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Small perforations in corrugated sandwich panel significantly enhance low frequency sound absorption and transmission loss

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ABSTRACT

Numerical and experimental investigations are performed to evaluate the low frequency sound absorption coefficient (SAC) and sound transmission loss (STL) of corrugated sandwich panels with different perforation configurations, including perforations in one of the face plates, in the corrugated core, and in both the face plate and the corrugated core. Finite element (FE) models are constructed with considerations of acoustic-structure interactions and viscous and thermal energy dissipations inside the perforations. The validity of FE calculations is checked against experimental measurements with the tested samples provided by additive manufacturing. Compared with the classical corrugated sandwich without perforation, the corrugated sandwich with perforated pores in one of its face plate not only exhibits a higher SAC at low frequencies but also a better STL as a consequence of the enlarged SAC. The influences of perforation diameter and perforation ratio on the vibroacoustic performance of the sandwich are also explored. For a corrugated sandwich with uniform perforations, the acoustical resonance frequencies and bandwidth in its SAC and STL curves decrease with increasing pore diameter and decreasing perforation ratio. Non-uniform perforation diameters and perforation ratios result in larger bandwidth and lower acoustical resonance frequencies relative to the case of uniform perforations. The proposed perforated sandwich panels with corrugated cores are attractive ultralightweight structures for multifunctional applications such as simultaneous load-bearing, energy absorption, sound proofing and sound absorption.

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1. Introduction

Sound transmission loss (STL) and sound absorption coefficient (SAC) of panels are the two biggest acoustic issues for investigators in this area in the past decades. The most appealing structures for sound transmission are sandwich structures made of multiple-layer panels and cores [1–8]. Sandwich panels can be designed to have low density, high stiffness-to-mass ratio, and excellent thermal and acoustic characteristics, and hence have been widely applied as soundproof concepts. Many kinds of cores exist for sandwich construction, such as air cavity, foams, honeycombs and corrugations (folded plates), to mention just a few. Extensive investigations have been devoted to evaluating the STL of a wide range of sandwich panels, which may be classified by the core types.

Double wall partitions with air cavity, perhaps the simplest sandwich construction, received much attention [9–15]. For example, Wang et al. [9] calculated the STL of double leafs with enclosed air cavity numerically using the statistical energy analysis approach, while Xin et al. [10] analytically predicted the STL of simply supported finite double leaf panels with air cavity. Instead of air cavity, numerous studies have also been carried out on sandwich panels with sound absorbing cores [6,7,16–23]. For instance, Bolton et al. [18,21] presented calculations of STL of double-panel structures lined with elastic porous material by applying the Biot theory, and Doutres and Atalla [17] proposed a theory to estimate the STL of double panel structures with multilayered absorbing blanket cores. Sandwich panels with sound absorbing cores turned out to improve the STL at structural resonance frequencies. With excellent mechanical efficiency, sandwich panels with honeycomb cores are more widely used in applications than those with air or

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sound absorbing cores. It is therefore natural that the STL of honeycomb sandwich panels has been extensively investigated [8,24–30]. Jung et al. [27] presented a theory to predict the STL of honeycomb sandwich by assuming the core is homogeneous orthotropic. Griese et al. [28] numerically calculated the STL performance of honeycomb sandwiches and analyzed the effect of core geometry. Zhou and Crocker [25] presented STL calculations of foam-filled honeycomb sandwich panels by statistical energy analysis. Rajaram et al. [29] investigated the effects of panel design parameters on the STL of honeycomb sandwiches. Tang et al. [26] presented a model to estimate the STL of cylindrical sandwich shell with honeycomb core. Among all the sandwich constructions, sandwich panels with corrugated cores are perhaps the most appealing alternative in the transportation industry (e.g., high speed train) due to excellent mechanical performance with limited thickness, simple two-dimensional (2D) configuration, structural stability and easy manufacture procedure. Shen et al. [31] and Xin et al. [32] presented analytical STL investigations of corrugated sandwich panels by modelling the corrugated core as translational and rotational springs. Bartolozzi et al. [33] calculated the sound transmission loss of sandwich panels with sinusoidal corrugated cores by treating the corrugated cores as an equivalent homogenous material. Nonetheless, despite the success applications of sandwich panels for settling the issue of STL, they are incapable of sound absorption.

On the contrary, micro-perforated panels (MPPs) are effective sound absorbers. MPPs are usually comprised of plates with submillimeter pores, an air cavity, and a rigid wall. The sound absorption mechanism of the MPPs is closely connected to the classical Helmholtz resonance absorption. Compared with the traditional sound absorbing materials, MPPs are more environment-friendly and suitable for severe situations, such as high temperature, high pressure, or presence of water. The sound absorption performance of the MPPs has been investigated, both theoretically and experimentally, by many investigators. Applying the method of electroacoustic analogy, Maa [34,35] first proposed an analysis model for the SAC of single and double MPPs. While Atalla and Sgard [36] attempted to evaluate the SAC of MPPs by employing rigid frame porous material models, Rao and Munjal [37] and Lee and Kwon [38] used an empirical impedance model to estimate the SAC of MPPs. Although efficient in SAC, MPPs are invalid structures for STL. Studies by Chen [39] and Dupont et al. [40] demonstrated that the STL of a MPP is even smaller than that of a single plate having the same thickness.

Nowadays, combinations of MPP and sandwich structures come into the view of researchers concerning both the STL and SAC of panels. Perforated pores in the face plates of the sandwich panels can provide effective sound absorption as MPP layers, while the backed plates and core structures can act as sound insulation barriers. Dupont et al. [40] first investigated the acoustic properties of a MPP coupling with a flexible plate both analytically and experimentally. It was found that the coupled MPP-air cavity-plate system could increase the STL while maintaining a good SAC. To improve the STL at mid frequencies, Toyoda and Takahashi [41] subdivided the air cavity of the MPP-air cavity-plate system by inserting honeycomb structures to the air cavity. Bravo et al. [42,43] proposed a fully coupled modeling approach to calculate the SAC and STL of single or multi-layer MPPs and plates. It was shown that the SAC and STL at acoustical resonance frequencies were controlled by the relative velocities of air-frame and the MPP-back panel. Mu et al. [44] added MPP layer both to the source and the transmitted side of double leaf panels and found that the MPP layer weakened the mass-air-mass resonance.

The investigations as discussed above concern the acoustical properties of sandwich panels with face plate perforations. The middle cores of these sandwich panels are air gap or honeycomb structures. None of these investigations considers corrugated sandwich panels with perforations. In addition to load-bearing, corrugated sandwich panels are an appealing structure for STL in application. Different from the honeycomb sandwich panels, corrugated sandwich panels can have perforations in the corrugated pores as well as in the face plates (see Fig. 1). It will be interesting for investigators in this area to see how the SAC and STL are affected by various perforation configurations in corrugated sandwich panels.

Perforations in the corrugated sandwich panels are often micro-sized that makes the manufacture of perforated sandwich panels extremely difficult by conventional manufacturing methods. Hence, the additive manufacturing (also known as 3D printing) is employed to fabricate the perforated corrugated sandwiches. In an additive manufacturing progress, the expected structure is created by laying down thin layers of materials according to the dig-

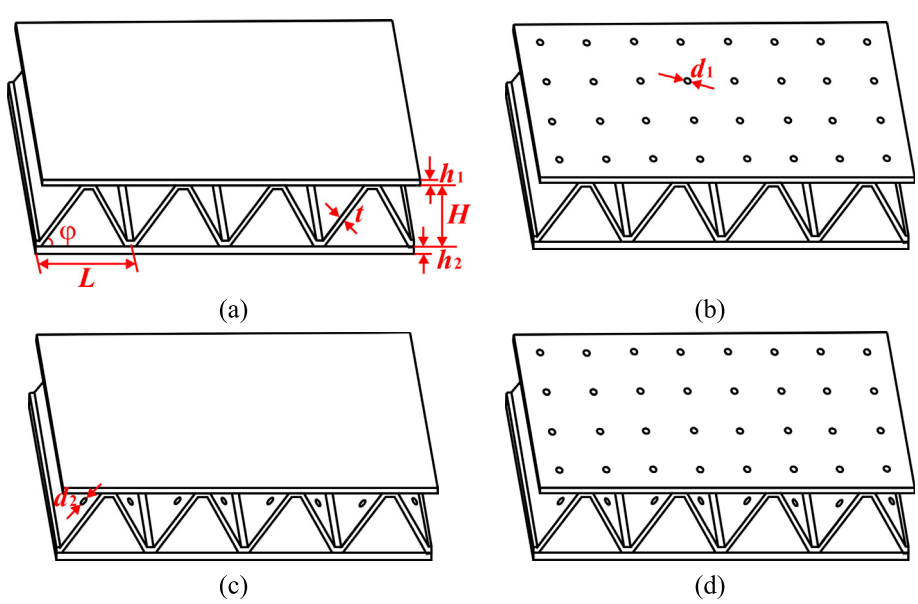

Fig. 1. Schematic of classical corrugated sandwich panel and corrugated sandwich panels with various perforation configurations.

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