Comparative Evaluation of Sound Absorption Performance of Various Types of Core Panels

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1 Introduction

Core materials such as honeycomb core panels are used in various industrial products as lightweight and high stiffness materials. As one of the characteristics of the core panel, the sound absorption effect due to the core structure is expected. By using a large core panel for a soundproof wall such as a highway, the possibility of producing a soundproof wall that is lighter than the conventional soundproof wall and has a high sound insulation/absorption effect is being studied. In addition, with the electrification of automobiles, further quietness in the passenger compartment is required, and the use of core panels is being considered for improving the quietness of various transportation machines such as automobiles. Therefore, in this research, we assume several types of core shapes and compare the sound absorption effect of the core panel by modeling the interaction between the core panel and the sound in the air using ALE-based FEM in LS-DYNA®.

2 Core panel geometry

There are many variations in the geometry of the core, but in this research, three basic types of core geometries, tetrahedron, hemisphere, and hexahedron were taken up for comparison. The geometry and the major dimensions are shown in Fig.1. These cores are formed as a unit on a hexagonal base with a side of 200 mm. And as shown in Fig. 2, 6 cores for horizontal direction and 7 cores for vertical direction are arranged and configure one core panel. The entire core panel is a square with a side length of 2400 mm. The material of the core panel is aluminum and is modeled as an elastic material. The

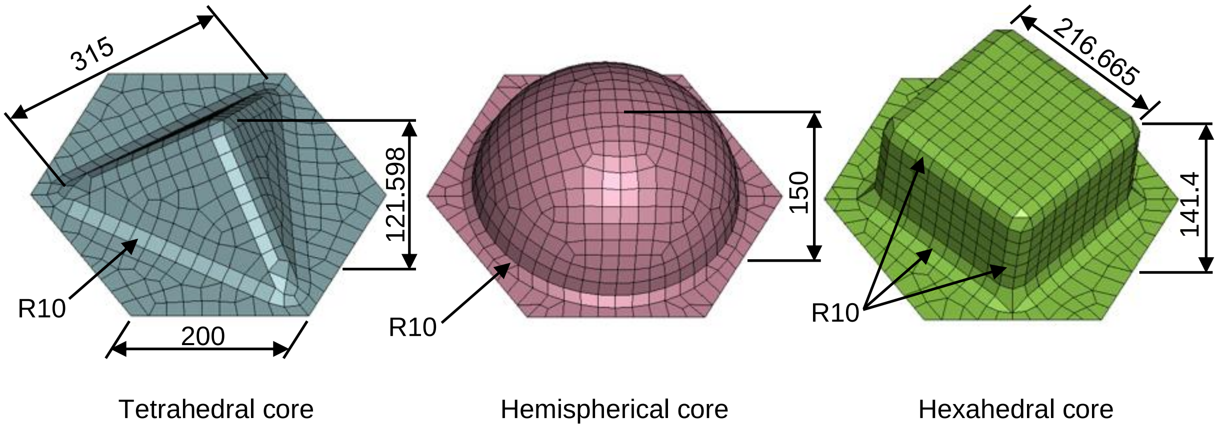


Fig.1: Core geometries to be compared (length unit : mm)

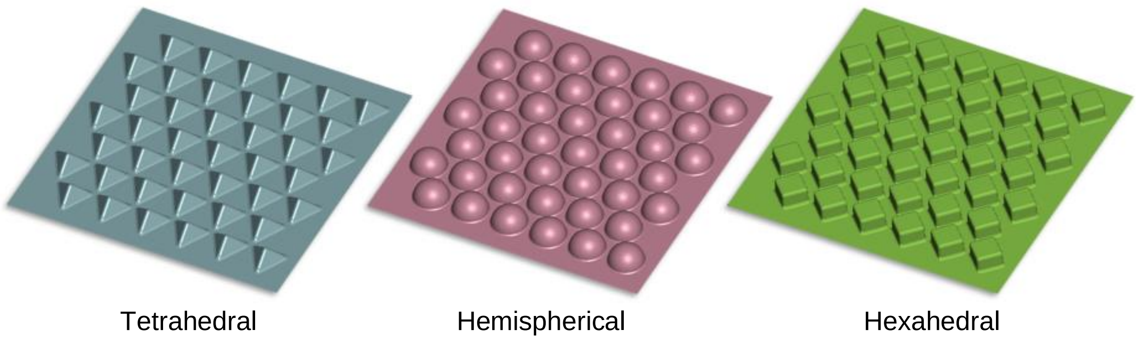


Fig.2: Geometry of three core panels

density is 2.7 x 10^{-9} ton/mm^3 and Young's modulus is 75 GPa. When comparing the sound absorption performance, it is necessary to compare the values per unit mass of the core panels. Therefore, the mass of each panel was unified to 37.433 kg by adjusting the panel thickness. The thickness of the tetrahedral core panel is set to 2.0 mm, and then, the thickness of the hemispherical core panel and the hexahedral core panel results as 1.6305 mm and 1.3831 mm, respectively.

3 Analysis model

3.1 Model configuration

The configuration of the model for acoustic analysis is shown in Fig.3. The model involves one core panel and a square plate with a side of 1000 mm as a sound source. The distance between the core panel and the sound source is 1300 mm. The core panel and sound source are embedded in the ALE part that models the air, and the ALE part is composed of cubic elements with a side of 100 mm. The sound source plate is modeled as rigid body. The equation of state of the air is expressed as Eq.1.

$$p(\mu, E_0) = (\gamma - 1)(\mu + 1)E_0 = (\gamma - 1)\frac{\rho}{\rho_0}E_0$$

$$\mu = \frac{v_0 - v}{v} = \frac{\rho}{\rho_0} - 1, \quad \gamma = \frac{C_p}{C_v} \qquad (1)$$

Where, E_0 ; initial internal energy per unit volume, v_0 ; initial volume, v ; current volume, ρ_0 ; initial density, ρ ; current density, C_p ; specific heat at constant pressure, and C_v ; specific heat at constant volume. Equation 1 is defined using ***EOS_LINEAR_POLYNOMIAL** in LS-DYNA with C_4=C_5=0.4 and e_0=0.25. The density of 1.2 x 10^{-12} ton/mm^2 is given on ***MAT_NULL** keyword.

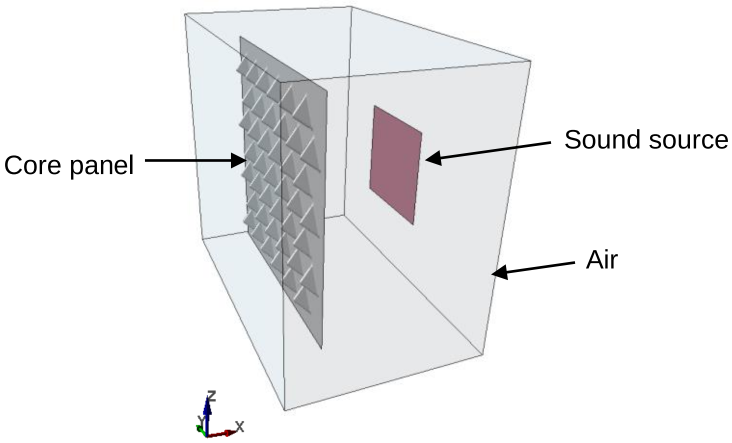


Fig.3: Model configuration for acoustic analysis

3.2 Analysis conditions

All the nodes on the edges of the core panels are completely constrained. A free boundary condition is applied on the surface of the ALE part. A cyclic prescribed motion through x-direction is defined on the sound source plate using ***BOUNDARY_PRESCRIBED_MOTION_RIGID** and ***DEFINE_CURVE_FUNC-TION** in which a function to describe the displacement is defined as follows;

$$A * \sin(2\pi f * time)$$

where, A ; amplitude, A=2 mm and f ; frequency (Hz). For each core panel, the computation was executed with a frequency changed from 100 Hz to 400 Hz by every 20 Hz. ***CONSTRANED_LAGRANGE_IN_SOLID** with ctype=4 (penalty coupling) is defined for shell-ALE coupling. As shown in Fig. 4, two ALE elements that output sound pressure are specified on the front and back sides of the core panel. The distance between the closest surface of element A and the core panel is 100 mm. The distance between the closest surface of element B and the core panel depends on the height of the core. The

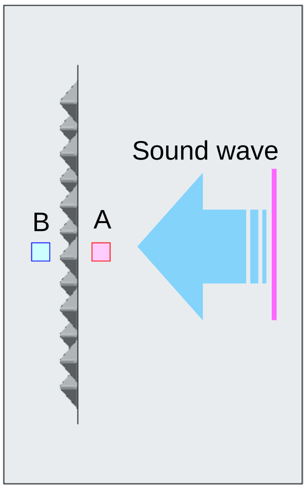


Fig.4: Position of ALE elements that output sound pressure (top view)

distance from the core tip to element B is 78.4 mm for the tetrahedral core, 50 mm for the hemispherical core, and 58.6 mm for the hexahedral core.

4 Results of simulation

Figure 5 shows an example of the results of acoustic analysis. In this figure, the atmospheric pressure is 0.1 MPa and pressure distribution around the core panel can be seen clearly. The pressure history at elements A and B are shown in Fig.6, 7 and 8 as "Front" and "Back" respectively. Here, it should be noted that the pressure at element A is a state in which the incident wave from the sound source and the reflected wave from the core panel are superpositioned. The sound pressure history in the time domain is obtained from the explicit computation of LS-DYNA. In order to obtain the transmission loss due to the core panel, the effective sound pressure was calculated from the sound pressure history using Eq.2.

$$p^e = \sqrt{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)dt} \qquad T = t_2 - t_1 \tag{2}$$

Where, t_1 and t_2 are the start time and end time to calculate the effective sound pressure. The transmission loss is calculated by Eq.3 using the effective sound pressures p_i^e at element A and p_t^e at element B.

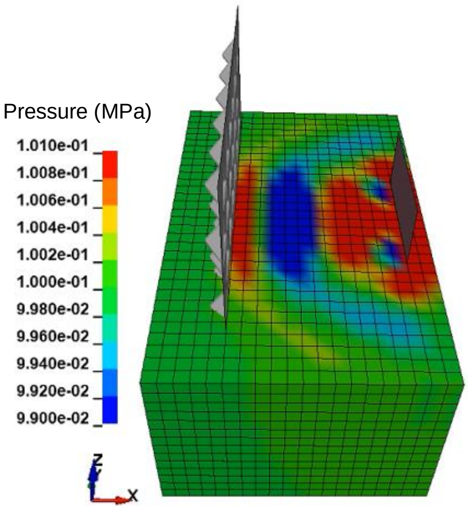


Fig.5: Sound pressure distribution example (tetrahedral core panel, 400 Hz)

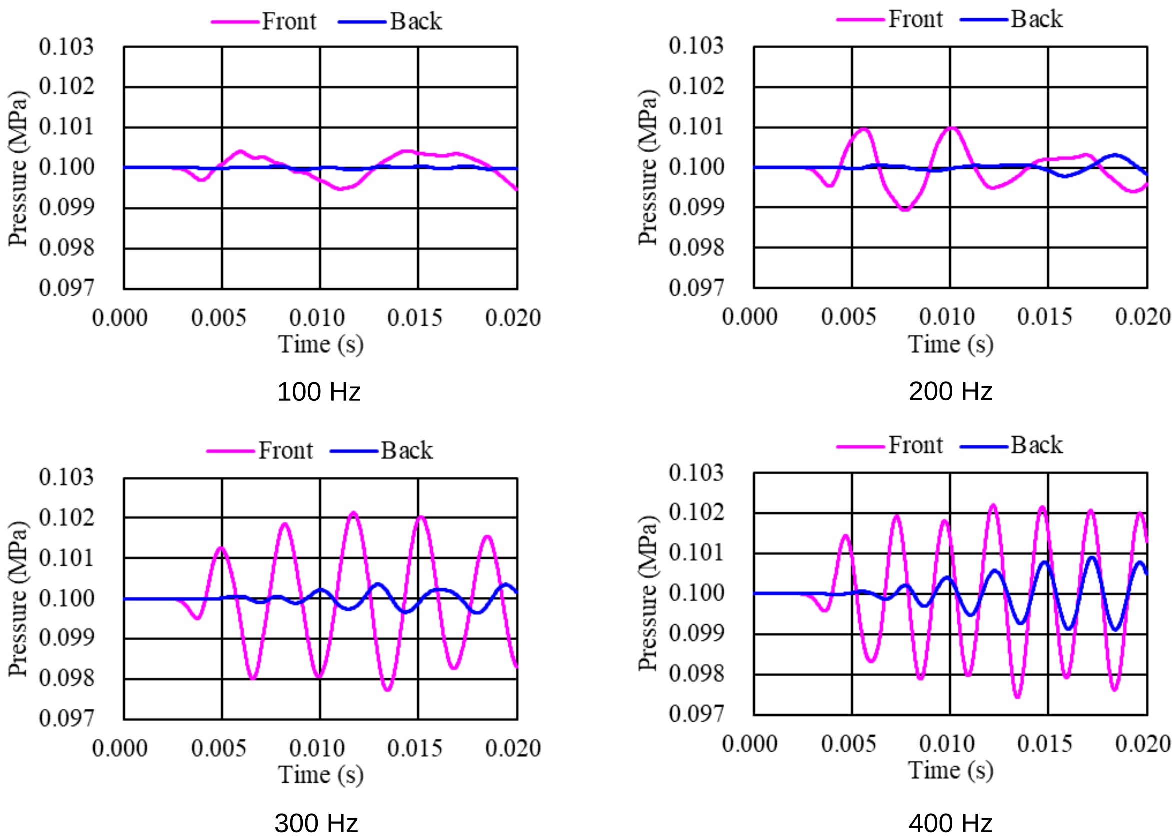


Fig.6: Pressure history for tetrahedral core panel

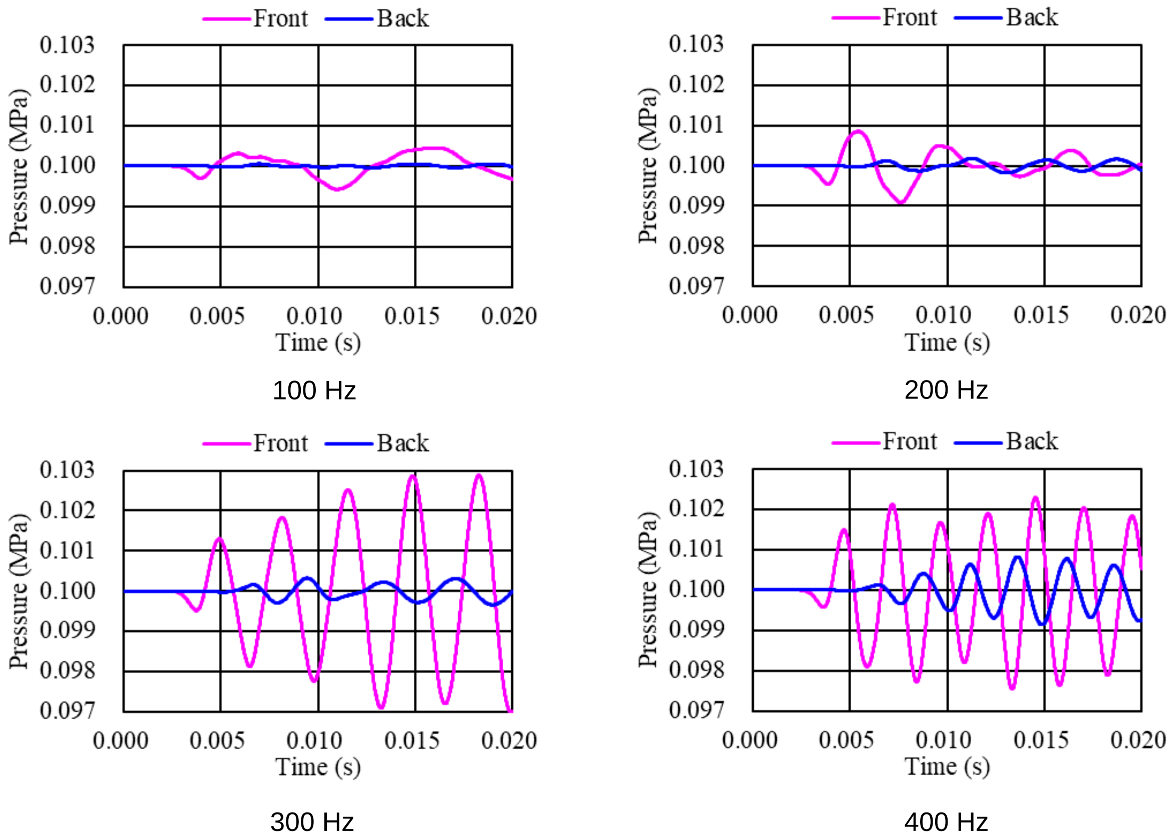
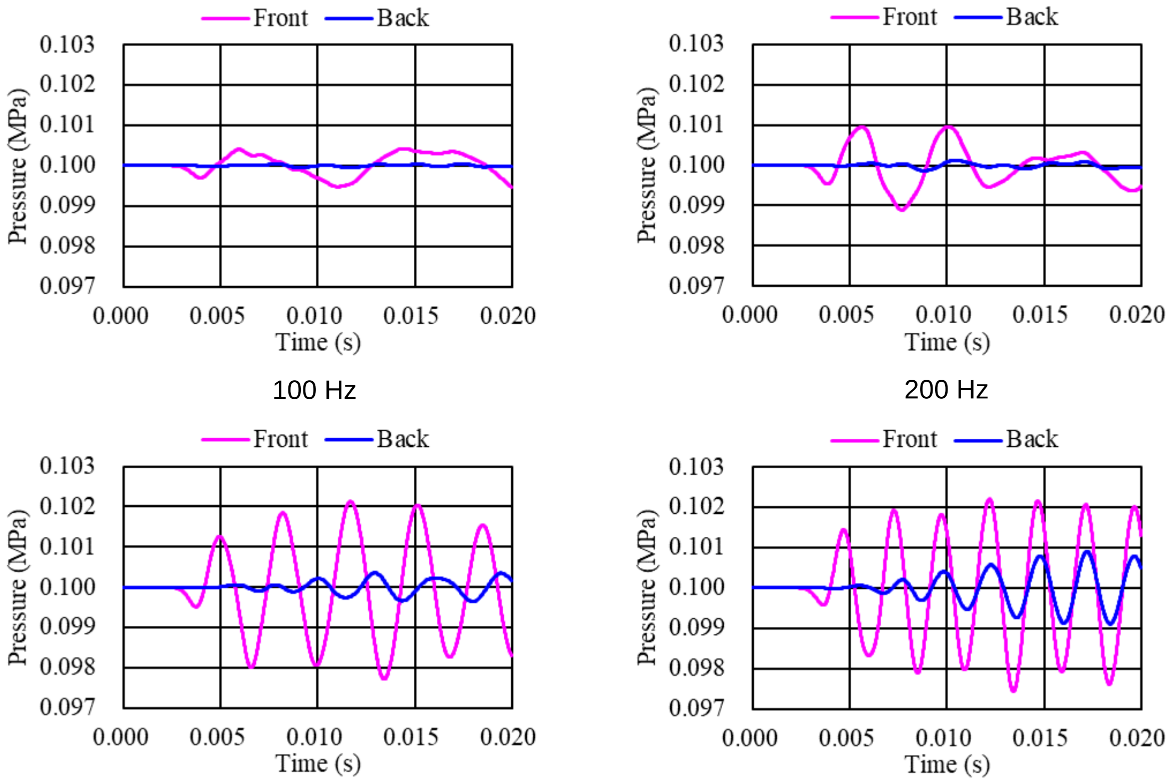


Fig.7: Pressure history for hemispherical core panel



100 Hz   200 Hz

300 Hz   400 Hz

Fig.8: Pressure history for hexahedral core panel

$$TL = 20\log_{10}\frac{p_i^e}{p_t^e} \quad (3)$$

Figure 9 shows the comparison of the transmission loss for three core panels. The hexahedral core showed maximum transmission loss between 100 Hz and 280 Hz, and the tetrahedral core showed maximum transmission loss between 280 Hz and 400 Hz. The average transmission loss of each core panel was 19.0 dB for the tetrahedral, 15.2 dB for the hemispheric, and 18.8 Hz for the hexahedral core panel.

5 Conclusions

The sound insulation performance of three types of core panels, namely tetrahedral, hemispherical and

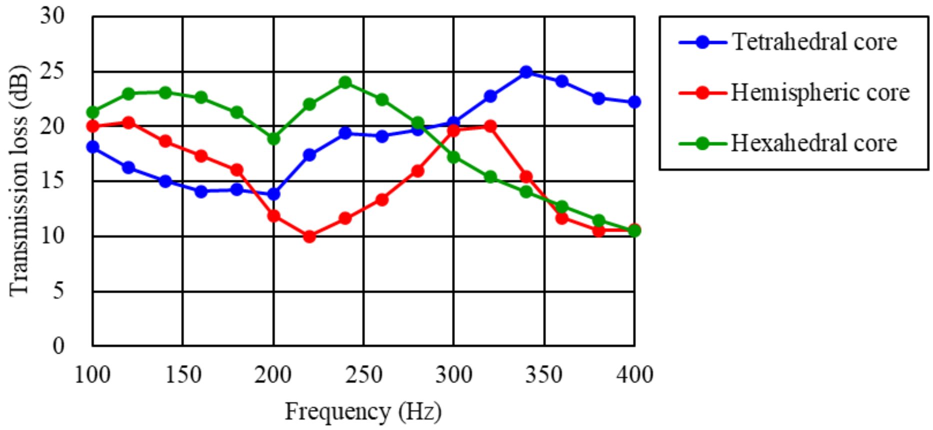


Fig.9: Transmission loss

hexahedral core panel, was compared using the ALE-structure coupling capability of LS-DYNA. As a result, highest sound insulation capability was shown for the hexahedral in the relatively low-frequency band, and for the tetrahedral in the high-frequency band. An interesting result was obtained that the sound absorption/insulation performance changes depending on the frequency. Sound absorption/insulation performance is considered to depend on the energy absorption by the panel and the scattering characteristics of sound waves. Furthermore, the scattering of sound waves changes depending on the geometry of the core. As future work, it is considered to obtain a core geometry that can obtain sound absorption/insulation performance in all frequency bands from low to high frequencies by a shape optimization technique.

6 Literature

[1] LS-DYNA KEYWORD USER'S MANUAL (LS-DYNA R11), LSTC, 2018