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Technical Note

Design and acoustical performance investigation of sound absorption structure based on plastic micro-capillary films

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ABSTRACT

Based on its constituting parallel micro-capillaries, the sound absorption behavior of multi-layer plastic micro-capillary film (MCF) structure has been investigated. The effects of micro-capillary diameter, perforation rate and perforation diameter on the sound absorption performance of the multi-layer MCF structures were studied using the standing wave tube method. It was demonstrated that the multi-layer MCFs had good sound absorption especially at low frequencies around the resonant frequency. The mechanical property of the MCF samples was measured by a strength tester and results demonstrated this sound absorption structures had stable mechanical behavior. Compared to two traditional sound absorption materials (perforated panel and porous material), the sound absorption coefficients of the MCF samples are comparable and competitive to them. Therefore the novel multi-layer MCFs, which are easy-to-manufacture and cost-effective, have promising applications in the field of sound absorption.

1. Introduction

Due to the rapid industrial development, noise pollution has become an important issue that needs to be addressed urgently to maintain a good sound environment in the transportation and building sectors. This is often achieved through the use of sound-absorbing materials and structures [1–3]. The research and development of efficient and environmentally friendly sound-absorbing materials and structures is therefore very important [4–7]. A sound-absorbing structure, typically a perforated plate or sheet with a sealed cavity of a certain depth, is usually developed based on the Helmholtz resonator [8] and can absorb low-frequency noises around the resonant frequencies. In recent years, the sound absorption bandwidths have been significantly broadened through combination of new resonance sound-absorbing structures and porous materials, leading to their significantly widened applications in the field of sound absorption [8–11]. Currently, porous materials, wood and metal are widely used for sound absorption [12]. However, their applications are impaired due to their relatively high costs and complicated processing. Therefore, it is necessary to develop novel sound-absorbing materials and structures as an alternative option.

Many researchers have reported the use of polymer-based sound-absorbing materials due to their wide versatility and relatively easy processing [13–18]. Multi-porous polymer microspheres with interconnected cavities were studied and good sound absorption was found especially in a low frequency range (about 200–500 Hz) [19]. Polyurethane (PU)/nano-silica nanocomposite foams were also investigated for use in sound absorption; the increasing nano-silica content leading to the increase of sound absorption ratio of PU/nano-silica foams [20]. Xiang et al. [21] developed electrospun polyacrylonitrile nanofibrous membranes, which were combined with traditional acoustical materials (e.g. perforated panels, foams and fibers) to achieve greatly enhanced acoustical damping performance in the low and medium frequency range (250–2500 Hz). In addition, the formation of a micro-perforated polymeric film for sound absorption was reported. Such film with tapered holes can provide a particular sound absorption spectrum [22]. Polycarbonate transparent micro-perforated membrane absorbers have excellent absorption properties, which was investigated by Zhang [23] based on the micro-perforated panel (MPP) theory presented by Maa [24]. Plastic micro-capillary films (MCFs), which are easy-to-manufacture, cost-effective, have been widely studied in a variety of fields, such as heat exchangers,

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chemical reactors, micro-pumps, and solar heat collectors [25]. However, research concerning the use of MCFs for sound absorption has not yet been extensively reported.

In this work, multi-layer MCFs have been developed and perforated. The constituting arrays of parallel, hollow and micro-capillary films represent a new type of resonance sound-absorbing structure. A standing wave tube method has been used to investigate their sound absorption performance by varying the micro-capillary diameter, perforation rate and perforation diameter. The MCF mechanical performance has been tested for sound-absorption application and the sound-absorbing performances of typical MCF samples have been compared to two traditional sound-absorbing materials. The potential application of these multi-layer MCFs as an effective perforated sound absorber is evaluated.

2. Experimental

2.1. Formation of MCFs

The plastic MCFs could be considered as a hybrid material with characteristics of polymer films, polymer hollow fibers and polymer foams [26]. Low- and high-voidage MCFs have been successfully produced via the blown film technique in our group [27]. Fig. 1a shows the 1-capillary and 28-capillary MCFs, which were processed by the extrusion line, and their typical physical and mechanical properties are listed in Table 1.

2.2. Preparation of multi-layer MCFs structures

The standard design process for multi-layer MCFs is shown in Fig. 1b. Typically, eight MCFs of the same size were superimposed with the micro-capillary directions of adjacent films being perpendicular to each other. The compression-resistant capacity resulting from the superimposition can lead to the enhanced mechanical properties of the multi-layer MCF structure. The adjacent MCFs were glued to each other after polishing the film surface. The multi-layer MCFs were then perforated with a diameter ranging from 1 mm to 2 mm (Fig. 1c).

Table 1
Physical and mechanical properties of MCFs.

Material	Density ($g\ cm^{-3}$)	Elasticity modulus (MPa)	Burst pressure (bar)	Micro-capillary diameter (μm)
LLDPE (Linear Low Density Polyethylene)	0.92	180	50–70	200–500

Before each measurement, the multi-layer MCFs in circular shape (96 mm in diameter) were uniformly perforated using a perforating bit with a diameter of 1 or 2 mm (Fig. 2a). The perforation diameter was kept constant to ensure the uniform size and shape of the perforated holes within a single sample, whilst the number of perforated holes was controlled by varying perforation rates. The materials were micro-perforated with diameters between 1 and 2 mm with ordinary drilling machine. As shown in Fig. 2b and c, the perforation and micro-capillary structure of the multi-layer MCFs are different with traditional micro-perforated panels.

2.3. Testing and measurement of the sound absorption coefficient

The simple, precise and convenient standing wave tube method is commonly used to determine sound absorption coefficients α. According to the International standard, ISO 10534-1 [28], a system for the standing wave tube testing was set up in this work. The type of standing wave tube is Brüel & Kjær 4002.

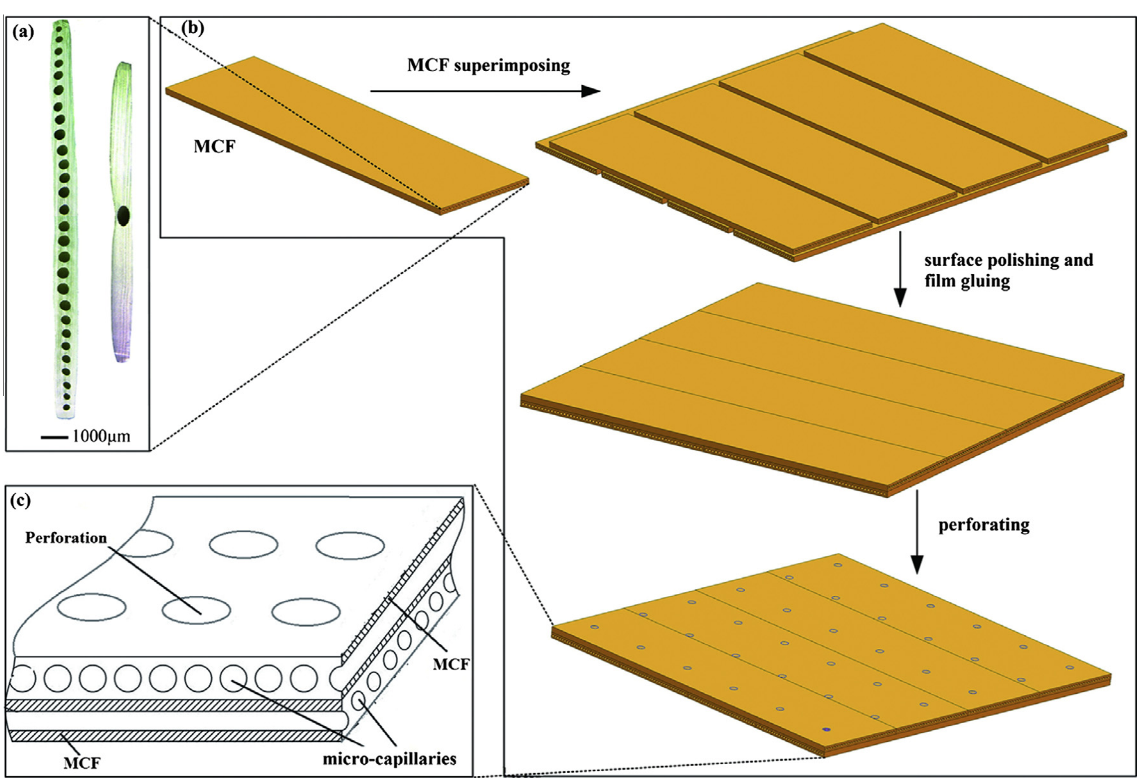

Fig. 1. (a) Cross sections of the typical 1-capillary and 28-capillary MCFs, (b) schematic of the process for preparing multi-layer MCF structures, and (c) schematic of the structure of perforated multi-layer MCFs for sound absorption.