

Technical Note

A note on the fabrication methods of flexible ultra micro-perforated panels

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ABSTRACT

Micro-perforated panel (MPP) absorber has been studied and developed for decades and is becoming more and more popular in an environment protective society. Although the traditional MPPs are rigid, the research results in recent years have indicated that flexible MPPs with ultra-micro perforations of diameter less than 100 μm (ultra-MPPs) may have great potential to become a wideband sound absorber in high frequency range. However, it is a great challenge for both traditional mechanical methods and micro-fabrication technology to fabricate so small holes directly on flexible materials, which greatly limits the development of flexible ultra-MPPs. Therefore a new technical solution is strongly desired. To meet this demand, a new process, based on mold manufacturing technology and casting technology, is developed, and the key and specific process steps are presented in this paper.

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1. Introduction

Nowadays, noise pollution has become more serious, and thus thin, wideband, clean and health-friendly types of sound absorbers are increasingly desired. A micro-perforated panel (MPP) is very promising as a sound absorber when combined with a finite depth air space [1–3] and is now being widely used in many applications [4–7], which complies with lightweight, transparency, fibreless and weatherproof requirements. Typically, an MPP is made of a metal, plastic or wooden panel with sub-millimeter perforations. And a single layer MPP absorber is the most basic type, consisting of an MPP, air space, and a rigid backing, as shown in Fig. 1. Their major advantages lie in the flexibility in design, variety of materials and simple structure. Also, high sound absorption coefficients can be achieved with relatively small thicknesses compared with traditional porous and fibrous sound-absorbing materials. But when it comes to absorption bandwidth, a single layer MPP absorber with a bandwidth of usually 1–2 octaves is always incapable to compete with porous sound-absorbing materials, which makes it insufficient to become a general purpose absorber. To overcome this problem, numerous studies have been conducted to extend the absorption bandwidth by various researchers for almost three decades since Maa's pioneering works [1]. However, so far, most of the efforts either resulted in thicker absorbers by arranging two-layer or multi-layer MPPs in series, or increased the structural

complexity by adding porous sound-absorbing materials to the cavity [8–10] or changing the cavity structure [11], or introduced active noise control [12,13].

Actually, the mechanism of sound absorption in MPP absorbers lies in that the sound energy is dissipated when sound causes oscillatory movement of air through the small holes in the perforated panel which results in viscous dissipation. To create substantial absorption, it is suggested that many small holes should be used rather than a few large holes. According to Maa's MPP model [14], reducing perforation diameters of an MPP can increase the energy dissipation of viscous flow whereby the absorption performance can be greatly improved and even the absorption limits of a single-layer MPP absorber in high frequency range can be achieved by using ultra-micro perforations of diameter less than 100 μm . Thus, in order to broaden the absorption bandwidth, a more straightforward and space-saving approach is to reduce the perforation diameter and increase the perforation ratio properly. However, although the theoretical prediction is proposed for several years, due to the difficulty for traditional methods to manufacture ultra-micro perforations of diameter less than 100 μm , it has not been experimentally verified until recently a study finding proves the correctness of the theoretical prediction [15]. Results show that effective absorption covering a bandwidth of almost 3 octaves can be obtained by proper adjustment of parameters in a single layer MPP absorber by using ultra-micro perforations of less than 100 μm . It is worth noting that the ultra-MPPs developed in the experiments are based on silicon, therefore they are rigid enough to neglect the panel vibration effect.

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However, many studies have been focused on flexible MPP absorbers in recent years, which show that the flexibility of the panel can greatly affect the acoustical performance of MPP absorbers, especially a lightweight and thin MPP absorber [16–18]. It was found that the panel vibration effect due to its flexibility can introduce an extra absorption peak in addition to the basic absorption peak offered by the oscillatory motion of air through the holes. In other words, the panel vibration effect constitutes a second absorption mechanism which may be used to widen the sound absorption bandwidth of a single layer MPP absorber. Thus, utilizing flexible MPP is another effective and space-saving approach to achieve a broadband sound absorber [17]. Moreover, flexible MPPs have more flexible applications compared with rigid MPPs, since they can be easily transformed according to the shape of the objects which produce noise whereby they can meet the special noise control requirements of equipments with complex geometry shapes.

Based on the above analysis, a flexible ultra-MPP may be promising to become a new generation of sound absorbing material. In fact, a recent study has indicated that the absorption bandwidth of a flexible MPP made of PDMS with 100 μm perforation diameter is significantly broadened [19].

However, even theoretically, there is no problem for a single-layer and flexible ultra-MPP to become a general sound absorber with broader effective bandwidth, the technology to fabricate so small perforations in the range of micron is really a major challenge. And so far, most of the research work related to MPPs is about their applications, absorption performance improvement, theory modeling, experimental tests and so on, while there are few researches to explore their manufacturing process despite of its importance. Due to this, little improvements has been made to MPP's fabrication in last three decades. Perhaps because the traditional MPPs used are usually rigid and with holes of diameter more than 0.2 mm. Thus it is easy for conventional mechanical methods to make these large holes. But when the perforation diameter is reduced to tens of micros, the conventional machining methods may no longer apply, whereas new processes are required. To the best of the author's knowledge, so far no papers have systematically discussed the manufacture process of MPPs in detail, especially for flexible ultra-MPPs whose fabrication is still a challenge even today. The present work thoroughly probes into the various micromachining processes of flexible ultra-MPPs, which aims to furnish some references for future.

2. Technical solution

Creating a series of ultra-micro holes directly on a flexible material may be the most straightforward way to fabricate a

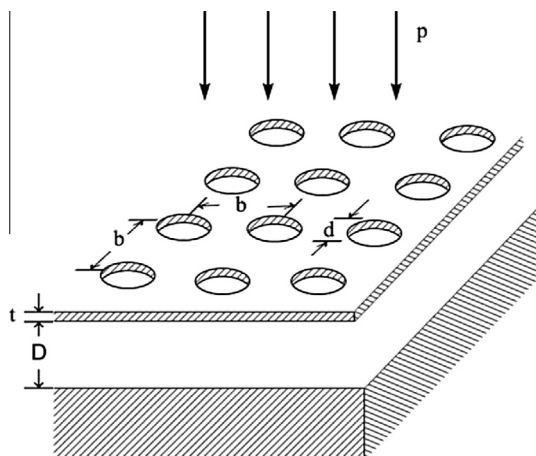


Fig. 1. Schematic diagram of a single-layer MPP absorber.

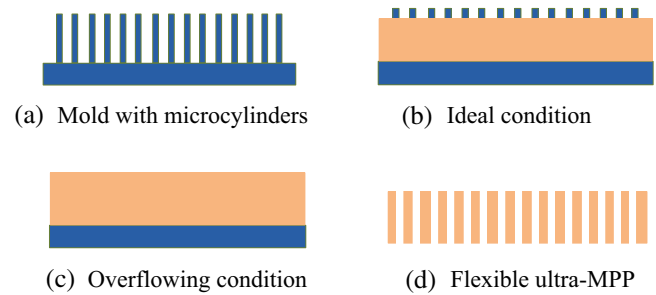


Fig. 2. Technical solutions to fabricate flexible ultra-MPP.

flexible ultra-MPP. But it is difficult for micromachining technologies to drill so small pores on flexible materials directly, because among them some require that the materials are rigid or conductive, and some have difficulty in accurately controlling the processing time when making holes. Taking the laser micromachining for example, it used the heat produced by the laser beam to melt and remove any unnecessary parts. As we know, the higher the energy of the laser beam, the higher the machining precision. For the rigid materials with high melting point, such as metals, ceramics, diamond and silicon which are very hard to melt and then the energy of the laser beam used can be very high. But for flexible materials, they are commonly of low melting point, and their thicknesses are usually the same order of magnitude as the perforation diameter in order to ensure the good absorption capacity of MPPs [1], therefore they are quite easy to melt. Consequently, if the energy is too high, the hole can become very big only in a very short time which makes it difficult to control. Conversely, if the energy is low, the machining precision cannot be guaranteed.

To overcome the above problems, we propose the following technical solution [20].

Firstly, a mold with microcylinder arrays is fabricated by a micromachining technology, as shown in Fig. 2a. Note that the molds are usually made out of rigid materials, such as silicon, ceramics, metals, and glass or plexiglass.

Secondly, by a solution casting technique, the flexible material in the liquid phase is poured over the prepared mold. And then the flexible material is solidified with proper temperature after removing the overflowing material. Now the flexible panel is completed. The ideal case is shown in Fig. 2b. However, there is always a serious problem in this step that ultrafluidous flexible material may cover the top of the microcylinder arrays, as show in Fig. 2c. Under this situation, the flexible panel can be reduced to needed thickness based on negative pressure method.

The last step is to peel the flexible material off from mold. With this, the flexible ultra-MPP is obtained, as indicated in Fig. 2d. The feasibility and effectiveness of this technical solution has been validated by experimental studies [19].

3. Fabrication process

From the above it can be seen that the crucial step is to develop appropriate mold with microcylinder arrays. The various processes to manufacture these molds are elaborated in the following sections.

3.1. MEMS technology

A silicon mold with microcylinder arrays that are 400 μm tall and 60 μm in diameter is fabricated based on MEMS technology. The normal glass mask with opaque circular patterns is used. Fig. 3 shows the detailed process schematic, which is explained as follows:

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