Numerical Analysis of Honeycomb Structure With Embedded Membrane for Tranmission Loss Improvement

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1 Introduction

Honeycomb structures find use in many applications because of their high stiffness to weight ratio and excellent mechanical impact energy absorption. However, their acoustic performance is poor. Li et al [1] studied the transmission loss (TL) of lightweight multilayer honeycomb membrane-type acoustic metamaterials experimentally and observed that the sandwich panel acoustic metamaterials exhibit good TL. A lightweight and yet sound-proof honeycomb acoustic metamaterial is investigated by Sui et al. [2] and Lu et al. [3]. The metamaterial structure is made of a lightweight flexible rubber material layer sandwiched between two layers of honeycomb cell plates. They demontrated excellent TL with minimum weight-penalty. Li et al. [4] presented a theoretical model to estimate the TL of acoustic micro-membranes, which demonstrate improved TL at low frequency.

In this study, the transmission loss of a honeycomb structure with embedded membranes is investigated using the finite element method. It is shown that the transmission loss of the honeycomb structure is significantly improved by the embedded membrane while the TL of the honeycomb structure core alone is zero. The influence of the honeycomb structure cell size is illustrated as well as the effect on the membrane material properties. The investigated structure presents good TL especially at low frequencies.

2 Finite element analysis of honeycomb structures with embedded membranes

Figure 1 shows a honeycomb structure with one embedded membrane layer. The thickness of each honeycomb structure layer in Fig. 1(a) is set to 4 mm and the thickness of the membrane is 1 mm. The boundary between the membrane and each honeycomb structure layer is considered fixed. Figure 1(b) illustrates the geometry used in the numerical simulations. An incident fluid and transmission fluid are connected to the structure and all the air domains within the honeycomb structure cells are defined. The cell size with a radius denoted by R_c is illustrated in Fig. 1(c) and the mesh of the geometry is shown in Fig. 1(d), which contains 44 968 domain elements and 14 702 boundary elements. Young's modulus, the density, and the Poisson's ratio of the honeycomb material structure are respectively 2.7 GPa, 1100 kg/m^3 and 0.38 with a cell size of 5 mm. The thickness of the incident and transmission fluid is set to 80 mm and the lateral dimensions of the geometry are 56 mm x 60 mm. A normal incidence plane wave with pressure amplitude of 1 Pa is applied on the inlet plane of the incident fluid domain while a plane wave radiation condition is applied on the inlet and outlet planes to minimize the reflection of the acoustic waves. Acoustic-solid interaction of COMSOL Multiphysics is used for the numerical simulations. The sound transmission loss is determined by the relation

$$TL = 10\ log_{10}\left(\frac{W_{\text{in}}}{W_{\text{out}}}\right) \qquad (1)$$

where W_{in} and W_{out} are respectively the incoming power at the inlet plane and the outgoing power at the outlet plane.

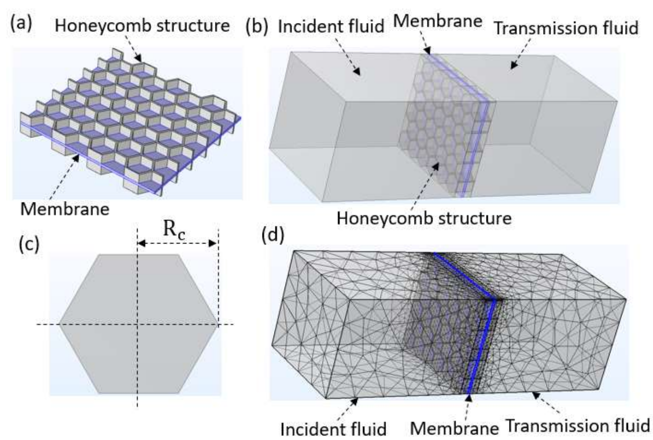

Figure 1: Honeycomb structure: (a) two honeycomb layers with embedded membrane (a) geometry (c) one honeycomb cell (d) mesh.

Different membrane material properties with Young's modulus that are gradually increased from 1.2 MPa to 100 MPa are considered as shown in Table 1. Membrane 1 is butyl rubber while membrane 3 is a silicone elastomer and membranes 2 and 4 are ethylene-vinyl acetate rubbers.

3 Finite element results

The impact of the membrane material properties on the TL is illustrated in Fig. 2 where the damping loss factor of each membrane is set to 0.1.

Table 1: Material properties of the membrane

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Membranes	Young's modulus (MPa)	Density (kg/m^3)	Poisson's ratio
1	1.2	910	0.4
2	5	660	0.45
3	12	1400	0.48
4	25	850	0.46
5	100	1100	0.49

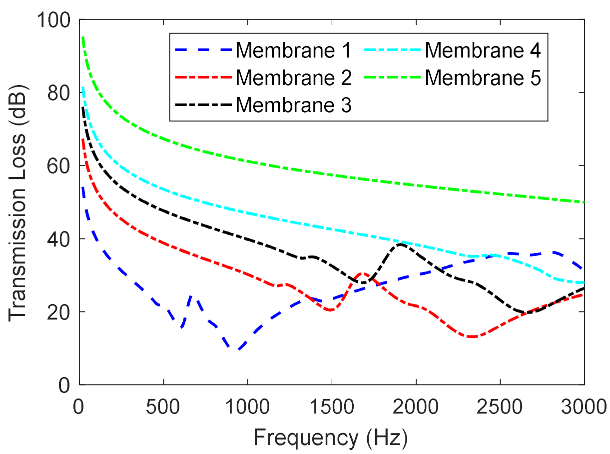

Figure 2: Normal Incidence Transmission Loss of honeycomb structure with embedded membrane.

In Fig. 2, it can be observed that the TL increases over a large frequency band as the membrane Young's modulus increases.

In Fig. 3, the effect of the honeycomb cell size on the TL is illustrated using membrane 2 of Table 1 with a thickness of 0.5 mm. In Fig .4, the influence of the number of membrane layers within the honeycomb structure is presented where membrane 2 of Table 1 is used with a thickness of 1 mm. For the two-membrane layer case, the thickness of the honeycomb cell between each membrane layer is set to 10 mm and for the three-membrane layer case; the thickness of each honeycomb cell is set to 5 mm. The simulations are conducted with one honeycomb cell with membrane fixed boundary conditions, which is connected to incident and transmission fluids.

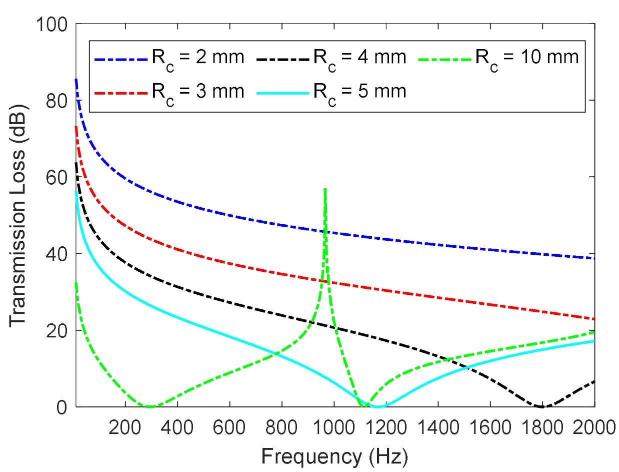

Figure 3: Effect of the honeycomb cell size on the transmission loss.

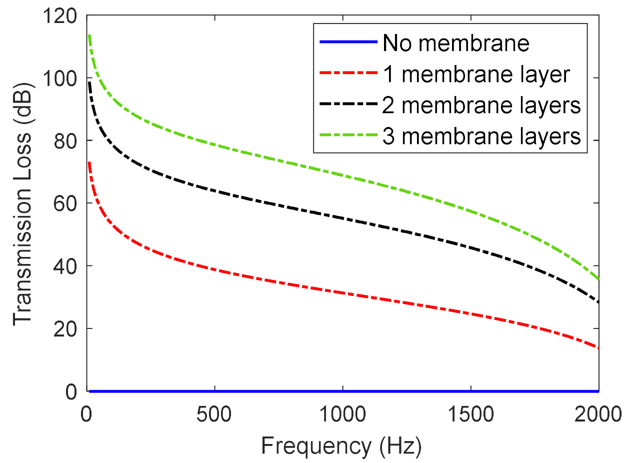

Figure 4: Effect of the number of membrane layers on the transmission loss.

In Fig. 3, the TL for $R_c = 10\ mm$ presents a peak value of 57 dB at 966 Hz. The TL increases over a large frequency band as the honeycomb cell size is reduced. The TL of the honeycomb structure alone without membrane in Fig. 4 is zero and when the number of membrane layers increases, the TL increases over the entire frequency range.

4 Conclusions

The transmission loss of a honeycomb structure with embedded membranes is studied using finite element method. It is shown that the TL increases over a large frequency band when the honeycomb cell size decreases. The influence of the membrane material properties on the TL is presented. The TL of the honeycomb structure alone without membrane is zero and when the number of membrane layers within the structure increases, the TL increases over the entire frequency range. The investigated structure can offer excellent performance in noise control engineering especially at low frequencies.

Acknowledgments

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