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# Influence of Loading Time of a Load Plate and Sample Size on the Measurement of Physical Properties of Resilient Materials

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This study investigates several factors that have not been specified in the standard for dynamic stiffness, compressibility, and long-term deformation; these factors can be used to evaluate the acoustic and physical performances of resilient materials. The study is intended to provide basic data for deriving the factors that need to be additionally reviewed through the standards. Since magnitude of dynamic stiffness changes with an increase in loading time, it is necessary to examine the setting of the loading time for a load plate under test conditions. Samples of size 300×300 mm, rather than 200×200 mm, yielded more reliable results for compressibility measurement. Since the test to infer long-term deformation of resilient materials after a period of 10 years in some samples showed variation characteristics different from those specified in the standards, it is recommended that the test method should be reviewed through ongoing research.

**Keywords:** resilient materials, dynamic stiffness, compressibility, long-term deformation.

## 1. Introduction

In Korea where apartment houses account for 60% or more of the types of residences problems related to floor impact sound are persistent in apartment houses A floating floor structure with resilient materials has been mostly applied in building floors of apartment houses. The main purpose of such structure is to reduce floor impact sound. In addition, thermal insulation of the floor structure must be ensured. Dynamic stiffness is one of the major properties of resilient isolators which influence the insulation performance of floor impact sound. As the dynamic stiffness decreases, lightweight floor impact sound is reduced to a greater extent (Cremer *et al.*, 1988). The dynamic stiffness of resilient materials used in the floors of apartment houses in Korea is limited to less than 40 MN/m$^3$. This is a minimum value defined by Korean domestic laws to ensure the floor impact sound insulation performance in apartment housings. Therefore, accurate measurement of dynamic stiffness became very important.

The most common resilient materials used in floating floors are expanded polystyrene (EPS) and ethylene vinyl acetate (EVA). Flat-type foamed floors are the most common type of floating floors. These resilient materials are installed on a concrete slab, and a mortar layer with lightweight aerated concrete, i.e. an Ondol layer, and a heating pipe are laid over the materials. Thus, the resilient materials are subjected to long-term loads by the Ondol layer installed on them, and this is likely to cause changes in the physical properties of these materials. The physical properties of resilient materials are defined by their dynamic stiffness, compressibility, long-term deformation, and damping.

Recently, products with low density and low dynamic stiffness (5 MN/m$^3$ or less) have been widely applied in order to further improve the insulation of floor impact sound and to ensure price competitiveness. Heavyweight impact sound as well as lightweight floor impact sound is found to be affected by the change in the dynamic stiffness of resilient materials (Kim *et al.*, 2009). Measurement results showed that the determining coefficient between dynamic stiffness and insulation performance of heavyweight impact sound is 0.74 (Kim *et al.*, 2009). Baron *et al.* emphasized the importance of deriving accurate values by examining the effects of the pulse excitation measurement mechanism (Baron *et al.*, 2004).

Accurate determination of the changes in the dynamic stiffness of resilient materials is important to predict any reduction in floor impact sound. In the previous study (Kim *et al.*, 2008) the dynamic stiffness was found to change as the load plate loading time increased. Other research also reported that the sample thickness was reduced on application of static load at the time of measurement, which increased the density and airflow resistivity; this implies that dynamic stiffness can be affected by a variety of factors (Schiavi *et al.*, 2011). However, no information or description about the loading time for the load plate is available in ISO 9052-1 from the viewpoint of the measurement of dynamic stiffness (ISO 9052-1, 1989). The ISO standard includes formula for dynamic stiffness, which is expressed in terms of the magnitude of airflow resistivity of materials.

The magnitude of compressibility indicates the decrease in the thickness of the resilient material after load was applied; compressibility is measured by determining the change in the thickness of resilient materials before and after loading according to ISO 29770(TC 163/SC1). The size of the specimens was 200×200 mm, as specified in ISO 29770 which does not have any specification for the thickness. Thick resilient isolators have high compressibility, and specimens with high compressibility would affect the upper layers such as the Ondol layer. Therefore, it is necessary to consider the thickness of specimen when measuring compressibility. In addition, various types of resilient materials with different shapes and sizes are available. In particular, several resilient materials are used to form uneven floors in order to prevent the transmission of impact sounds. Therefore, it is also important to examine whether a variety of sample types are suitable for ISO standards.

As a test method for determining the degree of dimensional changes, when specimens of resilient materials are subjected to long-term loading for a period of 10 years, long-term deformation was measured in accordance with ISO 20392. However, in Korea, test method to determine long-term deformation of resilient materials has not been developed as yet. In order to establish such a test method, the domestic applicability of the ISO 20392 standard should be considered.

In this study, the influences of the loading time of a load plate and sample size on compressibility of resilient materials were investigated. A total of seven resilient materials of different shapes were selected, and measurements were conducted for 560 days to examine the long-term deformations of resilient materials.

## 2. Test methods

### *2.1. Dynamic stiffness*

The dynamic stiffness of resilient materials is one of the evaluation items related to floor impact sound insulation performance. As dynamic stiffness decreases, lightweight floor impact sound is reduced to a greater extent. For a known value of dynamic stiffness, the degree of reduction in lightweight impact sound can be estimated (Cremer *et al.*, 1988).

The dynamic stiffness measuring method (KS F 2868, 2003) currently used in Korea was established in 2003 on the basis of Japanese Industrial Standard (JIS A 6321, 2000) and ISO 9052-1 (ISO 9052-1, 1989). Other research reviewed the appropriateness of measurement methods for resilient materials used in Korea (Kim *et al.*, 2005). Dynamic stiffness (s') is defined as the ratio of dynamic displacement to dynamic load, and can be expressed in Eq. (1) as follows:

$$s' = \frac{F/S}{\Delta d}\left(\frac{\mathrm{N/m^2}}{\mathrm{m}} = \frac{\mathrm{N}}{\mathrm{m^2 m}} = \mathrm{N/m^3}\right), \tag{1}$$

where $S$ is the area ($\mathrm{m}^2$) of the specimen; $F$ is the dynamic load (N) vertically applied to the specimen; and $\Delta d$ is the dynamic variation (m) in the thickness of specimen.

$$S'_t = (2\pi f_0)^2 \cdot m, \tag{2}$$

where $S'_t$ is the apparent dynamic stiffness per unit area [$\mathrm{MN/m^3}$]; $f_0$ is the resonant frequency [Hz]; and $m$ is the mass of the load plate per unit area [$\mathrm{kg/m^2}$].

Further, when dynamic stiffness is known, the degree of reduction in lightweight impact sound can be estimated using the equations (Eqs. (3), (4)) (Cremer *et al.*, 1988).

Lee *et al.* published a study that suggests that as the dynamic stiffness of resilient materials decreases, lightweight impact sound reduction level increases (Lee *et al.*, 2003).

However, the constraints in Eqs. (3) and (4) are as follows:

$$\Delta L = 30 \log \frac{f}{f_{\mathrm{res}}}, \tag{3}$$

$$f_{\mathrm{res}} = \frac{1}{2\pi}\sqrt{\frac{s'}{m}}. \tag{4}$$

In the case of resilient materials of floating floor structures, a load applied on the upper surface can lead to the destruction of fibrous tissue, reduction in thickness, and a gradual increase in dynamic stiffness, which, in turn, causes a change in the resonant frequency, thus causing variations in the estimates of impact sound insulation performance (Schiavi *et al.*, 2005). Schiavi *et al.* proposed a formula for the dynamic stiffness by taking into account the thickness deformation as the deformation of materials affects dynamic stiffness (Schiavi *et al.*, 2010).

Figure 1 is a schematic representation of the pulse excitation measurement mechanism for the determination of dynamic stiffness.

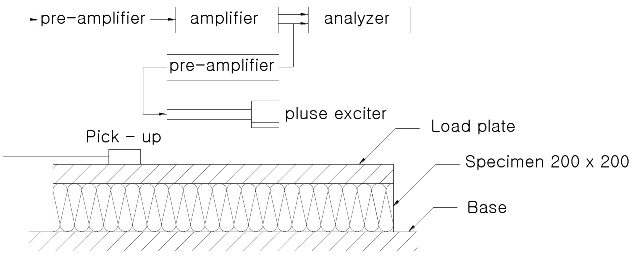


Fig. 1. Pulse excitation measurement configuration for measuring dynamic stiffness.

### 2.2. Compressibility

The measurement method for compressibility is defined in DIN EN 12431 of Germany (DIN EN 12431, 2007) and DIN standard has been introduced in ISO 29770 (ISO 29770, 2008). In Europe, the compressibility of resilient materials has been reviewed actively, and measurement results are specified in the product catalog. The details of the DIN test method are as follows.

- Specimen: 200 ± 1 mm, 10ea, store at 23 ± 5°C for 6 h and test.
- The test process
  - Apply a pressure of 250 Pa (1 kg), and measure thickness ($d_L$) after 2 min.
  - Apply a pressure of 2 kPa (8 kg), and measure thickness ($d_F$) after 2 min.
  - Apply additional pressure of 48 kPa (192 kg) for 2 min.
  - Measure height ($d_B$) in 2 or 5 min after the removal of additional pressure.

In the DIN standard from Germany, the difference between the thickness before and after applying the load ($d_L$–$d_B$) after a constant load has been applied to the resilient materials is represented as compressibility (c).

ISO accepted DIN EN12431 standard and established ISO 29770 in 2008. ISO 29770 specifies that the thickness should be measured after applying pressures of 250 Pa, 2 kPa, and 48 kPa in the same manner as in DIN standard.

### 2.3. Long-term deformation

ISO 20392, as any international standard to measure the thickness deformation due to application of load to resilient materials, describes a method for measuring the thickness deformation over a period of time under a certain load and conditions of temperature and humidity (ISO 20392, 2007). It also specifies that the thickness of specimens should be measured for 90 days or more under a certain load, and from the measured results, the thickness after 10 years can be predicted.

The size of specimens is to be selected from among 50×50 mm, 100 mm, 150 mm, 200 mm, or 300 mm, and any load can be applied to specimens; 200 kg/m$^2$ is the typically applied load. The thickness deformation under load is measured at 0.1 h, 1 h, 5 h, 1 day, 2 days, 4 days, 7 days, 9 days, 11 days, 14 days, 18 days, 24 days, 32 days, 42 days, 53 days, 65 days, 80 days, and 90–100 days of loading.

The thickness measured for more than 90 days in an interval of log scale can be used to estimate the thickness after 10 years through a linear regression equation. Long-term deformation is calculated based on the Eq. (5) by Findley (1994), and the thickness deformation after 10 years is as indicated by Eq. (6).

The number 87,600 in Eq. (6) denotes the value converted into the time unit of 10 years.

$$X_t = X_0 + mt^b \text{ (mm)}, \tag{5}$$

$$X_{10 \text{ years}} = X_0 + m87600^b \text{ (mm)}, \tag{6}$$

$$m = 10^a, \qquad a = y_m - bx_m,$$

$$b = \frac{\sum x_t y_t - \frac{\sum x_t \sum y_t}{n}}{\sum x_t^2 - \frac{(\sum x_t)^2}{n}}$$

where $X_t$ is deformation at time $t$, $X_0$ is initial deformation (60 s after loading), and $x_m$ is mean value of $x_t$

$$\left(x_m = \sum x_t/n\right)$$

$$y_m : \text{mean value of } y_t$$

$$\left(y_t = \sum y_t/n\right)$$

$$x_t : \text{ time, } \log \mathrm{t}$$

$$y_t : \text{ deformation, } \log X_{ct}$$

$$X_{ct} = X_t - X_0.$$

Other research has reported the amount of deformation after 10 years using the simple equation (Eq. (7)) inferred from the measurement results of compressibility (Schiavi *et al.*, 2007). In addition, they proposed a new equation to estimate dynamic stiffness based on the change in compressibility.

$$X_{10 \text{ years}} \approx d_L - d_B \text{ (mm)}. \tag{7}$$

## 3. Materials

The resilient materials used in this study were expanded polystyrene (EPS), ethylene vinyl acetate (EVA), expanded polyethylene (PE), and expanded polypropylene (EPP). For EPS and EVA, products from different manufacturers were selected for the test. The dynamic stiffness, compressibility, and long-term deformation of the selected resilient materials were measured, and the measured specimens are shown in

Table 1. Test specimens.

| Specimen | PE | EVA-1 | EVA-2 | EVA-3 | EPP | EPS-1 | EPS-2 |
|---|---|---|---|---|---|---|---|
| Lower part shape | flat | uneven | uneven | uneven | flat | uneven | flat |
| Thickness [mm] | 21 | 20 | 30 | 30 | 21 | 25 | 20 |
| Upper side |  |  |  |  |  |  |  |
| Bottom side |  |  |  |  |  |  |  |

Table 1. Different specimens were selected for measuring each of the three items in the test.

Since dynamic stiffness changes with the loading time of a load plate, a loading time of 48 h has been suggested by the results of existing studies (Kim *et al.*, 2008).

In this study, for a loading time of 120 days which is longer than the 45 days suggested in existing studies, the dynamic stiffness was measured and the degree of change was investigated over a longer time of application of a load plate than in previous studies.

Figures 2 and 3 show the measurement settings.

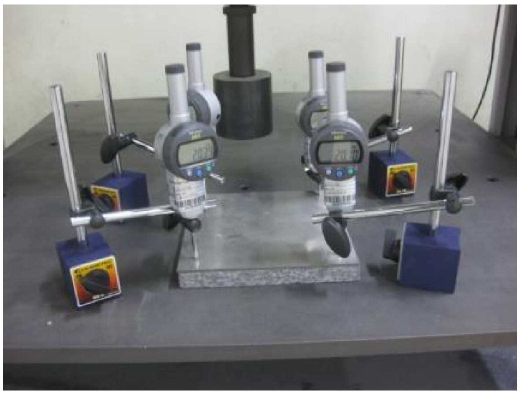

Fig. 2. A view of the test setup for compressibility measurement.

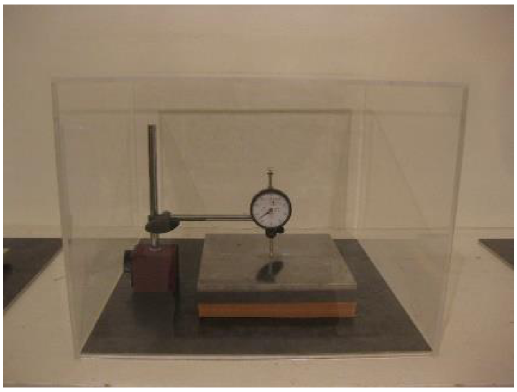

Fig. 3. A view of the test setup for the measurement of long-term deformation.

For compressibility, specimens of sizes 200×200 mm and 300×300 mm, as specified in the ISO standard (ISO 29770, 2008), were used to examine the changes in size. Because the bottom surface of resilient materials is uneven, the evaluation was made under the assumption that the size of specimens is expected to affect load stability. In addition, for a large number of specimens, the correlation between compressibility and dynamic stiffness was examined, assuming that as the dynamic stiffness decreases, the impact sound reduces to a greater extent though the load stability is expected to be degraded.

Under a load plate of 8 kg weight (200 $\mathrm{kg/m^2}$) of the same size as the specimen (200×200 mm) to act as the load of an Ondol layer, the thickness was measured at one point in the center at 1-day intervals using a dial gauge (ID-C1050XB). The ISO 20392 specifies that the long-term deformation after 10 years is estimated by measuring any deformations for 90 days or more. In this study, deformation for 560 days was measured, and the measurement results are compared with the results of ISO standard. The measuring equipment used is described in Table 2.

Table 2. Test equipment.

| Equipment | Model and Maker |
|---|---|
| Frequency analyzer | SA-01, RION |
| Microphone | G.R.A.S. (Type 40AE) |
| Microphone Pre-amplifier | G.R.A.S. (Type 26CA) |
| Impact hammer | 086C02, PCB |
| Accelerometer | PV-41, RION |
| Compressive loader | DS-120, Daekyoung-Tech. |
| Dial gauge | ID-C1050XB |

## 4. Results and discussion

### *4.1. Dynamic stiffness*

Figure 4 and Table 3 shows the measurement results for changes in the characteristics of dynamic stiff-

Table 3. Correlation equation [between duration of loading (days) and dynamic stiffness].

| Specimen | Correlation equation | Determination coefficient $r^2$ | Correlation coefficient $r$ |
|---|---|---|---|
| EPS-1 | $y = 0.0969\ln(x) + 4.7653$ | 0.52 | 0.82* |
| EPS-2 | $y = 0.7503\ln(x) + 14.544$ | 0.60 | 0.77* |
| EVA-2 | $y = 0.3905\ln(x) + 5.2841$ | 0.58 | 0.65* |
| EVA-3 | $y = 1.2222\ln(x) + 5.3934$ | 0.77 | 0.78* |

* $P < 0.001$

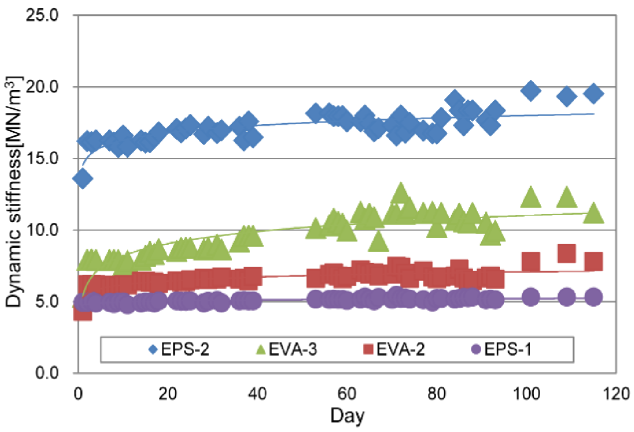


Fig. 4. Measurement results of the dynamic stiffness.

ness after 120 days with an increase in the loading time of the load plate. Except for EPS-1, dynamic stiffness was found to increase from the initial value over the time. A change in dynamic stiffness due to an increase in loading time showed the same tendency as the results of a previous study (Kim *et al.*, 2008).

In the case of EPS-1 specimen, after 120 days, the dynamic stiffness increased to 5.3 MN/m$^3$, an increase of 7% from its initial value of 5.0 MN/m$^3$. In the case of EPS-2, after 120 days, the value changed to 19.6 MN/m$^3$ from its initial measurement value of 13.6 MN/m$^3$. The measurement value for EVA-2 increased to 7.8 MN/m$^3$, an increase of approximately 80% from its initial measuring value of 4.3 MN/m$^3$. In the case of EVA-3, which showed the most significant change, the dynamic stiffness increased by more than 2 times to 11.2 MN/m$^3$ from 5.3 MN/m$^3$. From the correlations between the loading time of the load plate and dynamic stiffness, determination coefficients appear to be in the range 0.58–0.77, showing close correlation between them. Correlation coefficients were distributed between 0.65 and 0.82. The analysis results of correlation between the dynamic stiffness of the material and the elapsed time were 0.82, 0.77, 0.65, and 0.78 for EPS-1, EPS-2, EVA-2, and EVA-3, respectively. The results were considered significant for $p$ values less than 0.001.

The continuous loading attributed to the load plates installed on the samples may cause deformation of the shape of cells within the specimen and of the air layers within the cells. The deformation is expected to be manifested as dynamic stiffness.

Since the increase in dynamic stiffness over a long period of time is clearly observed with ISO Standard (ISO 9052-1, 1989), which does not specify the loading time of load plates, it is difficult to determine the degree of long-term changes in dynamic stiffness. However, the loading time of a load plate needs to be specified, and hence, ongoing research on various materials is needed because some products, depending on the type of material used, are not affected by changes over time.

### *4.2. Compressibility*

For compressibility, ISO standard (ISO 29770, 2008) specifies that the size of the specimen to be measured should be 200×200 mm. Nevertheless, specimens of various shapes are used; in particular, products whose bottom surfaces have a corrugated profile are also in use. Given that the test was designed to assess the stability against a downward perpendicular loading, and under the assumption that the number and surface area of the corrugations on the bottom surface would influence the measurement results, specimens with larger surface areas of 300×300 mm were used to examine the changes.

The measured results of changes in the size of a specimen, as shown in Fig. 5, indicate that compressibility showed a tendency to decrease as specimen size

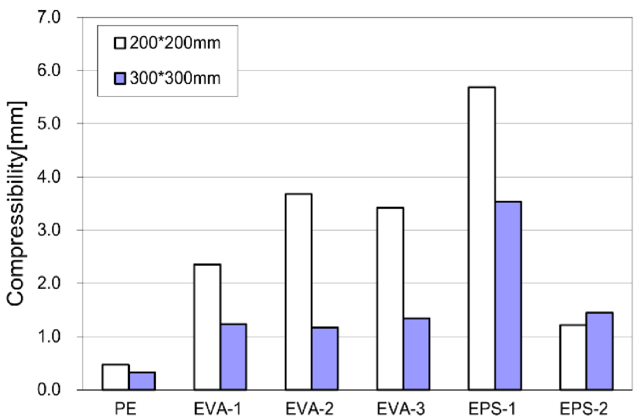


Fig. 5. Changes in the specimen size and compressibility.

increases. Particularly, in EVA-1, EVA-2, EVA-3, and EPS-1 specimens with uneven lower surfaces, there was a greater decrease in compressibility than in the other specimens.

Because the loading on the upper surface is supported by the unevenness in the lower surface, the increase in the number of corrugations with the increase in specimen size is considered to cause an increase in the structural stability. In EVA-2 and EVA-1, semi-circular shape corrugations of height 10–15 mm with spacing of 40–60 mm were present, while corrugations in a grid pattern were present in the case of EVA-3. In EPS-1, longitudinal grooves were formed.

Table 4 presents standard deviations of the compressibility, which was measured five times for each specimen. The table shows that the measured results for each specimen were stable, showing a decrease in standard deviation, as the specimen size increased. Therefore, in order to measure the compressibility of specimens with unevenness, it is necessary to provide criteria for the specimen size.

Table 4. Standard deviations for different specimen sizes.

| Specimen size | EVA-1 | EVA-2 | EPS-1 |
|---|---|---|---|
| (200×200 mm) | 0.44 | 0.31 | 0.19 |
| (300×300 mm) | 0.13 | 0.10 | 0.10 |

By acting as a pillar installed in the lower slab, the unevenness at the bottom surface of resilient materials serves as a support for the upper load. Because an increase in load-bearing area and the unevenness (pillar) also increase the stability against the load of the material itself under conditions in which a constant load per unit area is applied, the sample size and the number of corrugations are important factors related to compressibility.

Figure 6 shows the correlation between dynamic stiffness and compressibility. The dynamic stiffness of 41 specimens was measured after the compressibility test.

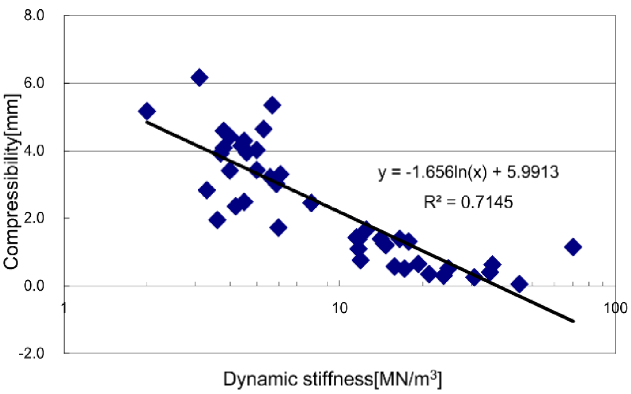


Fig. 6. Correlation between dynamic stiffness and compressibility.

The correlation equation and determination coefficients were calculated based on the measured results. Inverse correlation of a logarithmic function showed that the determination coefficient was 0.71, indicating close correlation between the compressibility and dynamic stiffness, and the compressibility tended to increase with decreasing dynamic stiffness. However, in the specimens with a dynamic stiffness of 10 $MN/m^3$ or less, the difference in compressibility appeared to be large. Dynamic stiffness represents the rate of change of thickness of samples when a constant load is applied to a unit area ($m^2$) of the samples. Even the same dynamic stiffness is considered to generate a deviation in compressibility through differences in the physical properties of materials, manufacturing processes, and composition of internal tissue of the material; in particular, such a phenomenon was found to have frequently occurred for a low range of dynamic stiffness as in the experimental results of the present study.

Materials such as EVA and PE play an important role in providing a force on the opposite side when an air layer trapped in it is deformed, thus resisting the deformation due to the loading (Kilhenny, 2008). Differences in these physical properties of materials are found to cause deviation in compressibility. Bettarello *et al.* showed in his study that in the case of materials with many pores, such as fibers, a high load applied for measuring compressibility can destroy the fibrous tissue, causing an increase in compressibility (Bettarello *et al.*, 2010). The degree of compressibility is somewhat different even for the same dynamic stiffness.

### *4.3. Long-term deformation*

In Fig. 7 the thickness deformation of a specimen with a load plate installed is expressed via a time series.

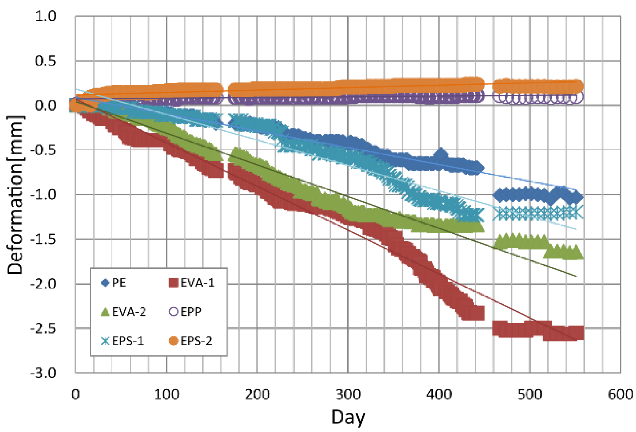


Fig. 7. Deformation (the specimen and load plate).

EPP and EPS-2 represent the initial measurement errors. Therein, deformation was observed to exceed 0. However, the change in thickness was reduced to al-

Table 5. Correlation equation (load plate).

| Specimen | Correlation equation | Determination coefficient $r^2$ | Correlation coefficient $r$ |
|---|---|---|---|
| PE | $y = -0.0019x + 0.0917$ | 0.96 | $-0.98^*$ |
| EVA-1 | $y = -0.0049x + 0.0709$ | 0.97 | $-0.99^*$ |
| EVA-2 | $y = -0.0036x + 0.045$ | 0.96 | $-0.98^*$ |
| EPP | $y = 0.00008x + 0.073$ | 0.38 | $0.62^*$ |
| EPS-1 | $y = -0.0029x + 0.1852$ | 0.93 | $-0.97^*$ |
| EPS-2 | $y = 0.0003x + 0.1186$ | 0.72 | $0.85^*$ |

$^*$ $P < 0.001$

most zero over time. In the remaining specimens, the deformation increased with increasing time. It was also shown that larger deformation occurred in specimens with uneven bottom surfaces, compared to deformation in the specimens with a flat panel, and the most significant deformation, about 13%, occurred in EVA-1 during the measuring period. In most specimens, the thickness continued to decrease with some deviation as the measuring time elapsed.

ISO 20392 presents an equation to calculate long-term changes for a period of more than 10 years in the thickness of specimens by considering the thickness change of resilient materials, only using the measurement results for 90 days. According to the standard, although a regression equation is formulated based on the measurement results for 90 days, its high determination coefficients can help determine the change in thickness after a long period of time. A determination coefficient of $> 0.9$ in the regression equation is presented as an example of ISO standard.

The change in thickness after 10 years was calculated using linear regression equations defined in Table 5 based on the results for 560 days or more. The results for changes in thickness in this study in the time intervals at which the thickness was measured differ from the results of ISO standard. The thickness in the present study was measured almost daily whereas in ISO standard the thickness was measured at logarithmic intervals. The results of deformation after 10 years using the regression equations of the present study were derived from the measured results and compared with the results from the method defined in ISO standard. Further, the change in thickness was estimated by applying the results of this study, measured at the time intervals specified in ISO standard.

Table 6 shows the deformation after 10 years of loading specimens with a load plate. The values inferred from the measured results as shown in Fig. 7 and the calculated values of ISO standard are shown in Fig. 8. In the figure the difference between the specimens is evident, and in particular, a significant difference is seen in the case of EVA-2. For most specimens, the measured values were lower than the values calculated by ISO standard. For EPP and EPS-2, there

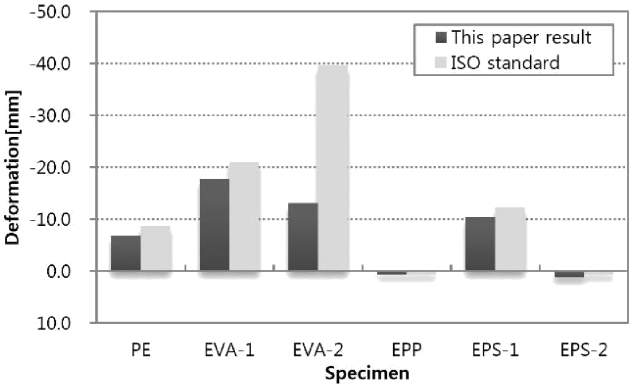


Fig. 8. Comparison of 10-year deformation predicted in this study and ISO standard results.

was almost no deformation during the measurement period, even in the predicted values after 10 years. Errors in Table 6, expressed in percentage, represent the difference between the measurement results of this study and the values of ISO standard. Except for EPP and EPS-2, in which almost no deformation occurred, the specimens had errors between 15% and 67%.

Table 6. Errors in 10-year deformation between the results of this study and ISO standard results.

| Specimen | 10 years deformation [mm] | | Error [%] |
|---|---|---|---|
| | This result | ISO standard | |
| PE | −6.8 | −8.7 | 21.6 |
| EVA-1 | −17.8 | −21.0 | 15.3 |
| EVA-2 | −13.1 | −39.7 | 67.0 |
| EPP | 0.4 | 0.2 | −52.1 |
| EPS-1 | −10.4 | −12.2 | 15.0 |
| EPS-2 | 1.2 | 0.5 | −129.0 |

ISO standard suggests an equation such as Eq. (6) based on the results converted to a log. Hence, the predicted values of long-term deformation differ from these results, which were calculated by using linear regression equations.

As shown in Fig. 7, for the result of thickness deformation as measured for 560 days or more, the determination coefficients were higher in the case of linear regressions rather than in the equations calculated on the basis of log values. This is due to the difference from the predicted equation of ISO standard. Table 7 shows the determination coefficients of the specimens, calculated using linear and log equations. Except for EPP and EPS-2, in which almost no deformation occurred, the determination coefficients were higher for linear regression equations rather than for log equations.

Table 7. Determination coefficient.

| Specimen | Determination coefficient $r^2$ | |
|---|---|---|
| | linear | log |
| PE | 0.9679 | 0.6490 |
| EVA-1 | 0.9741 | 0.6978 |
| EVA-2 | 0.9691 | 0.7756 |
| EPP | 0.3869 | 0.6319 |
| EPS-1 | 0.9361 | 0.5947 |
| EPS-2 | 0.7279 | 0.9340 |

However, since sample thickness has not changed continuously over time and is not physically compressed anymore after it reaches a certain level, characteristics with a linear change in thickness, as seen in these results, are not likely to be observed. A significant change in the thickness of samples to be measured is observed over a long period of time, and the measurement period of about 560 days may not be enough to fully understand the extent of change. It is necessary to derive an equation to predict the long-term deformation by determining the extent of continuous change.

## 5. Conclusions

The present study investigated the physical properties of resilient materials, including dynamic stiffness, compressibility, and long-term deformation of several specimens.

Dynamic stiffness changed as the loading time of the load plate elapsed. Compressibility is the test method to determine the change in thickness of specimens under a certain load. Since a load is applied to the specimens, the size of the specimens is considered as an important affecting factor. The size of specimens for evaluating the compressibility of products seems to be more reasonable in specimens of size 300×300 mm than in those of size 200×200 mm. The long-term measured results of thickness deformation in the resilient materials appeared to decrease over time. However, since sample thickness did not change continuously over time and is not physically compressed anymore when it reaches a certain level, the characteristics with a linear change in thickness, as seen in the results of this study, are not likely to be seen. It is necessary to derive an equation to predict long-term deformation by determining the extent of continuous change.

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## References

1. Baron N., Bonfiglio P., Fausti P. (2004), *Dynamic stiffness of materials used for reduction in impact noise: comparison between different in measurement techniques*, Acoustica, paper ID: 066/1-8.
2. Bettarello F., Caniato M., Di Monte R., Kaspar J., Sbaizero O. (2010), *Preliminary acoustic tests on resilients materials: comparison between common layers and nanostructured layers*, Proceedings of 20th International Congress on Acoustics.
3. Cremer L., Heckel M., Ungar E.E. (1988), *Structure-Borne Sound*, 2nd, Ed, Sprinter-Verlag, Berlin.
4. DIN EN 12431 (2007), *Thermal insulating products for building applications – Determination of thickness for floating floor insulating products.*
5. Findley W.N. (1994), *Creep Characteristics of Plastics*, Symposium on Plastics, American Society of Testing and Materials.
6. ISO 9052-1 (1989), *Acoustics-determination of dynamic stiffness – Part 1: materials used under floating floors in dwellings.*
7. ISO 20392 (2007), *Thermal-insulation materials – Determination of compressive creep.*
8. ISO 29770 (2008), *Thermal insulating products for building applications – Determination of thickness for floating-floor insulating products.*
9. Japanese Industrial Standard (2000), *JIS A 6321 Rock wool isolating material for floating floors.*
10. Kilhenny B. (2008), *Open and closed case. The difference between various mounting tapes*, FLEXO, Technologies & Techniques.
11. Kim K.W., Choi H.J., Yang K.S., Sohn J.Y. (2008), *A Study on the Change in Dynamic Stiffness of Resilient Materials according to the Load Duration*, Proceedings of The First International Conference on Building Energy and Environment.
12. Kim K.W., Jeong G.C., Yang K.S., Sohn J.Y. (2009), *Correlation between dynamic stiffness of re-*

*silient materials and heavyweight impact sound reduction level*, Building and Environment, **44**, 1589–1600.

13. Kim H.G., Kim M.J., Kim B.K. (2005), *Study on measurement the dynamic stiffness of materials used under floating floors in dwellings*, Journal of the Architecture Institute of Korea, Planning & Design, **21**, 1, 229–234.

14. Korean Standard, (2003), *KS F 2868 Determination of dynamic stiffness of materials used under floating floors in dwellings.*

15. Lee J.W., Jeong G.C., Kwon Y.P. (2003), *Correlation between dynamic characteristics of isolation material and impact sound reduction of lightweight impact source*, Proceedings of the KSNVE Annual Spring Conference, 191–195.

16. Schiavi A., Guglielmone C., Miglietta P. (2011), *Effect and importance of static-load on airflow resistivity determination and its consequences on dynamic stiffness*, Applied Acoustics, **72**, 705–710.

17. Schiavi A., Pavoni Belli A., Corallo M., Russo F. (2007), *Acoustical performance characterization of resilient materials used under floating floors in dwellings*, ActaAcustica United with Acustica, **93**, 477–485.

18. Schiavi A., Pavoni Belli A., Russo F. (2005), *Estimation of acoustical performance of floating floors from dynamic stiffness of resilient layers*, Building Acoustics, **12**, 2, 99–113.

19. Schiavi A., Pavoni Belli A., Russo F., Corallo M. (2010), *Dynamic stiffness of resilient materials: some consideration on the proposed revision of ISO 9052-1 standard*, Proceedings of 20th International Congress on Acoustics.