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Sound insulation performance of double leaf wall improved by inhomogeneous application of adhesive

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ABSTRACT

Double-leaf walls are often made of two or more sheets of gypsum board to offer enhanced sound insulation. Sound insulation depends on how the adhesive that bond the gypsum sheets is applied, even if the adhesive is not a viscoelastic material. This study tested various applications of adhesive for their effects on the wall's insulation performance for high-frequency sound, including the critical coincidence frequency f_c. First, we measured the sound reduction index R for several types of gypsum boards laminated with various application patterns of adhesive, such as dots and lines. We found that the application pattern affects the bonding area. The sound reduction index R at f_c was shifted to lower frequency if the bonding area was larger. Second, the tests showed that R can be improved for the frequency range around f_c if adhesive is applied heterogeneously so that the bonding area is different for each part of the board. Moreover, we have found that the sound insulation performance of a double-leaf wall built of boards bonded with inhomogeneous application is increased by more than 5 dB, in comparison with the performance of a wall with homogeneously applied adhesive, even if the total amount of adhesive is the same in both cases.

Keywords: sound insulation, gypsum board, critical coincidence frequency
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1. INTRODUCTION

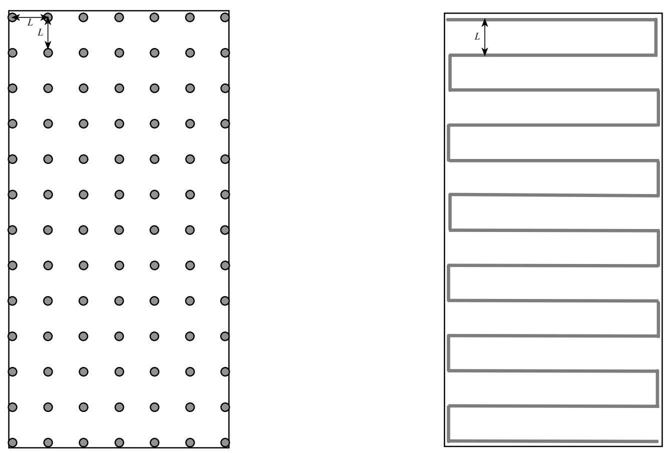
Double-leaf walls are often made of two or more leaves of gypsum boards and are used in multiple-dwelling structures. Two layers of boards are connected directly to the studs using screws or nails, or the layers are glued together with adhesive and staples after the bottom layer is attached to the studs using screws or nails. In the latter step, the application of adhesive can affect the sound insulation performance. For example, Davy found that the sound insulation performance can be improved using viscoelastic glue[1)]. We also reported that polyvinyl acetate emulsion (PVAc) adhesive, which is frequently used to construct walls in Japan, has some effect on sound insulation performance across the entire measured frequency range[2)]. The performance increases as less adhesive is applied.

However, the amount of adhesive also affects the fire-resistance of the wall, so the adhesive can not be reduced so much. Therefore, the sound insulation performance should be improved in some cases without decreasing the amount of adhesive applied. In this study, we first measured the sound reduction index for several types of two-layer gypsum boards glued together using various application patterns of PVAc adhesive, like dots and lines. The measurement results clarify the relation between the manner of application and the sound insulation performance. Using these test results, we have proposed an adhesive application method that can increase sound insulation performance for high-frequency sounds including the critical coincidence frequency f_c, while applying the same amount of adhesive.

2. ADHESIVE APPLICATION PATTERNS

2.1 Sound insulation performance of laminated gypsum boards

We measured the sound reduction index of laminated gypsum boards made from two sheets of 12.5-mm-thick fire-resistant gypsum board (GB-F 12.5) bonded together with PVAc adhesive and staples. The measurements for the specimens with 1820 × 910 mm^2 size were conducted by utilizing the two-room method. The test rooms were 51.4 m^3 and 56.7 m^3 in volume. The test opening had almost the same dimensions as the measured specimens. The gaps in the four edges of the specimens were filled with clay. Adhesive was applied as shown in Fig. 1. The intervals between the dots were 75, 150 and 300 for the dot pattern applications, and the interval between lines was 75 mm for the line pattern application.



Dot pattern (L = 75, 150 and 300 mm)   Line pattern (L = 75)

Figure 1 Adhesive application schemes for laminated gypsum boards.

Figure 2 compares the application manner and the measured results of the sound reduction index, *R*, for several types of laminated boards that were measured after at least two days' curing time, and the amount of the adhesive was kept constant at 200 g/m^2 in all cases. The results for specimens with 6.5 g/m^2 and 400 g/m^2 of adhesive are also shown in this figure. When the density of applied glue is 6.5 g/m^2, a decrease in *R* appeared at the same frequency as the critical coincidence frequency f_c for a single board. The value of f_c was calculated to be 2.8 kHz.

As the amount of adhesive increases to 200 g/m^2, the dip in *R* was shifted to a lower frequency, even though the interval between dots of adhesive was still 300 mm. Furthermore, the dip in *R* was shifted gradually to a lower frequency by narrowing the interval to 75 mm. However, it was decreased to the same frequency as the full-bonding case with 400 g/m^2 of adhesive when the adhesive was applied in lines with intervals of 75 mm.

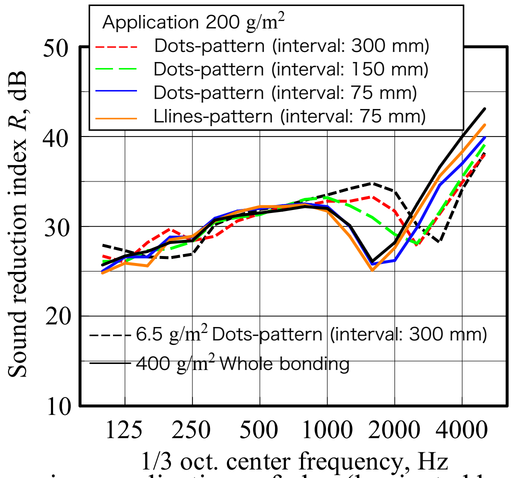
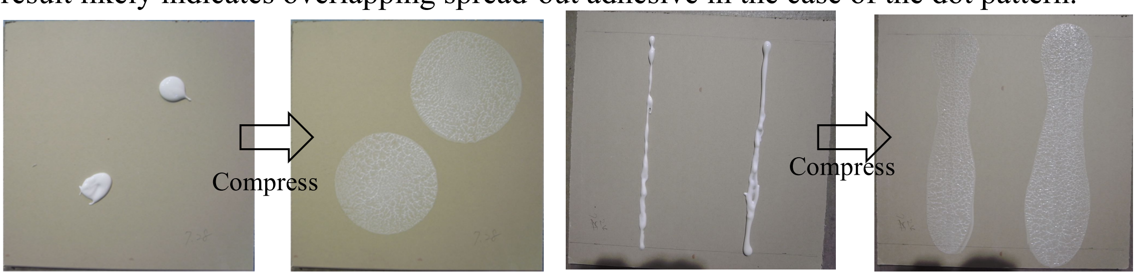


Figure 2 Results with various applications of glue (laminated board: GB-F12.5 + GB-F12.5).

2.2 Bonding area, loss factor and bending stiffness

We estimated the bonding area of a single dot or a 250 mm long line using a simple method. First, we measured the area into which the adhesive spread by pressing the adhesive between two sheets of gypsum as shown in Fig. 3. The approximate values of the bonding area per unit area φ were obtained by multiplying the estimated values by the total number of dots or total length of the line in the unit area. Table 1 lists the approximate values of the bonding area φ. These values may be overestimated because they do not include cases in which spread-out glue overlaps.

The value of φ increases to approximately 100% as the interval decreases, while the amount of adhesive is constant. However, in the case of 200 g/m^2 of adhesive, the dot pattern yields higher φ than the line pattern, though the intervals are the same. This result likely indicates overlapping spread-out adhesive in the case of the dot pattern.



Dots-pattern Lines-pattern

Figure 3 Estimation of adhesive bonding area.

Table 1 Approximate φ values of adhesive.

Amount, g/m²	Pattern	Interval between dots or lines, mm	Bonding area per unit area φ, %
6.5	Dots	300	5
200			47
		150	69
		75	98
	Lines	75	74
400	Whole surface	–	100

The results in Table 1 indicate that the bonding area φ is affected by whether the adhesive is applied in dots or lines, and by the separation between dots or lines, while still applying the same amount of adhesive per unit area. In further tests, then, we measured the internal loss factor η and the Young's modulus E for various values of the bonding area of the laminated gypsum boards φ, using the mechanical impedance method[3)]. The specimen for these tests was made of two strips of 12.5-mm-thick fire-resistant gypsum board (GB-F 12.5) with dimensions of 350 × 30 mm. Less than 100 g/m^2 of adhesive was applied. The Young's modulus E and the critical coincidence frequency f_c were calculated from the equivalent bending-rigidity modulus $B_{eq,3}$ at the third order resonance frequency $f_{res,3}$, following ISO 16940 Annex B, as follows:

$$E = \frac{12}{t^4}\rho_m\left(f_{res,3}\frac{2\pi L^2}{\lambda_3^2}\right)^2, \qquad (1),$$

$$f_c = \frac{c^2}{2\pi t}\sqrt{\frac{\rho_m}{E}}, \qquad (2),$$

where t, ρ_m and L represent the thickness, density and half-length of the specimen, respectively, and $\lambda_3 = 7.85476$.

Figure 4 shows the internal loss factor η for various bonding areas of the laminated gypsum boards φ that were allowed to cure two or more days after construction. The values of η for 50% application are nearly equal to the values for 5% application in the frequency range including f_c; however, in the case of φ = 70%, η approaches the value for 100%.

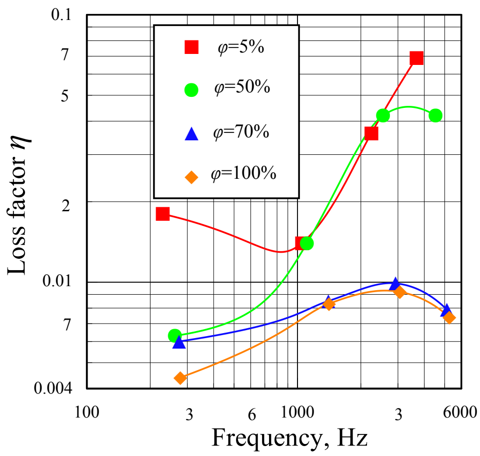


Figure 4 Comparison between internal loss factor and bonding area.

Figures 5 and 6 plot the measurements of Young's modulus E and the critical coincidence frequency f_c, respectively. The value of E increases with increasing φ; however, the change in E as φ changes from 70% to 100% is smaller than the change from 5% to 70%. The change in f_c is similar but in the opposite direction.

Conversely, the measurements of R in Fig. 2 show the same trend; namely, when bonding the sheets using lines of glue with intervals of 75 mm, R decreased at the almost same frequency as the whole-bonding case with 400 g/m^2 of glue. However, from the results shown in Fig. 2, the decrease in R at f_c occurs at less than 2000 Hz. Therefore, we found that the sound insulation performance of two-ply gypsum boards bonded with adhesive can be controlled by the amount of the adhesive and by the bonding area.

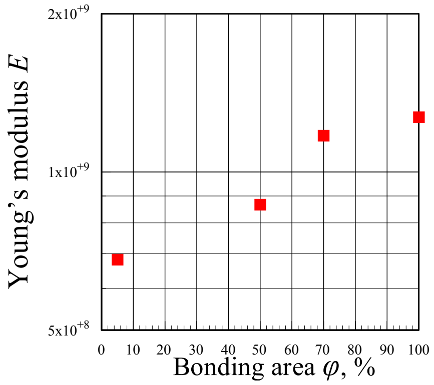


Figure 5 Relation between Young's modulus E and bonding area.

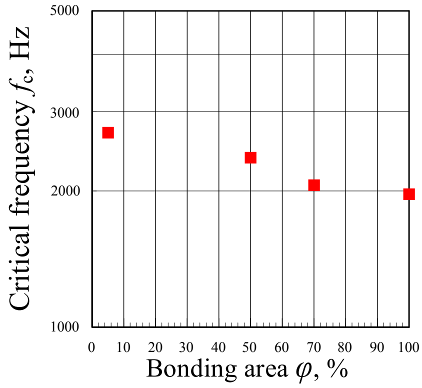
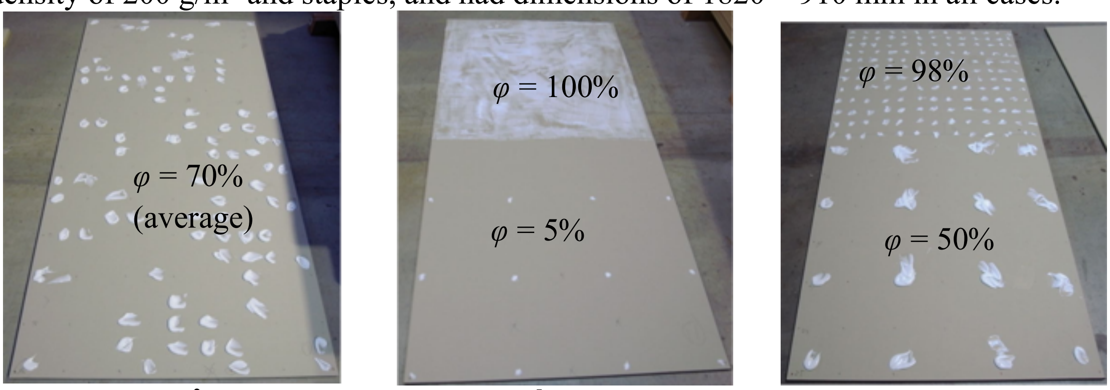


Figure 6 Relation between critical freaquency f_c and bonding area.

3. IMPROVEMENT OF SOUND INSULATION AT f_c

3.1 Inhomogeneous adhesive application

From the tests introduced above, we conclude that the inner loss factor of gypsum boards laminated with adhesive covering 50% of the board area is nearly equal to the inner loss factor with 5% bonding area in the high-frequency range that includes f_c. Therefore, the sound insulation performance does not decrease much if the bonding area is less than 50%. Furthermore, we guess that the coincidence effect is hardly observed when building a laminated from parts with different bending stiffnesses. Thus, we measured the sound reduction index R of laminated boards that were bonded with adhesive applied so inhomogeneously that the bonding area was less than 50% in a part, as shown in Fig. 7. The specimens were made from two sheets of 12.5-mm-thick fire-resistant gypsum board (GB-F 12.5) held together with PVAc adhesive applied at density of 200 g/m^2 and staples, and had dimensions of 1820 × 910 mm in all cases.



Case A 200 g/m^2 Random

Case B 6.5 g/m^2 (interval 300 mm) + 400 g/m^2 (whole bonding)

Case C 200 g/m^2 (interval 300 mm) + 200 g/m^2 (interval 75 mm)

Figure 7 Gypsum boards with inhomogeneous adhesive application.

Figure 8 compares the application pattern of the glue and the measurements of *R*. The measurements of samples with homogeneously applied glue are also plotted as broken lines. In Case A with randomly distributed dots, *R* is decreased more in the frequency range that includes f_c than it is in the homogeneous case. In Case C, the decrease is shifted to a lower frequency than it is in the homogeneous case; however, the decrease for Case B becomes shallower in the high-frequency range. Therefore, we found that the sound insulation performance of the laminated gypsum board can be improved in the frequency range that includes f_c by applying adhesive differently.

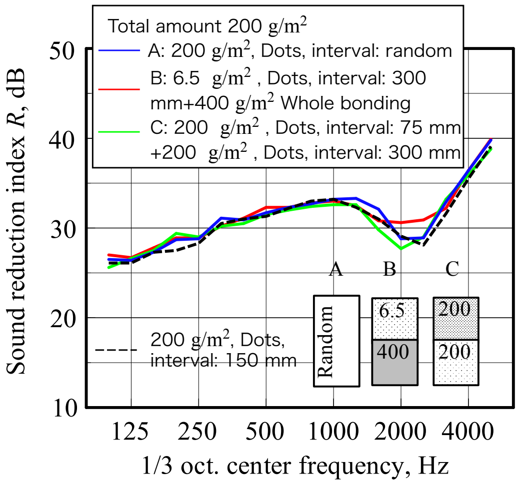


Figure 8 Results for various inhomogeneous applications of glue (laminated boards are both GB-F12.5).

3.2 Improving the sound insulation performance of double-leaf wall

We measured the two types of specimens shown in Fig. 9. In both cases, the specimens were constructed on staggered 50-mm steel studs that were spaced 606 mm apart. Fire-resistant gypsum board (GB-F 12.5) with thickness of 12.5 mm was used for the underlayer and was attached to studs with screws. GB-F 12.5 was used for the top layer and was fixed to the under layer with PVAc adhesive and staples.

An average of 200 g/m^2 of adhesive was applied. The adhesive was applied as lines spaced in 75-mm intervals in Case X. In Case Y, adhesive was applied at the density of 6.5 g/m^2 in dots separated by 300 mm in half the area and in 400-g/m^2 lines separated by 38 mm in rest of the area, like Case B in section 3.1. The application pattern in case Y spreads glue over approximately the half area between the sheets. The areas with different application patterns were in a checkerboard pattern as shown in Fig. 10. The gaps in the four edges of the wall were filled with acrylic sealant and 24 kg/m^3 of dense glass wool (thickness: 50 mm) was installed in the air cavity.

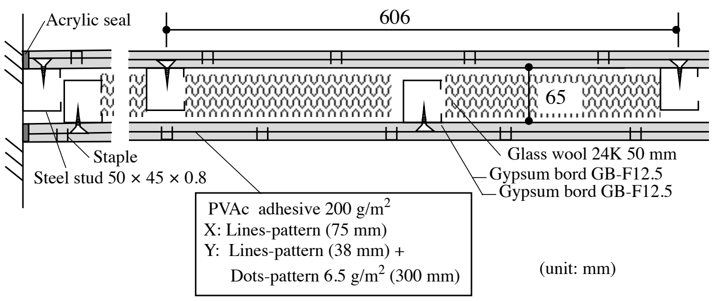


Figure 9 Horizontal cross section of the specimens.

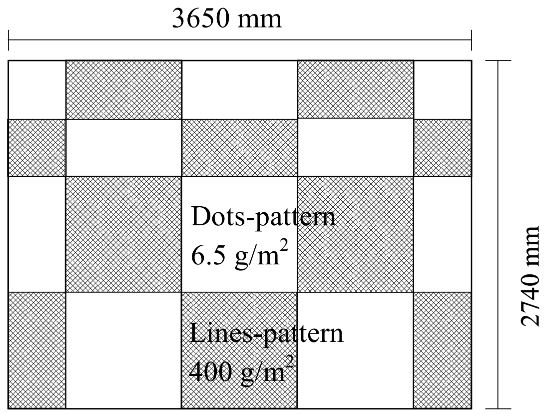


Figure 10 Application pattern of adhesive on the whole surface of wall in Case Y.

The sound reduction index R was measured using the two-room method[3)]. The size of the opening was 3.65 m × 2.74 m (=10.0 m^2). Figure 10 shows the measurement results for both walls. These results were obtained after the walls cured for 6 days, which was enough to stabilize the sound insulation performance.

In Case Y, the dip in R at high frequencies around the critical coincidence frequency f_c is about 5 dB greater than in the homogeneous case (Case X). The same amount of adhesive was applied in both cases. These results indicate that inhomogeneous application of glue increases the value of R over a wider frequency range.

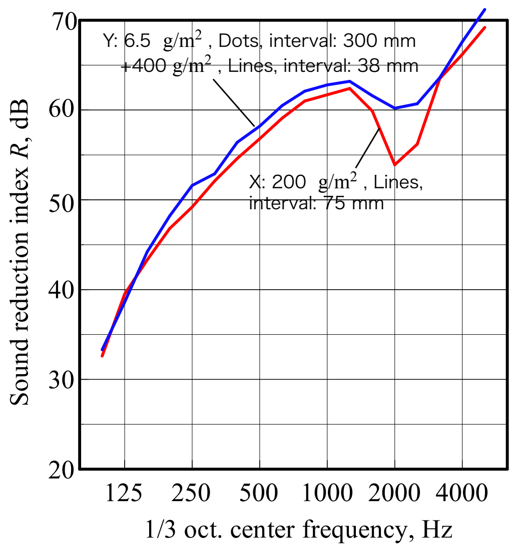


Figure 11 Comparison of measurement results for inhomogeneous and homogeneous adhesive application.

4. CONCLUSIONS

We have investigated the sound insulation performance of laminated gypsum boards held together with PVAc glue applied in various manners. The results suggest the following conclusions:

1) The bonding area can be controlled by varying the pattern with which adhesive is applied, the separation between dots or lines, and the amount of adhesive.

2) The loss factor and the bending stiffness of the laminated gypsum board depend on the bonding area.

3) Consequently, both the amount of glue and the bonding area affect the sound insulation performance. For example, the critical coincidence frequency f_c is shifted to a lower frequency as the bonding area increases even if the same amount of glue is applied.

4) Furthermore, the sound insulation performance can be improved with inhomogeneous application of glue, using different glue patterns on each part of the board.

Moreover, we have measured the sound reduction index of a double-leaf wall composed of laminated gypsum boards bonded together by heterogeneously applied adhesive. The results indicate that the dip in R at high frequencies around the critical coincidence frequency f_c is increased by about 5 dB from the case of homogeneously applied glue.

5. REFERENCES

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3. ISO 16940: Glass in building - Glazing and airborne sound insulation - Measurement of the mechanical impedance of laminated glass.