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Effect of structure on sound absorption and sound transmission loss of composite sheet

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The effects of structure on sound absorption and sound transmission loss (TL) of a composite sheet were investigated. Non-woven polyethylene terephthalate fabrics were bonded to the top side and the bottom side of the polypropylene (PP) board by hot press method. The absorption coefficient of the composite sheet using non-woven fabric with a surface density of 0.64 kg/m^2 was 0.1~0.2. It showed 100~400% improvement compared to that of plain PP board. TL of a composite sheet was increased with the surface density of PP board and with introducing hemi-sphere cavities. Two different structures of composite sheet were prepared using flat sheet and sine-wave sheet to investigate the structure effect. The composite sheet A with a sine-wave sheet on both sides of flat PP board showed increased TL of 7 dB compared to the composite sheet B with a flat PP board on both sides of a sine-wave sheet.

Keywords: composite sheets; absorption coefficient; transmission loss; impedance tube method; trunk mat

1. Introduction

Automobiles are an important part of modern life, and recently the automotive industry in Korea has shown a rapid growth. Domestic car ownership has increased from 12.5 million units in 2000 to 18.5 million units in 2011,[1] which is equivalent to one car per 2.7 persons. The development of eco-friendly and high-efficiency low-noise vehicles through performance improvements has been an important goal of the automotive industry. The weight of automobiles is directly related to fuel efficiency, and it has been reduced using plastics and composite materials since the 1970s. The properties of a plastic trunk mat can be represented by absorption and transmission loss (TL). The low level of noise achieved by improving the absorption and TL properties is needed in an automotive trunk mat.

Absorption is an indicator related to the acoustic characteristics of materials and requires a theoretical interpretation. Zwikker and Kosten [2] interpreted absorption as a phenomenon in the 1940s, and Boit,[3] Lambert,[4] and Allard [5] expanded the absorption theory further. Additionally, the experimental techniques were developed to prove the theories. The traditional method uses standing waves,[6] and the spectrum

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density method uses two microphones.[7–9] Many studies have focused on materials development and the TL characteristics.[10–13] In this study, the surface and the structure of an automotive trunk mat were modified and the effect on absorption and TL was investigated. This study could be used to develop a superior absorption and TL properties of automotive parts.

2. Experimental setup

2.1. Sheet preparation

Polypropylene (PP) board with a thickness of 2–5 mm and polyethylene terephthalate (PET) non-woven fabric with a surface density of 0.02–0.64 kg/m^2 from Kokyung Co. (Cheongwon, Korea) were used. To make a composite sheet, non-woven PET fabrics were placed on the top and bottom of the PP board and were heat bonded at 200 °C. In order to investigate the effect of cavities on the absorption and TL properties of the composite sheet, the heat-bonded sheets with the hemisphere cavities were used as shown in Figure 1.

2.2. Measurement of absorption coefficient

The absorption coefficient is widely used as an indicator of absorption properties, and the tube method [14] was chosen to measure the absorption coefficient in this study. An impedance tube with a diameter of 45 mm, length of 1 m, and thickness of 3 mm was used. Speakers and the specimen were installed inside of the tube, and the specimen was placed perpendicular to the propagation direction of the incoming sound waves. The auto spectrum density of the specimen to the incoming sound waves (S_a) and that of the reflecting waves (S_b) was measured, and the absorption coefficient was calculated using Equation (1)

$$\text{Absorption coefficient} = 1 - S_a/S_b \tag{1}$$

2.3. Measurement of TL

Materials with TL properties block incoming sound waves and prevent reflection of the incoming sound waves. TL was measured using the tube method.[14,15] The specimen

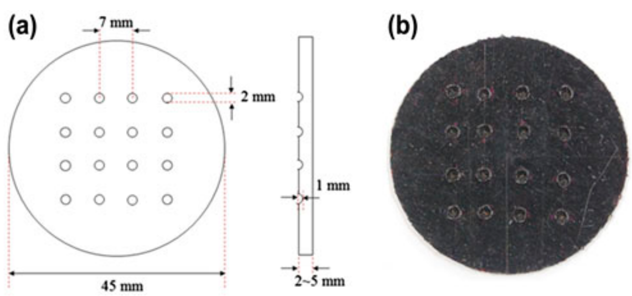

Figure 1. Structure of a specimen with hemispheric cavities. (a) Schematic drawing and (b) image of top surface.

was installed in the middle of the tube and microphones 1 and 2 and microphones 3 and 4 were placed at the left and the right side of the specimen, respectively, as shown in Figure 2. The distances between microphones 1 and 2, and 3 and 4 were the same and the distances from specimen to microphone 1 and from specimen to microphone 3 were same. TL was calculated after measuring the sound pressures at microphones 1–4.

3. Results and discussion

3.1. Absorption coefficient

The absorption coefficient of the non-woven fabric used on the top and bottom sides of the PP board as a function of surface density is shown in Figure 3. The absorption coefficient was measured after the non-woven fabric was bonded to the PP board with a thickness of 1.3 mm. The non-woven fabric side was faced toward the speaker. The sheet with a surface density of 0.02 kg/m^2 had a minimum absorption coefficient of 0.048 (Figure 3). The absorption coefficient increased as surface density increased and a maximum absorption coefficient of 0.14 was obtained from the specimen with a surface density of 0.64 kg/m^2. The absorption coefficient of the composite sheet with non-woven fabric of a surface density of 0.64 kg/m^2 as a function of frequency is shown in Figure 4. An absorption coefficient at a frequency range of 1000–2000 Hz is important for automotive applications. A composite sheet with non-woven fabric with a surface density of 0.64 kg/m^2 showed an absorption coefficient of 0.1–0.2, indicating 100–400% increase in the absorption coefficient compared to that of plain PP board. Hemisphere cavities were introduced to improve the absorption properties of the sheet. By introducing the hemispheric cavities, the absorption coefficient increased at each frequency compared to that of plain board (Table 1). The increase in the absorption coefficient was dominant at 2000 and 4000 Hz compared to those at 500 and 1000 Hz. This result indicates that the hemispheric cavity may act as a Helmholtz resonator from the viewpoint of acoustics. A Helmholtz resonator (f_r) can be obtained from Equation (2):

$$f_r = \frac{c}{2\pi}\sqrt{\frac{A}{l \cdot V}} \tag{2}$$

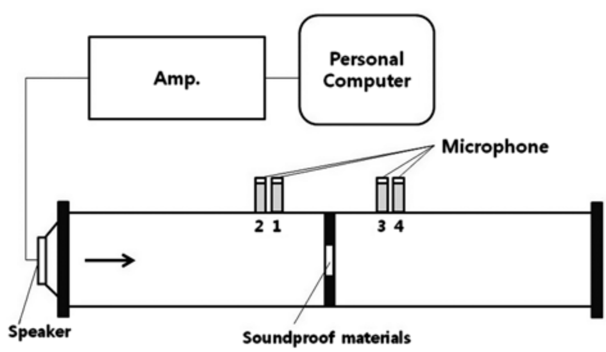

Figure 2. Experimental setup for TL measurements.

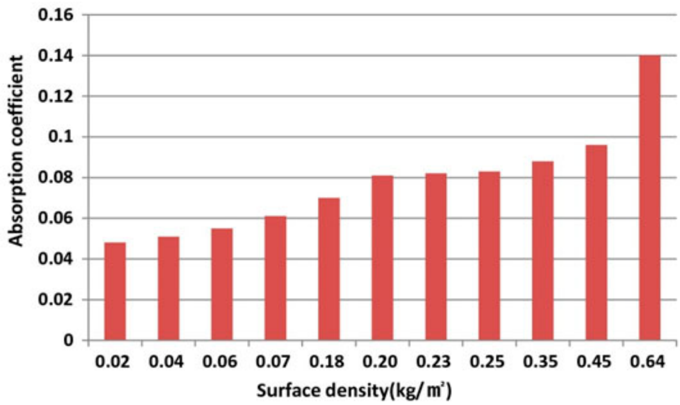

Figure 3. Sound absorption coefficient vs. surface density of a non-woven fabric.

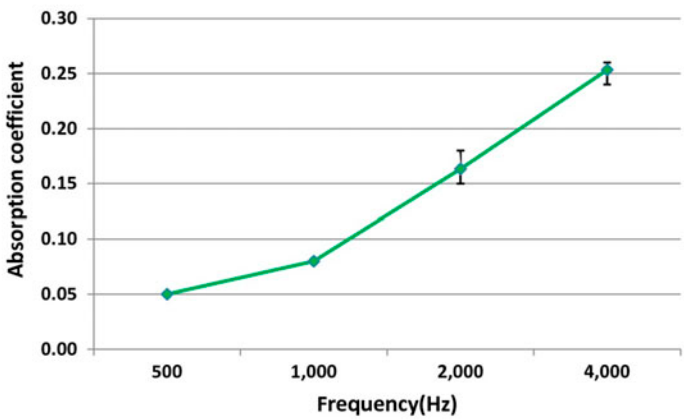

Figure 4. Sound absorption coefficient variation as a function of frequency.

Table 1. Sound absorption coefficient of a flat sheet and sheet with hemispheric cavities at various frequencies (sheet thickness: 2.2 mm and surface density of non-woven fabric: 1.0 kg/m^2).

	Absorption coefficient			
Surface	500 Hz	1000 Hz	2000 Hz	4000 Hz
Flat	0.053	0.085	0.211	0.282
With hemisphere cavities	0.054	0.090	0.236	0.306

where c is sound velocity, A is cross-section area (m^2) of the neck, l is the length of the neck, and V (m^3) is cavity volume.

In Equation (2), a small sized hemispheric cavity is more effective at high frequency than at low frequency. In other words, the space between non-woven fabrics may act as the neck of resonator and the hemispheric cavities become open space. It is more effective not only at a single frequency but also at high frequency range due to the various cavity volumes.

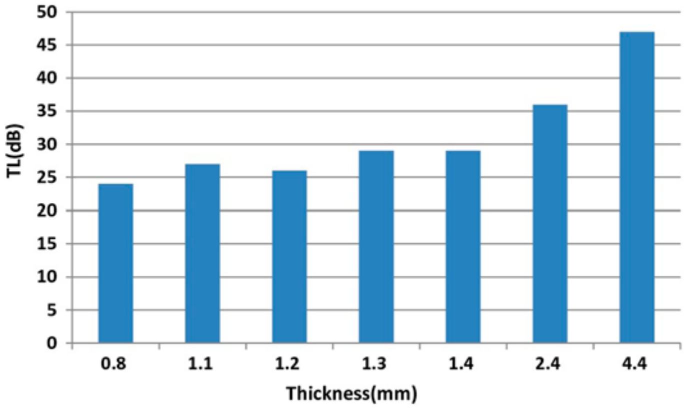

Figure 5. TL as a function of thickness of the PP board.

3.2. Transmission loss (TL)

The TL of the PP board with respect to thickness is shown in Figure 5. TL increased with thickness of the PP board. The TL and surface density (m) of a sound proof sheet can be related as in Equation (3):

$$\text{Transmission loss} \propto 20 \log(\text{m}) \tag{3}$$

Figure 5 shows the trends of Equation (3). To improve the TL properties of a sheet, hemispheric cavities were introduced on the sheet with a thickness of 2.2 mm, and the TL of the sheet with hemispheric cavities was compared to that of a plain sheet. Table 2 shows the TLs of a plain board at 500 and 1000 Hz where the TLs of the sheet without cavities were higher than the sheet with hemispheric cavities. However, the TLs were opposite at 2000 and 4000 Hz. To clarify the effects of hemispheric cavities on TL,

Table 2. Transmission loss of flat sheet and a sheet with hemispheric cavities at various frequencies (sheet thickness: 2.2 mm and surface density of non-woven fabric: 1.0 kg/m^2).

	Transmission loss (dB)			
Surface	500 Hz	1000 Hz	2000 Hz	4000 Hz
Flat	44.4	36.9	26.2	39.2
With hemisphere cavities	40.0	29.7	28.3	42.6

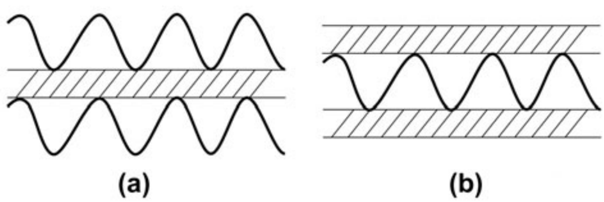

Figure 6. Structures of a composite sheet (a) Sheet A and (b) sheet B.

Table 3. Transmission loss of specimens *A* and *B*.

Specimen	Surface density (kg/m^2)	Transmission loss (dB)				
		500 Hz	1000 Hz	2000 Hz	4000 Hz	Average
A	4.69	54.6	48.1	33.5	41.1	44.3
B	4.68	51.4	41.9	23.1	31.1	36.9

cavity volume and the structure of the empty space were changed using flat and sine-wave sheets as shown in Figure 6. Figure 6 is a schematic structure of the composite sheet. The TL of the composite sheet at several frequencies is shown in Table 3. The composite sheet A with a sine-wave sheet on both sides of flat PP board showed increased TL of 7 dB compared to composite sheet B with a flat PP board on both sides of a sine-wave sheet.

4. Conclusions

Various composite sheets were prepared and their absorption and TL properties were investigated. The following conclusions were obtained:

(1) The absorption coefficient of a sheet increased with the surface density of non-woven fabric, and the sheet with hemispheric cavities showed a higher absorption coefficient at each frequency than that without hemisphere cavities.
(2) TL of the sheet increased with thickness and surface density.
(3) The empty space between the board and non-woven fabric was an important factor for TL. Additionally, the structure of the empty space was critical to TL when the surface density of the sheets was the same.

Absorption and TL were improved by changing the surface density of non-woven fabric and the structure of the empty space. These results could provide innovative ideas to develop a trunk mat and other materials.

Acknowledgments

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