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Effect of Joint to Flexural Wave Propagating in Honeycomb Sandwich Panel

ハニカムパネルを伝搬する屈曲波に対する接合の影響

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1 Introduction

Recently, the direction of guidance sound has been considered to play an essential role in an auditory guiding system to make a user intuitively understand the direction of guidance. Hence, a loudspeaker that can indicate the right direction regardless of position on a pathway is necessary. To meet such demand, we have proposed a panel loudspeaker that emits sound with an inclined angle from a flexural wave propagating in an elastic plate (hereafter, we call this “inclined sound”). The inclined sound is radiated in the air when the phase velocity of the flexural wave is larger than the sound velocity in air, and people perceives the direction of arrival of the sound wherever the inclined sound propagates[1]. Hence, if we can cover a ceiling of corridors with large panel loudspeakers, an evacuation guidance system that enables people to perceive the destination direction intuitively would be achieved for example[2].

Focusing on the structure of the panel speaker that emits the inclined sound, it has been found that a panel with a layered structure is suitable to emit a sound of audible frequency. Hence, a design method of the flat-panel loudspeaker for generating inclined sound using a honeycomb sandwich panel has been established[3]. The validity of such a design method is confirmed by analyzing a distribution of the intensity of the inclined sound using the finite element model (FEM) and measurement of phase velocity characteristics using various panels[3].However, it is necessary to joint the edge of the panel to cover long corridors with the loudspeaker. Although reflection of Lamb wave in the continuum has been studied[4], that of flexural wave between honeycomb panels has not been investigated yet, to our knowledge. Hence, in this paper, we investigate the reflection of the flexural wave when there exists a gap in honeycomb sandwich structure using FEM.

2 Numerical model of honeycomb sandwich panel and its joint

Figure. 1 shows a honeycomb sandwich panel that is modeled by two face plates and a Honeycomb core layer. Table. 1 shows physical parameters of this

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Table 1 Parameters of panel model.

Parameter	Value
Thickness of face plate, h_f	1 mm
Height of honeycomb core, h_c	23 mm
Wall thickness of honeycomb core, d	70 µm
Side length of honeycomb core, a	3.67 mm
Density	2700 kg/m^3
Young's modulus	70 GPa
Poisson's ratio	0.33

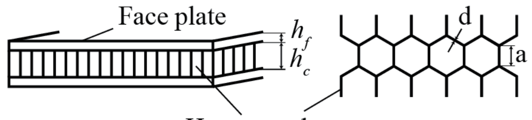

Fig. 1 Model of sandwich panel.

model. We examined two types of joint for honeycomb panels as shown in Fig. 2. Figure 2(a) shows a model with one honeycomb panel cut into two honeycomb cores, honeycomb-core gap model. Figure 2(b) shows a model in which the upper and lower face plates are cut into two each for one honeycomb panel, face-plate gap model. The gap distance between the honeycomb cores in the former model is g_c, and the gap distance between the face plates in letter model is g_f. The length of the face plate in every model is defined as L. The longitudinal direction of the honeycomb panel is the x axis, and one end of the panel is the origin. To prevent the reflection at the edge, Rayleigh damping is introduced to a panel in right hand side so that the attenuation coefficient α linearly increasing by the distance. Driving force F_0 in the normal direction of the face plate was applied to the left end.

Figure 3 shows the honeycomb sandwich panel modeled by shell elements in three dimension using FEM simulation software (COMSOL Multiphysics 5.4). For these two models, the surface plate was divided into triangular elements and the honeycomb core was divided into quadangular elements. Figure 4 and Fig. 5 shows mode shapes and displacement fields, and reflection coefficient |ρ| with varying the core gap g_c and the faceplate gap g_f when L = 0.66 m. As shown in Fig. 4. The reflection coefficient is evaluated from standing

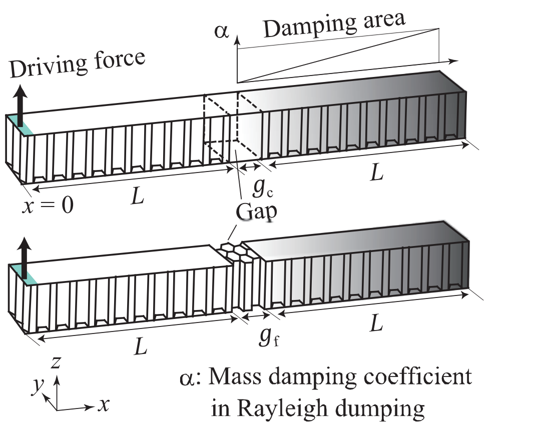

Fig. 2 Two types of joint. (a) honeycomb-core gap model,(b) face-plate gap model.

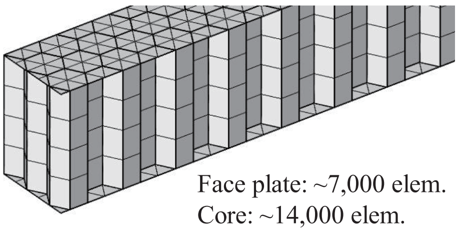

Fig**. 3 F**inite element division with shell elements

wave ratio (SWR) in the plate of left half. When a gap is formed in the core, the reflection coefficient $|r|$ increases in proportion to the frequency at 2 – 10 kHz. On the other hand, when a gap is made in the surface plate from Fig. 5, the reflection coefficient decreases in proportion to the frequency at 2 – 10 kHz. If both g_c and g_f are $0.01a$ or less, the reflection coefficient is within 0.1. Therefore, it is considered that the influence of reflection can be ignored if the gap between the face plate and the honeycomb core is small.

3. Conclusions

In this paper, the effect of reflection on the joining method of two types of honeycomb panels was examined by numerical analysis. As a result, it was found that the effect of reflection is small if the gap between the surface plate and the core is very small. This suggests that joining only face plates with a very small core gap achives acoustical smooth connection of honeycomb sandwich panels. In the future, the experimental confirmation of numerical analysis and investigation of practical method for joint are planned.

Acknowledgment

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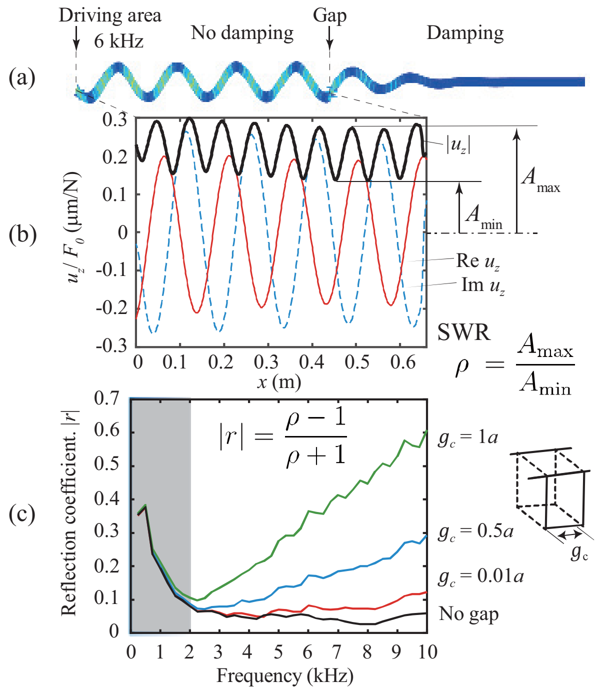

Fig. 4 Reflection of flexural waves by face-plate gap. (a) Mode shape, (b) Displacement field, and (c) Reflection coefficient |ρ|.

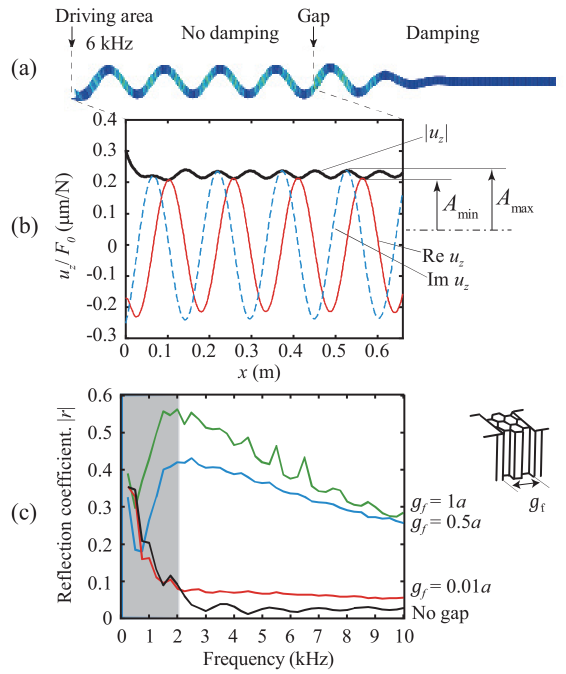

Fig. 5 Reflection of flexural waves by honeycomb-core gap. (a) Mode shape, (b) Displacement field, and (c) Reflection coefficient.

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