around some perforates that may result to a partial or a complete obstruction of these perforations. The direct consequence of these defaults is a modification of both the open area ratio and the designed hole diameter. One way to solve this default is to make use of a drill with a diameter smaller than the designed diameter to remove the shavings. It is important not to introduce a bevel edge around the perforation outlet as this can cause a modification of the acoustic response of the sample. Later on, the sample may be submitted to high air pressure flows to remove small material particles inside the perforations. The resulted sample, after the removal of the defaults, is considered to be without (with less considerable) default. Fig. 2 shows an observation picture of a laser drilled MPP (holes diameter is 1.6 mm) after removal of the defaults. One can observe the absence of shavings and a very good circularity of the cylindrical perforations.

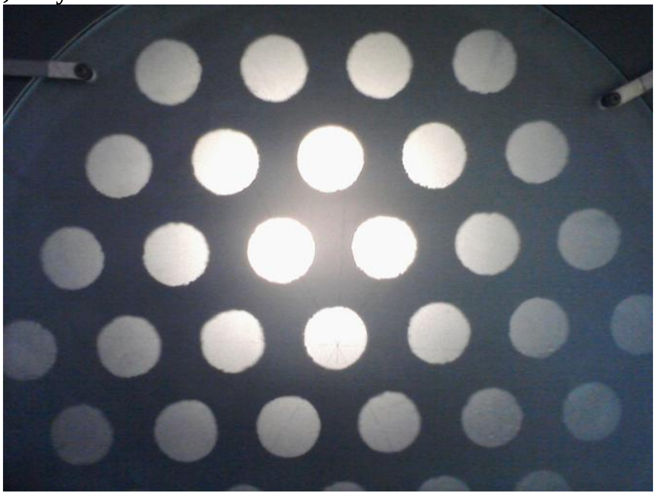

Fig.2 Observation of a laser drilled MPP after removal of the defaults (shavings and material particles). Observation obtained with a DELTRONIC profile projector (enlargement x10).

B. Effect on the effective hole diameter

The drilling process of the samples can also introduce an error to the estimated hole diameter due to the inner roughness of the perforations. In this work, the estimated error for the studied samples is calculated to be 10^{-5} m. Fig. 3 depicts the picture of a single perforation (nominal diameter of 1.6 mm) laser drilled with a beam ray of 0.3 mm.

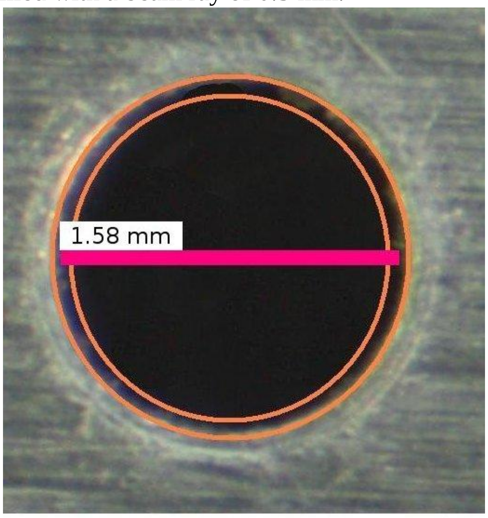

Fig.3 Picture of a single perforation laser drilled for a nominal diameter of 1.6 mm. Laser beam ray of 0.3 mm. Observation obtained with a digital microscope (x20).

C. Effect on the effective plate thickness

The advantages of a laser drilling process over a manual process is that the laser drilling process does not imply any considerable mechanical effort and closely separated holes can be obtained with a very good precision insuring a minimal distance between these perforations for structural reasons. Nevertheless, every drilling process normally creates residual stresses in the MPP sample. Depending on its magnitude and distribution, the effect of residual stress may cause a fatigue or a structural failure of the MPP sample [17]. Whenever this minimal distance is not accounted for, with a great number of holes, this may result to a bending effect of the plate. This

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
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latter effect is a consequence of the bending stresses that distort the plate during the drilling process. Fig.4 shows the front and profile view of an MPP sample with the following characteristics: 4300 perforations with a hole diameter of 0.9 mm, plate thickness of 1 mm, distance between two consecutive holes is 1.3 mm. One can clearly observe the resulted structural failure caused by the drilling. In some cases, this failure is not easily observable and may affect the sample absorption characteristics as it introduces acoustic leaks. Very often, it is requested to have a plate thickness smaller than the perforation diameter. In fact, the minimum diameter of a perforation should be equal to the MPP thickness for a proper drilling.

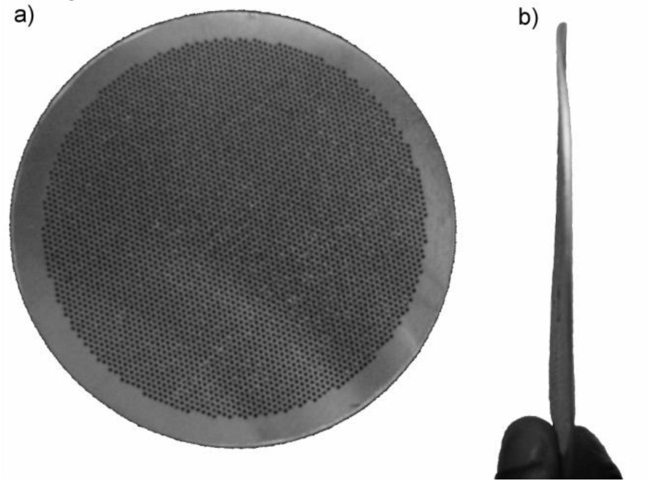

Fig.4 Picture of a Micro-perforated panel with 4300 holes of 0.9 mm in a circular plate of 100 mm diameter. The plate thickness is 1 mm and the distance between two consecutive holes is 1.3 mm. (a) front view; (b) profile view showing the resulted plate bending.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The measurements are performed on steel-made MPP samples with different characteristics. All the perforated samples (of circular shape) have an external diameter of 100 mm. The samples characteristics are given in table 1. The perforations of each sample are laser drilled (focused laser beam of 300 µm size) for an estimated fixed discharge coefficient of 0.6 (sharp-edged orifice).

Table. I Characteristics of the MPP Samples used for the measurement.

	Thickness	Hole diameter	Porosity
MPP1	2 mm	1.6 mm	0.95 %
MPP2	2.2 mm	0.7 mm	1.3 %

The presented results in this paper are obtained thanks to an impedance tube (Fig. 5). This impedance tube is a rigid circular plane-wave tube with a diameter of 100 mm (cut-off frequency of 1.7 KHz). A soundproof plunger is used as the rigid backing wall. The sealing for the plunger is ensured using a rubber. By moving the plunger along the longitudinal axis of the tube, one is able to create an air cavity behind the sample. The sample is mounted between the acoustic source (a speaker) and the plunger. The sound excitation delivered by the source is a periodic random noise signal. The tube has a thickness of 7 mm to provide a sound-hard boundary condition. Two 1/4" microphones are used to perform the signal detection. They are used to calculate the surface impedance of the MPP sample by the two microphones standing waves method described by Chung and Blaser [18]. The distance between these microphones is 50 mm. And the distance between microphone 2 (microphone close to the sample) and the sample is 10 mm. An LMS System is used for the data acquisition unit. The measurements are performed considering an MPP sample with an air cavity and a rigid wall. The sound pressure reference used is 20 µPa. Before acquiring the data, a careful calibration phase of the microphones is done for the separate phase and magnitude calibration of the two microphones.

Fig.6 represents the measured and simulated absorption coefficients of sample MPP1 for an air cavity depth of 50 mm. Both measured results (with and without the defaults) are presented. The confidence range is presented in gray area around the measurement. The simulation is in good agreement with the measurement without default and fits well within the confidence range around the resonance frequency.

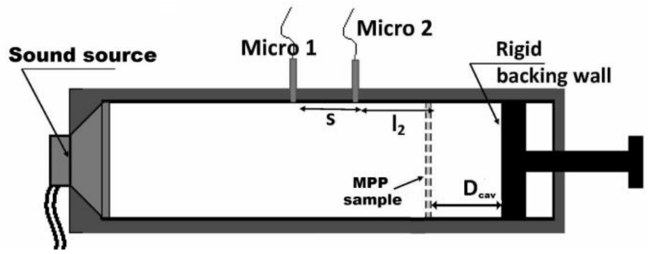

Fig.5 Impedance tube used for the measurement.

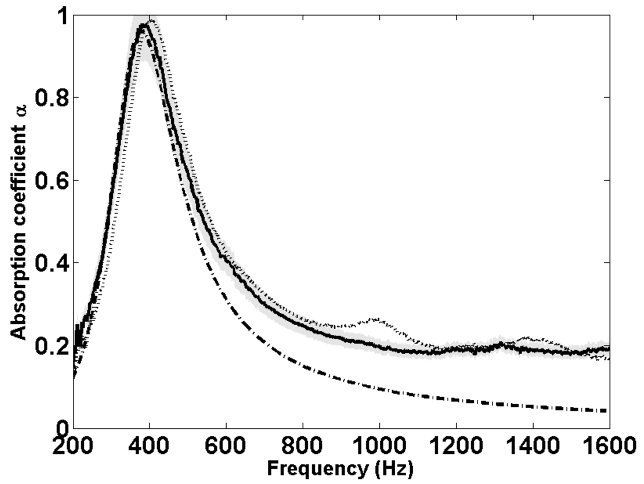

Fig.6 Absorption coefficient of sample MPP1. Air cavity depth of 50 mm. Solid line: measurement without the defaults; dotted line: rough measurement with defaults; dotted-dash line: simulation; Gray area: the confidence range.

Fig.7 depicts the measured and simulated absorption coefficients of sample MPP2 for an air cavity depth of 50 mm. As for MPP1, both measured results (with and without the defaults) are presented. The first peak around 480 Hz is directly link to the viscous effect whereas the second peak

ISSN: 2277-3754
ISO 9001:2008 Certified
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around 900 Hz is linked to the structural (vibration) effect of the panel. It is worth mentioning that the model does not account for the structural effect and therefore does not match the second peak. Nevertheless, the simulation fits well within the confidence range and is in very good agreement with the measurement without defaults.

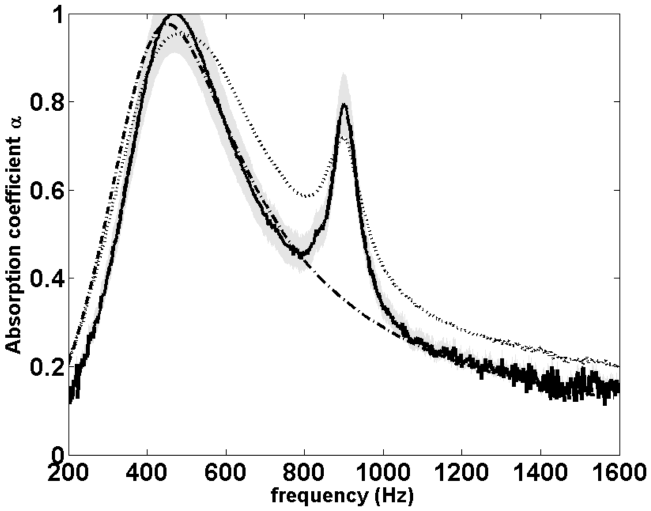

Fig.7 Absorption coefficient of sample MPP2. Air cavity depth of 50 mm. Solid line: measurement without the defaults; dotted line: rough measurement with defaults; dotted-dash line: simulation; Gray area: the confidence range.

V. CONCLUSION

The present work investigated some important difficulties related to the fabrication of metallic Micro-Perforated Panels (MPP) for noise control applications. It presented some limitations that may appear due to the holes drilling process on the MPP sample. One non-negligible effect created by this drilling process is the introduction of residual stresses in the MPP sample that cause structural failure. Other defaults are the inner roughness of the perforation and the presence of shavings or material particles. It is particular shown that variations of the entry parameters, i.e. porosity, holes diameter and thickness may occur during the fabrication process of the sample and may lead to serious discrepancies between the measurement and the simulation for the absorption characteristics of the sample. Therefore, the exact values for these parameters are necessary for good prediction of the models.

ACKNOWLEDGMENT

Part of this work was initiated at the University of Burgundy. The author wish to thank the Vibration and Acoustics team in the DRIVE laboratory for the fruitful discussion.

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ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 11, May 2014

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He was awarded the best PhD student poster presentation from the French Society of Physics in 2008 and recently won both the young scientist grant 2012 in Prague from the European Acoustics Association (EAA) and the international young scientist grant 2012 in New York from the International Noise Control Engineering (INCE, InterNoise).

His work was recently examined by the "Marquis Who's who in the world" committee and his biography was accepted for publication in one of the 2013 edition of this Revue. He is currently working as a Physics teacher and his research work deals with the numerical characterization of macroscopically homogeneous and inhomogeneous materials in both media of air and water. Author contact: rtayongb@ulb.ac.be.