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Study of the compatibility between sound insulation performance and ventilation performance in gaps by installing nonwoven fabrics

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ABSTRACT

Gaps, slits, and openings for natural ventilation that occur around doors and windows cause sound leakage and decrease sound insulation performance. However, if airtight materials are used to close these gaps, as is typical, the ventilation performance is lost. In the gaps, the particle velocities become large, and this phenomenon is reported as the “gap effect.” Furthermore, it is suggested that the sound insulation performance is improved by suppressing the particle velocities in the gaps with breathable sound-absorbing materials. Therefore, a balance between the suppression of sound leakage and maintaining the air ventilation is obtainable by considering the balance between the total equivalent clearance and the flow resistivities of the breathable sound-absorbing materials. In this study, for the installation of thin nonwoven fabrics as a breathable material in the gaps, improvements in the sound insulation performance and the amount of ventilation as the total equivalent clearance area are verified. Additionally, the relations between the sound insulation performance and the air ventilation performance using these nonwoven fabrics in the gaps are discussed. As a result, an improvement in the sound insulation performance is obtained while maintaining the air ventilation performance by installing thin nonwoven fabrics that have low flow resistivities because the large particle velocities are effectively suppressed in the gaps.

1. Introduction

Gaps, slits, and openings for natural ventilation that occur at the perimeter and bottom of a door set, sliding door, or sash window cause a decrease in the sound insulation performance. To reduce the sound leakage through these gaps, airtight materials and rubber-based devices are generally used. However, in cases in which airtight materials and devices are used, it is not possible to ensure ventilation through the door set. This is particularly required in toilets and facilities for the elderly that require constant ventilation. Various studies have been conducted on sounds transmitted through these gaps.

For sound transmission through holes, gaps, and slits in walls, Gomperts studied the sound insulation performance using an approximation approach with experiments, conducted experimental verification of the influence of their parameters on the sound insulation characteristics, and proposed a prediction method incorporating the effects of air viscosity [1,2]. However, the approximation method proposed by Gomperts is limited to slight gaps that are shorter than the sound wavelength.

Wilson et al. proposed a method that removed this limitation and was experimentally verified [3]. Then, Sauter et al. proposed a method that extended this approach to a rectangular section [4]. Lewis et al. conducted experimental studies on the characteristics of an entire window set and their effect on the sound insulation performance, including the effects of the gaps around the window [5]. Sound insulation prediction formulas, which have used the prediction method given by Gomperts [1], have been proposed by Hongisto et al. This prediction method incorporates the influence of the transmitted sound through the gaps around the door sets, and they have been empirically verified using door gaps [6,7]. To reduce the sound leakage from these gaps, Horiuchi et al. conducted numerical analyses and experiments on the sound transmitted from noise barrier gaps [8], and Kimura et al. measured and confirmed the effects of sound barrier gaps on the sound insulation performance [9]. Similarly, Asakura et al. have conducted a numerical

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analysis using a finite difference time domain (FDTD) method and experiments on sound insulation improvement techniques for sash-window gaps, which involve suppressing the sound transmission through the gaps using sound-absorbing materials [10–12]. Additionally, Yamashita et al. reported the effects of the treatment of soft boundary surfaces at the gap edges using resonator techniques [13].

With regard to the physical characteristics of sound transmission through gaps, the pressure gradient becomes large in areas where a large difference in sound pressure occurs, such as at the edges of a thin rigid plate. This phenomenon is known as the "edge effect," and the details have been reported by Kawai [14], who also reported that the particle velocity can be effectively reduced by installing sound-absorbing, thin, permeable materials with an appropriate flow resistivity in the area where the particle velocity is large. On the one hand, many studies on air ventilation have been conducted. Cockroft et al. reported the ventilation of an enclosure through a single opening [15]. Barclay et al. proposed a method that quantifies the interaction of building noise exposure with the natural ventilation potential [16]. For air ventilation and influence of noise, De Salisa et al. reported noise control strategies for naturally ventilated buildings [17]. Bibby et al. conducted field measurements of the acoustical and airflow performance using interior natural-ventilation openings and silencers and reported their optimization and application [18,19]. Sakamoto et al. conducted a numerical and experimental study of the noise shielding effect of eaves/louvers attached to a building facade [20].

However, in these previous studies, the discussions are limited to the sound insulation performance and the air ventilation opening with silencers or eaves/louvers. On the other hand, in our previous studies [21,22], it was suggested that the sound insulation performance is effectively obtained by suppression of the "gap effect." However, no studies have argued the relations between the air permeabilities and the sound insulation performance of the gap with sound-absorbing materials [25,26]. In this study, the effects of applying an acoustic-absorbing treatment to gaps to suppress the particle velocities and thereby reduce the sound leakage are investigated using nonwoven fabrics that have an air permeability. From this investigation, it is confirmed that the transmitted sound can be reduced while maintaining the air permeability through the gaps using this method.

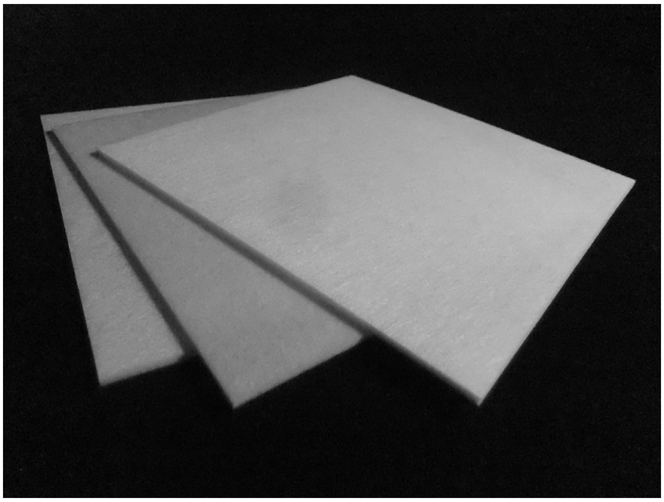

Fig. 1. Nonwoven fabrics.

2. Measurement of the physical properties of the nonwoven fabrics

In this study, the nonwoven fabrics shown in Fig. 1 are used as a sound-absorbing material in order to maintain air ventilation. At first, the physical properties of nonwoven fabrics, which are made of a core–sheath-type composite fiber, as shown in Fig. 2, are measured. The structure and fiber of the nonwoven fabrics used in this study are common among all samples. The physical properties of the samples are presented in Fig. 5 and Table 1.

At first, in order to obtain the air permeability of the nonwoven fabrics through the gaps, the differential pressures and air permeabilities between two chambers were measured using the experimental equipment shown in Figs. 3 and 4 by varying the amount of ventilation with use of a fan. In Fig. 3, each chamber has the same dimensions of W 1300 mm × L 1300 mm × H 2400 mm, and the dimensions of the aperture are W 940 mm × H 2200 mm. The total equivalent areas that show the amount of ventilation are calculated using the following equations:

$$Q = a(\Delta P)^{1/n}, \tag{1}$$

and

$$\alpha A = bQ_{9.8}, \tag{2}$$

where the coefficient $b = 0.689$ because the temperature during measurement was 21.7 °C. The permeation coefficient a and gap characteristic value $1/n$ are obtained by an approximate equation obtained by plotting the measured amount of ventilation Q and differential pressure ΔP. Then the amount of ventilation $Q_{9.8}$ is obtained when ΔP is 9.8 Pa in Eq. (1), and the total equivalent area αA is obtained with $Q_{9.8}$ multiplied by b in Eq. (2).

In Fig. 5, the relations between the surface densities, total equivalent clearance areas, and flow resistivities are shown. The normal incident sound absorption coefficients of the nonwoven fabrics used in this study are shown in Fig. 6. These sound absorption coefficients were measured at normal incidence by using Impedance tube 4206 manufactured by Bruel & Kjaer.

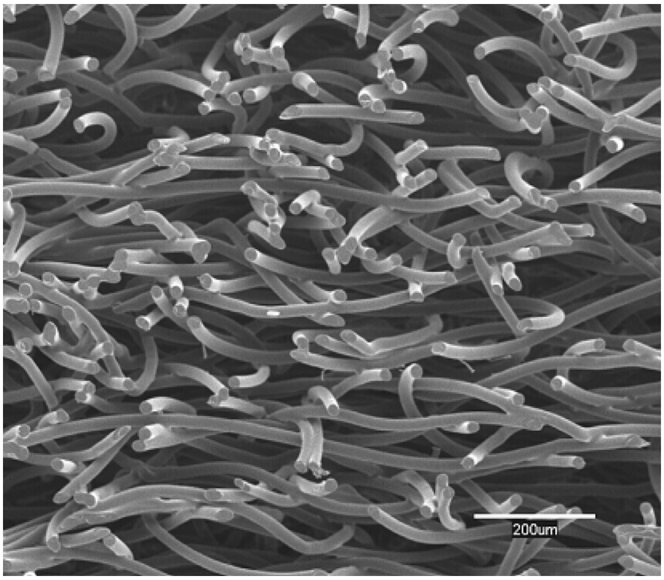

Fig. 2. Magnified image of the nonwoven fabrics of sample B (extended 100 times).