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Experimental Study on the Comparison of the Material Properties of Glass Wool Used as Building Materials

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Artificial mineral fibers such as glass wool or stone wool are commonly used in building walls, ceilings and floors as a major insulation material for buildings. Among the material properties of building materials, thermal conductivity, the sound absorption coefficient, compressibility, and dynamic stiffness are regarded as important performance requirements since they directly affect the thermal and acoustic properties of the building. This study measured the changes of the thermal and acoustical performances of glass wool that was actually installed for a long time to the outer wall of a building as an insulation material through a comparison with recently produced glass wool. The results showed that the measured thermal conductivities of the old and the new specimens both rise with an increase of temperature, showing quite similar results in both specimens over temperature ranges of (0 – 20) ºC. The noise reduction coefficient decreased by 0.1 in the old specimen and the difference of the compressibilities in both specimens was shown to be 7.32 mm. The dynamic stiffness of the old specimen was found to be 1.28 MN/m^3 higher than that of the new specimen.

Keywords: glass wool, thermal conductivity, acoustic property, building insulation.

1. INTRODUCTION

In order to maintain a constant temperature within a building it is required to restrict the rate at which heat energy is exchanged with the surroundings. Keeping heat inside a building for as long as possible conserves energy and reduces heating costs [1]. For this purpose, insulation materials are used in the building envelope, including the outer wall, roof, and floor of the building. The performance of the building envelope is determined by the thermal, acoustic and physical properties of the materials used. When selecting materials for thermal insulation for buildings, the physical properties of the material need to be considered.

Good thermal insulation reduces heat loss in buildings and minimizes the risk of surface condensation on interior surfaces. The use of thermal insulation in buildings does not only save energy costs, but also extends periods of indoor thermal comfort, especially in between seasons. The use of thermal insulation can reduce noise disturbance from adjacent areas or from outside. This enhances the acoustical comfort and fire protection of insulated buildings [2].

Insulation materials are classified into several types, these being inorganic, organic, combined, and other types, depending on the chemical structures. Fibrous insulation materials are used for both building and industrial applications. They can be used for many different applications, due to adaptability in form and shape and also resistance to biological, chemical and mechanical impacts, such as vibration [3].

In Korea, artificial mineral fiber materials [4] such as glass wool or stone wool are commonly used in walls, ceilings and floors of buildings as major insulation materials. They also play an important role as resilient materials for sound absorption or reduction of floor impact sound when installed to the inside of dry wall or under the floor. Therefore, all properties of insulation materials used in buildings are very useful in providing general information for building and facility designs [5 – 7]. Several studies have been conducted on the material properties of building materials. Moon et al [8] investigated the hygrothermal properties of building materials for the evaluation of hygrothermal conditions. Through the study, they intended to provide important information to the building design through building a database for the hygrothermal properties(bulk density, porosity, specific heat capacity, thermal conductivity, water vapour diffusion resistance factor, moisture storage function) for the major building materials used in Korea.

R. Cerny et. al. [9] introduced the concept of effective specific heat of building materials to understand the general processes in building materials at higher temperatures. The characteristics of light heat-insulating materials depend on the content of organic compounds which are subject to structural changes and chemical reactions in higher temperature regions.

Saleh A. et. al. [10] used a hot disk system to measure the thermal conductivity of some building insulation materials and compared the results with the manufacturer's claimed conductivity data. The thermal conductivity was measured at elevated temperatures of 22, 35, 50 and 65 ºC. The results show that the measured thermal conductivity values at 22 ºC were in close agreement to the claimed values of the manufacturers.

Kim et. al. [11] examined the relationship between dynamic stiffness and heavy weight impact sound levels, and some 51 types of building resilient materials were measured for such. As the dynamic stiffness of resilient materials decreased, the heavy weight impact sound level also decreased, thus there was a correlation between dynamic stiffness and heavy weight impact sound.

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Schiavi et. al. [12] investigated the relationship between the change of the dynamic stiffness coefficient and the floor impact sound reduction level for resilient materials against floor impact sound, including glass wool.

There has been little research conducted on thermal and acoustic properties and the physical properties of materials used as building materials over long periods of time.

The present study reports on building insulation materials that have major impacts on the thermal and acoustic properties of buildings, asmentioned above. As an experimental insulation material, glass wool as a artificial mineral fiber was used in this study.

The purpose of this study was to investigate the material properties through measurement of the thermal conductivity, sound absorption coefficient, compressibility, and dynamic stiffness of glass wool that was actually installed to the outer wall of a building for a long period of time as an insulation material.

2. EXPERIMENTAL

2.1. Materials

For this study, glass wool that was used for building insulation on the outer wall of an office building built in 1997 in Korea was prepared with new glass wool produced in 2012. The old glass wool installed on the outer wall was acquired during the renovation of the building in 2012. Since the initial material properties of the glass wool at the time of the construction of the building were unknown and much time had elapsed after the installation, the degree of changes in the initial values could not be determined. Therefore, a specimen old enough to be similar to the glass wool and a specimen recently produced were prepared for a comparison of material properties.

The glass wool insulation obtained a while ago was maintained at room temperature after acquisition and made into a specimen according to the measurement method. The size of the specimen for measuring thermal conductivity and compressibility was 300 mm × 300 mm, and 200 mm × 200 mm dynamic stiffness. To measure the sound absorption coefficient, a specimen with a diameter of 50 mm was prepared using an impedance tube. All glass wool specimens were preprocessed in a laboratory chamber with a relative humidity of 50 % ±5 % R.H. and a temperature of 23 ºC ±2 ºC for 48 hours prior to the experiment. The glass wool that was used as a building material is referred to as the old specimen while the insulation material recently produced as the new specimen. Table 1 provides the information about the test specimen properties.

Table 1. Properties of test specimens

Specimen	Number of specimen	Thickness [mm]	Density [kg/m^3]	Fiber orientation
Old	5	49.7	34.1	Random
New	5	50.0	30.4	Random

2.2. Tests

2.2.1. Morphology test (SEM)

The surface morphology of the test specimens was observed with the use of a scanning electron microscope (SEM, S-3400n, accelerating voltage 17.0 kV) in order to check the fabric particles of the glass wool.

2.2.2. Thermal property

In general, heat transfer in insulation materials occurs due to radiative heat transfer, thermal conductivity and convection in the air layer between materials, and convection via air flow.

Thermal conductivity is a measure of the rate at which heat is conducted through a particular material under specified conditions. Thermal conductivity, or the K-value (W/mK), is measured as the steady state of heat flow across a thickness of 1 m of material for a temperature difference of 1 degree K. Knowledge of the thermal conductivity values allows for a quantitative comparison to be made between the effectiveness of different thermal insulation materials [2].

Among the thermal properties of insulation materials, thermal conductivity is regarded to be the most important since it directly affects the resistance for transmission of heat (*R*-value) that the insulation materials must offer [10].

To measure the thermal conductivity, KS 9016 [13, 14] and ISO 8301 [15] were applied for this study. The instrument (HFM 436 Lambda Series, NETZSCH) was used for measuring the thermal conductivity of the test specimens with the heat flow meter method (HFM). The accuracy of the measuring device was ±2 % – ±5 %.

Thermal conductivity was measured at different mean temperatures of –10, 0, 10, 20, 30 and 40 ºC and the temperature difference between the high and low sides of each temperature was set to ±10 ºC based on the mean temperature.

2.2.3. Acoustic property

In order to use an insulation material for sound absorption, the performance on sound absorption must be a primary consideration, and changes in the compressibility and dynamic stiffness are also to be examined for use as a resilient material against floor impact sound. In general, the sound absorption coefficient, compressibility and dynamic stiffness are major test criteria to estimate the acoustic properties of building materials.

The measurement of the sound absorption coefficient was performed based on ISO 10534-2 [16] that was able to be tested using a small specimen. In addition, ISO 29770 [17] and ISO 9052-1 [18, 19] were respectively applied to measure the compressibility and dynamic stiffness.

As measuring devices, FFT (SA-01, RION, frequency range: 1 Hz – 40 kHz), Impedance tubes (SW-260, BSWA-Tech, frequency range: 100 Hz – 6.3 kHz) and compressive loader (DS-120, Daekyong-Tech., sensitivity: 0.01 kN) were used.

3. RESULTS AND DISCUSSION

3.1. SEM observations

Fig. 1 and Fig. 2 show the surfaces of the glass wool in SEM micrographs for both the old and new specimens. The glass wool from the old specimen appears to be entangled and somewhat swollen for unknown reasons. It is shown to be largely thin and partly broken in Fig. 1 where the thickness of the fiber was measured to be about

1.98 µm – 13.4 µm. Alternately, the spacing of the glass wool from the new specimen appears to be densely distributed and the thickness is homogeneous at 8.48 µm – 16.0 µm, which is thicker than the old one. Also, the glass wool was shown to be configured to a constant direction.

For the old specimen, such was exposed to the low temperatures of winter (below –10 ºC) and the high temperatures of summer (above 30 ºC) while having been used as an actual insulation material of a building for about 16 years. As a result, it is likely that the physical properties had deteriorated after being humidified (summer season: 50 % – 80 % R.H.) or dried (winter season: 10 % – 30 % R.H.) due to weather changes in the outdoors.

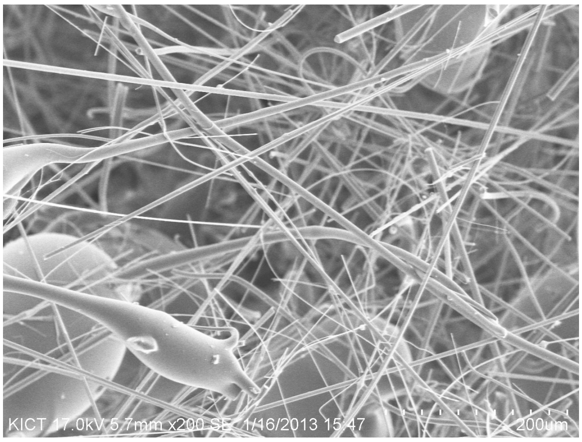

Fig. 1. SEM micrograph of glass wool used as building material for many years (old specimen, magnification 200×)

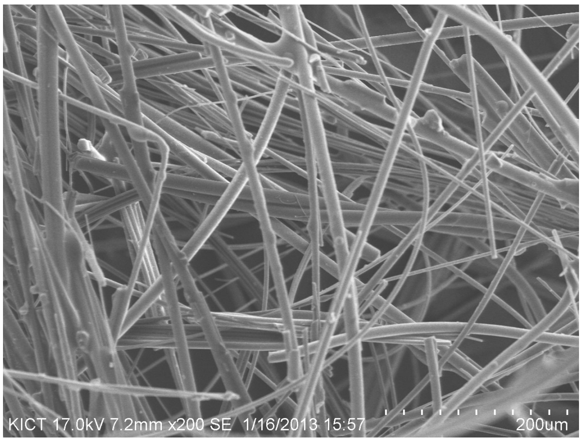

Fig. 2. SEM micrograph of recently produced glass wool (new specimen, magnification 200×)

3.2. Thermal conductivity

In general, effective conductivities depend on density, test temperature, moisture content as well as constituents and voids present in the structure of a material. Thermal conductivity rises with increasing temperature [5, 10].

The thermal conductivities of the old and new specimens were measured by changing the mean temperature as shown in Fig. 3.

The measurement results show that the measured thermal conductivity increases linearly with the increasing mean temperature. The measured thermal conductivity of the old specimen is shown to be higher by 1.6 % at –10 ºC and that of the new specimen to be higher by 2.5 % and 4.0 % at 30 ºC and 40 ºC, respectively. However, the measuring value of both specimens remained quite similar at temperatures of 0 ºC – 20 ºC. From these results, it is shown that the thermal performance of the glass wool (old specimen) that was used in the older building for a long time did not deteriorate. There is a difference in the thickness and shape of the fiber between old specimen and new specimen in SEM micrographs. However, because there is no change in the air space between the fibers and structure of fibers old specimen retains thermal properties.

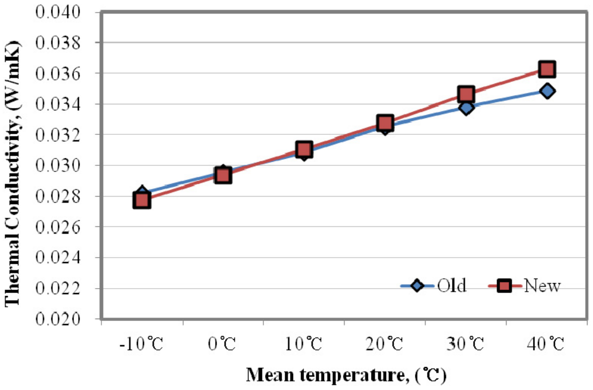

Fig. 3. Measurement results of thermal conductivity

3.3. Compressibility

The compressibility is one of the required performances for products used in floating floor structures to reduce floor impact sound and corresponding Korean industrial standards KS F 2873:2011 [20] based on ISO 29770 that was enacted in 2011. In the case where the products are used for floating floor structures in buildings in Korea, limit valuesof the compressibility are to be observed. The limit value of less than 30 mm of thickness sample is 2 mm. And more than 30 mm of thickness sample is 3 mm.

As a result of the measurements, it was found that the deformation of the old specimen, which is 16.51 mm, is higher than that of the new specimen, which is 9.19 mm, resulting in more compressibility of the old specimen. As shown in the values of d_F and d_B, the extent of the restoration of thickness in the old specimen after the load was removed appears to be relatively low compared to that of the new specimen (Table 2). The lowered elasticity of the specimen through the passage of time is regarded as a major reason for the low extent of restoration. When used for floating floor structures for a long time, the specimen is likely to experience increased deformation, which results in deformation of the mortar layer on the upper side of the specimen.

Table 2. Measurement result of compressibility

Specimen	Thickness(mm)			d_L–d_B
	d_L	d_F	d_B	
Old	44.77	36.36	28.27	16.51
New	45.45	30.56	36.25	9.19

Glass fibers are damaged by high compression through the compressibility test and significant deformation occurs [21]. Schiavi et. al. [22] suggested that 10 years later the degree of deformation can calculate through compressibility test. For long-term use, the compressibility is an important evaluation item. Since the specimens for measurement were shown to exceed the limit values for compressibility, additional investigation is necessary to prevent an increase in density and deformation in order to be able to be considered for use in floating floors in Korea.

3.4. Dynamic stiffness

As one of the important physical properties that affect the insulation performance of floor impact sound on the materials for floating floors, dynamic stiffness decreases with improvements to insulation performance [23].

The dynamic stiffness of the specimens was measured before and after compressibility testing, and the degree of change in the measurements was examined. In the case of the resilient materials used in Korea for floor structures, a mortar layer (40 mm – 50 mm) is installed on top of the materials. Therefore, whether deformation occurs in the resilient materials and changes occur in the dynamic stiffness can be important factors in conjunction with the reduction of floor impact sound.

Fig. 4 shows the measurement results of dynamic stiffness before and after compressibility testing. As shown in the figure, the dynamic stiffness of the old specimen appears to be relatively high compared to that of the new specimen. An increase in the dynamic stiffness represents a decrease in the reduction of floor impact sound, resulting in degradation of the insulation performance.

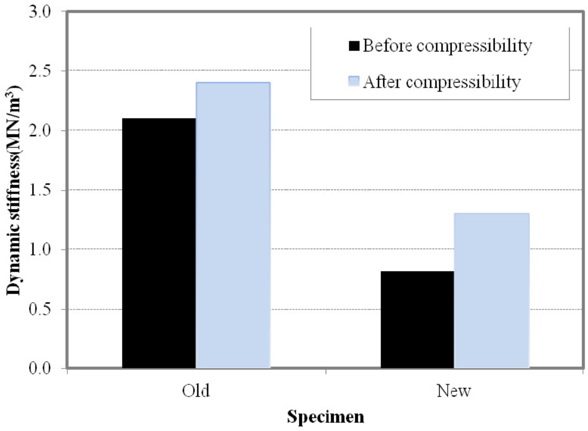

Fig. 4. Measurement results of dynamic stiffness

As shown in the results of the measurements of the dynamic stiffness before and after the compressibility test, the dynamic stiffness increased after compressibility test. The dynamic stiffness of the old specimen had increased by 14.4 % after compressibility test, and that of the new specimen increased by 58.5 %. According to the study by Dikavicius and Miskinis [24], measurements of dynamic stiffness in both open and closed cell resilient materials were found to decrease after compressibility testing, which shows conflicting results from the present study. A compressibility test aims to determine the extent to which the deformed thickness is restored, by adding a certain load (50 kPa) to the specimen. Because the fiber of the specimen was destroyed and the air layer between cells was deformed due to load applied to the specimen, the changes in dynamic stiffness after the test are taken for granted. However, the difference between the results from this study and the study of Dikavicius and Miskinis [24] is regarded to be derived from the fact that the number of specimens was limited and the comparison was not made using the same type of specimen in both studies.

3.5. Sound absorption coefficient

The measurement results of the sound absorption coefficient on the specimens are as shown in Fig. 5. The sound absorption coefficient of the old specimen is shown to decrease slightly in the middle range frequency band (500 Hz – 2500 Hz) compared to that of the new specimen. The noise reduction coefficient of the old specimen appears as 0.52, and that of the new specimen was 0.62.

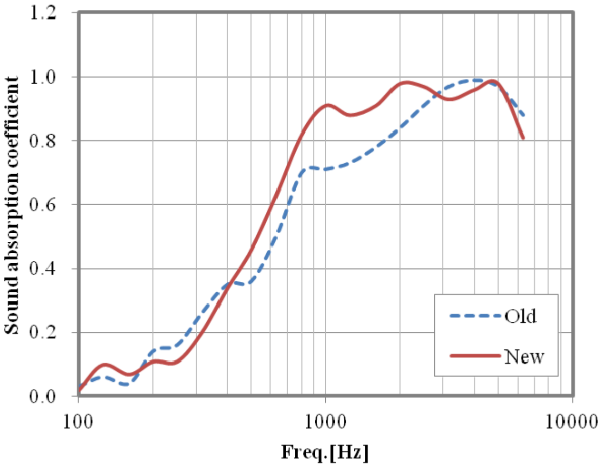

Fig. 5. Measurement results of sound absorption coefficient

The sound absorption coefficient of sound-absorbing materials depends on the thickness, density and air flow resistivity of a specimen, and the thickness and length of the fiber. In the case of the old specimen, changes in the thickness of the fiber, etc. are considered to be derived from the aging process; however, further investigation through various specimens is required to determine the exact causes of deterioration.

4. CONCLUSIONS

In this study, the changes in material properties were investigated though a comparison of the thermal and acoustical performances of glass wool that had been actually installed to the outer wall of a building and used over a long period of time as an insulation material, to a specimen of the same material that had been recently produced.

In this study, among the material properties, the thermal conductivity, sound absorption coefficient, compressibility, and dynamic stiffness that represent common properties of insulation materials were also measured.

1. The changes to the fiber structure and condition of the glass wool that was used on the outer wall of an older actual building were observed using scanning electron microscopy analysis. As shown in the results, the fibers of the old specimen wererelatively thin and had large spaces between the fibers compared to those of the new specimen. Therefore, the physical strength of the glass wool is expected to be rather low.

2. The heat flow method (HFM) was used for this study in order to measure thermal conductivity of the specimens. The thermal conductivities of both the old and new

specimens were measured at different temperatures expected to be reached at the outer wall of the building in practice after consideration of the climate of Korea. The measurement results showed that the measured thermal conductivities of both the old and the new specimens increased with the rise of temperature and showed quite similar results over temperature ranges of 0 ℃ – 20 ℃. Thermal conductivity of glass wool used as insulation material on the outer wall for a long time remains unchanged.

3. Differences in the acoustic properties between the old and new specimens apparently occurred. The sound absorption coefficient of the old specimen was shown to decrease slightly in the range of (500 Hz – 2500 Hz) compared to that of the new specimen. Also, the compressibility of the old specimen was larger than that of the new specimen. As shown in the results of the measurements, the dynamic stiffness of the old specimen appeared to be higher than that of the new specimen, and after the compressibility test, the measurements for dynamic stiffness in both the old and new specimens were found to have increased. Changes in temperature, moisture over a long period are believed to have effects on acoustic performance of glass wool. Exposure to external environments over a long period of time affect glass wool itself showing symptoms including shortness in length of fiber, decrease in formation of fibrous tissue, decrease in fiber flow resistance and deemed to have changed the results of acoustic assessment.

Further studies will be conducted to examine the factors affecting material properties of glass wool and the extend of effects including physical composition, external conditions affecting glass wool materials.

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