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Development of Floor Structures with Crumb Rubber for Efficient Floor Impact Noise Reduction

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Abstract

Korea has a high population density, considering the size of its territory. Therefore, the importance of convenient and comfortable apartment buildings and high-rise residential–commercial complex buildings has been rising. In addition, because of the improvement in the standard of living along with continuous national economic growth, the interest in well-being and the expectation of a quiet life with a comfortable and pleasant residential environment have also been increasing. However, Koreans have a lifestyle involving sitting on the floor, so floor impact noise has been occurring more and more frequently. Because of this, neighborly disputes have been a serious social problem. And lately, damage and disputes from noise between floors have been increasing much more. The present work, therefore, used waste tire chips as a resilient material for reducing floor impact noise in order to recycle waste tires effectively. Also, a compounded resilient material, which combines EPS (expanded polystyrene), a flat resilient material on the upper part, with waste tire chips for the lower part, was developed. After constructing waste tire chips at a standardized test building, experiments with both light-weight and heavy-weight floor impact noise were performed. The tests confirmed that waste tire chips, when used as a resilient material, can effectively reduce both light-weight and heavy-weight floor impact noise.

Keywords: floor impact noise; crumb rubber; floor structures; light-weight and heavy-weight impact noises

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1. Introduction

With the continuous improvement in living standards and national economic growth, the interest in the well-being of residents has been increasing. Accordingly, the interest of residents in quiet living in a comfortable and pleasant residential environment has also been increasing. Especially due to the increased weight on the apartment floor and the living habits of sitting, the frequency of floor impact noise is so high that damage and conflict often occur. On account of this, in domestic housing, studies and developments are continuously in progress to improve sound insulation between floors. As a result, the current major sound insulation type for floor impact noise used in domestic housing only increases the thickness of structural concrete slabs or uses resilient materials of light quality, such as EPS and EVA [1]. However, this kind of structure is problematic in that it increases not only floor thickness but also the total construction cost [2].

A measuring method for the dynamic stiffness of resilient material for floor impact noise was established; interest in the performance of resilient material has been heightened, and its performance has been recognized as an important element in reducing floor impact noise. According to the study results by Lee, J.W., in the case of light impact noise, as dynamic stiffness increased, the reduction amount was reduced on a large scale, and at a constant level; it was reduced by an exponential function ratio without any change, but the change was maintained. It was shown that within a range of dynamic stiffness of 20~80 MN/m^3, there was a change of about 5~6 dB [3]. In a study by Kim, K.W., the relationship between dynamic stiffness and the reduction in heavy impact noise for resilient material for floor impact noise was identified, and the coefficient of determination was shown to be higher in most frequencies. Therefore, it was shown that if a resilient material with a dynamic stiffness of 8 MN/m^3 and below is used to reduce heavy impact noise, it might prevent resonance, which occurs at 63 Hz. In addition, the dynamic stiffness of resilient material decreased when materials of different quality were layered, and the reduction in light impact noise increased [4]. Also, according to the study by Ryu, J.K., in the case of resilient material in the EPS series, it was shown that the products that contain embossing at the bottom improved the performance for heavy impact noise, which was not due to a simple increase in thickness. In the case of the resilient material in the EVA series, it was found that by using the composite configuration of an EP net and noise-absorbing material, the reduction performance for heavy impact noise improved [5]. The study by Kim, J.H., investigated the effect of resilient materials on heavy-weight impact noise in wall-structured apartment buildings. According to the research results, it was found that, generally, as dynamic stiffness increases, the sound pressure level also increases at frequencies above 80 Hz. The responses at 50 Hz, 60 Hz, and 80 Hz showed amplification due to the resonance phenomenon of the resilient materials, and the frequency at which this amplification occurs varied depending on the type of resilient material [6]. Lee undertook floor impact noise tests using 19 different resilient materials, including EVA, PET, PP, and PS sheets. The results showed that a maximum reduction of 5 dB in heavy-weight floor impact noise could be achieved compared to a bare concrete slab [7]. Similarly, Kim measured the dynamic stiffness of nine specimens comprising EVA, EPS, PE, crumb rubber, and glass fiber materials. He found that dynamic stiffness decreases with an increasing thickness of the composite materials, regardless of the type of resilient material used [4]. Another similar experiment used 20 mm of EVA resilient material with a concrete slab of 180 mm thickness, resulting in a 2 dB reduction in heavy-weight floor impact noise [8]. Based on the above results, it can be predicted that the composite configuration of materials with different properties will reduce dynamic stiffness and result in the improvement of noise reduction performance for the light and heavy-weight impact noises.

Therefore, much research has discussed the composition of various elastic materials. With respect to the thickness and composition of the buffer material, the thicker the buffer layer, the lower the dynamic stiffness, thereby reducing weight impact noise [9]. As a result of investigating the difference in the reduction performance of the floor impact noise through shape transformation for the EVA single material, it was confirmed that there is an effective shape difference according to the frequency characteristics of the impact noise [10]. Furthermore, studies have shown that the floor impact noise reduction performance can be improved by adjusting the composition ratio of the buffer material, even when using the same material [11,12].

The annual global production of waste tires is estimated to be around 1 billion units (approximately 17 million tons) [13], and this figure is expected to continue to increase due to global population growth and the rising number of automobiles in emerging countries. Moreover, waste tires have emerged as a significant environmental concern due

to their large volume, resistance to natural decomposition, and associated risks of fire and contamination. Landfilling such waste materials exacerbates environmental burdens, while incineration can release hazardous substances. Consequently, recycling waste tires as construction materials has gained attention as a sustainable solution to reduce landfill pressure, mitigate pollution risks, and lower carbon emissions.

Accordingly, recycling waste tires by shredding them into tire chips offers advantages such as reducing environmental burden and lowering overall construction costs due to the low material cost. Due to their cost-effectiveness and environmental friendliness, waste tire chips are used in various additional materials. Research results have been published that demonstrated applicable usability by mixing waste tire chips with wood [14]. Based on the evaluation method proposed by the Japanese Architectural Association, research has shown that waste tire chips can effectively insulate light-weight impact noise [15]. Crumb rubber is also a prospective material with high sound insulation performance for the floor impact noise due to its high elasticity and a gap between particles. In addition, crumb rubber in its crushed form is convenient to apply as a layered structure and can be applied in various fields. In a study by Navid Chalangaran, waste tire chips were added to concrete to create samples, and the sound insulation was measured using an impedance tube as part of efforts to recycle waste tires. It is concluded that substituting sand aggregates with rubber crumb specimens containing 15% fine-grained crumbs or 15% coarse-grained crumbs could improve the STL by up to 190% and 228%, respectively, while the implementation of 5% and 10% rubber crumb material showed beneficial effects in reducing low-frequency noises [16]. In the study by Anu Bala, thermal resistivity and sound absorption performance were measured for rubberized concrete (RC), which incorporated waste tire chips. Increasing rubber content increases the porosity of the concrete mix, thereby increasing thermal resistivity and sound absorption [17]. In addition, several studies have confirmed that incorporating crumb rubber increases the porosity of concrete, which enhances both thermal resistance and sound absorption performance, particularly in the mid- and high-frequency ranges. Noise reduction coefficients (NRCs) up to 0.56 and thermal conductivity values as low as 0.035 W/mK have been reported, highlighting the effectiveness of rubber modification in improving both acoustic and thermal performance [18–21]. However, when crumb rubber is mixed with concrete, the compressive strength is lowered, so these structural limitations should be addressed [22].

Therefore, in this study, crumb rubber was applied as a resilient material to control impact noise in the current floor structure system. Also, based on the dynamic characteristics resulting from the change in the composition of resilient material for the floor impact noise, this study aims to propose a method that can satisfy the required sound insulation performance.

2. Floor Structure with Crumb Rubber as Resilient Material

2.1. Crumb Rubber as Resilient Material

2.1.1. Residual Deformation Measurement

Resilient materials are elastic materials installed beneath the finishing layer used in Korean-style floor heating systems (ondol). These materials play a dual role by not only reducing floor impact noise but also contributing to the thermal insulation performance of the floor structure. However, soft resilient materials have low dynamic stiffness, which may cause cracks in the upper mortar layer or the heated floor structure. Therefore, an evaluation of residual deformation is required to ensure the long-term structural stability of the floor system.

In KS F 2873 (measuring method of compressibility of resilient materials for floor impact noise), the compressibility of resilient materials is assessed through the measurement

of residual deformation, which refers to the permanent reduction in thickness after a series of compressive loads [23].

The test is conducted using a Universal Testing Machine (UTM, CHUN KWANG PREC.INS.IND, Seoul, Republic of Korea), and a specimen of 300 mm × 300 mm is placed between a loading plate and a support plate. The specimen is sequentially subjected to loads of 250 ± 5 Pa, 2000 ± 20 Pa, and 50,000 ± 500 Pa. After a specified period of time, the thickness of the specimen is measured again to calculate the residual deformation.

The time-dependent load application procedure is shown in Figure 1.

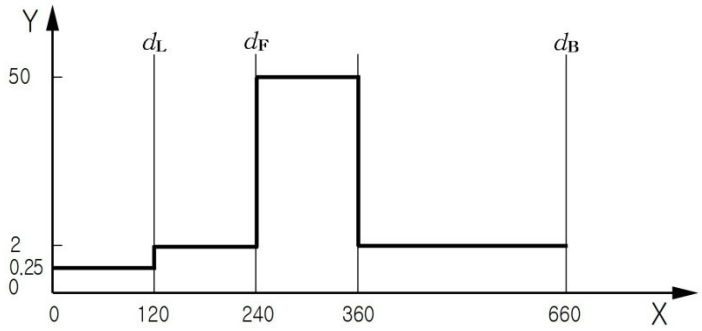
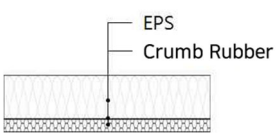
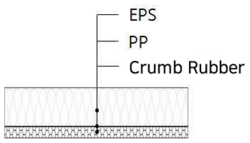


Figure 1. Time-dependent load variation.

This study aimed to develop a composite resilient material using waste tire chips and EPS. The residual deformation test was conducted to prevent deformation of the EPS caused by the irregular shape of the waste tire chips under the dead load of the structure and to address concerns about structural cracking above the resilient layer or settlement of the material itself, which could lead to reduced performance and instability.

As shown in Table 1, the initial specimen (Type 1) was composed only of EPS and waste tire chips. The particle size of the waste tire chips was not specifically designed or altered, as they are produced at a fixed size through a reprocessing facility. In particular, Sambucci et al. [24] reported that deformation behavior varies with particle size, and accordingly, two particle sizes were applied in this study. From the perspective of overall material thickness and structural performance, the rubber chip content was determined with reference to previous studies [25]. The application rate of the waste tire chips was approximately 1600 g/m^2, but this exceeded the standard and was reduced to 850 g/m^2. However, as the tire chips penetrated the EPS layer, excessive deformation persisted. To resolve this, a PP sheet was inserted between the layers. In order to minimize thickness deformation, the thinnest PP sheet was tested first, and the 0.4 mm sheet was found to be the most appropriate.

Table 1. Specimens for residual deformation measurement.

Category		Type 1	Type 2	Type 3
Composition				
EPS	Thickness (mm)	25	25	25
PP Sheet		-	-	0.4
Crumb Rubber	Particle Size (mm)	5~7	5~7	5~7
	Application Rate (g/m^2)	1600	850	850
	Test Results	Exceeds Standard		Meets Standard

Through this process, Type 3 was finalized as the optimal specimen configuration.

2.1.2. Dynamic Stiffness Measurement

The dynamic stiffness of resilient materials used in apartment buildings for the reduction in floor impact noise was measured in accordance with KS F 2868 (determination of dynamic stiffness of materials used under floating floors in dwellings) [26]. As shown in Figure 2, the test was conducted in a laboratory using the impulse excitation method, where the resonance frequency was identified from the frequency response function of the vibration transmissibility measured by an accelerometer.

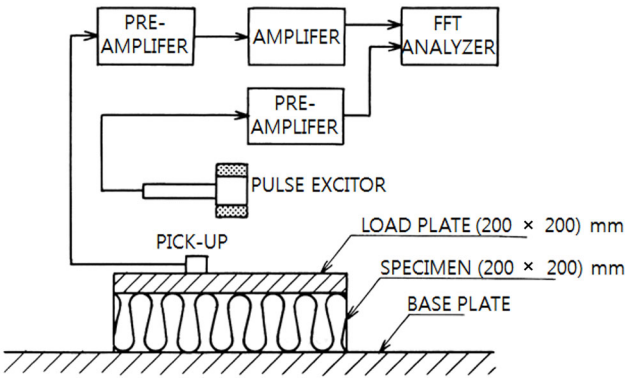


Figure 2. Pulse excitation method diagram.

Based on the measured resonance frequency, the apparent dynamic stiffness per unit area (s'_t) was calculated using the following equation.

$$S\prime_t = (2\pi f_r)^2 \cdot m'_t \quad (1)$$

where f_r is the resonance frequency of the vibration system (Hz) and m'_t is the mass per unit area of the loading plate (kg/m^2).

Based on the results of residual deformation measurement, the resilient materials were designed with a total thickness of 30 mm, and specimens were fabricated as shown in Table 2. The measured dynamic stiffness of the EPS alone was 5.69 MN/m^3, whereas Type 1 and Type 2 showed reduced values of 3.54 MN/m^3 and 4.78 MN/m^3, respectively. These results demonstrate that, as reported in previous studies, the composite configuration of different materials can effectively reduce dynamic stiffness, which is expected to lead to enhanced floor impact noise insulation. The architectural dimensions of the standard test room used in this study are summarized in Table 3.

Table 2. Specimens for dynamic stiffness measurement.

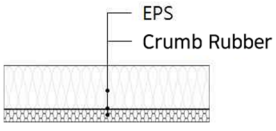
Category		Type 1	Type 2
Composition			
EPS PP Sheet	Thickness (mm)	25 0.4	28 0.4
Crumb Rubber	Particle Size (mm)	5~7	2~3
	Application Rate (g/m^2)	1600	850
Dynamic Stiffness (MN/m^3)		3.54	4.78

Table 2. *Cont.*

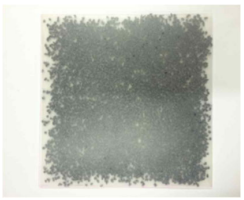
Category	Type 1	Type 2
Fabricated Specimens		

Table 3. Architectural dimension of standard test room for floor impact noise.

Classification	Architectural Dimension of Standard Test Room
Length (L)	5.1 m
Width (W)	4.5 m
Height (H)	2.5 m
Volume (V)	58.6 m^3
Floor area (F)	22.9 m^2
Thickness of concrete slab	180 mm

2.2. Floor Structures

Based on the results of previous studies, design criteria for the resilient material were established using a composite structure of crumb rubber and EPS. During the review of design criteria, the floor impact noise reduction performance was compared by varying the particle size of crumb rubber while keeping the thickness of the resilient layer constant.

In addition, a PP sheet was used between layers of EPS and crumb rubber because the crumb rubber may cause deformation by penetrating the low-density EPS at the top layer. This may degrade the floor impact noise insulation performance due to the increased contact area between the EPS and the slab. Therefore, to address this issue, a structure was developed in which a PP sheet was inserted between the crumb rubber and the EPS layer.

Two floor types were constructed for the experiment: Type 1 with a particle size of crumb rubber 5∼7 mm, PP sheet 0.4 mm, and EPS 25 mm; Type 2 with a particle size of crumb rubber 2∼3 mm, PP sheet 0.4 mm, and EPS 28 mm. Figures 3 and 4, as follows, show the cross-sections of the floating floor structures for Type 1 and 2 floors depending on particle size. Since the resilient material exhibited relatively weak performance in reducing heavy-weight floor impact noise, an additional measurement was conducted using only a 180 mm concrete slab without the floating floor structure. This test was intended to isolate the baseline noise level and more clearly assess the reduction performance of the resilient material.

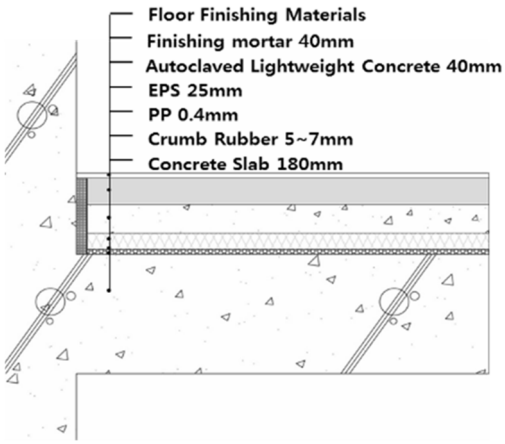


Figure 3. Section of Type 1 floor (crumb rubber 5~7 mm; EPS 25 mm).

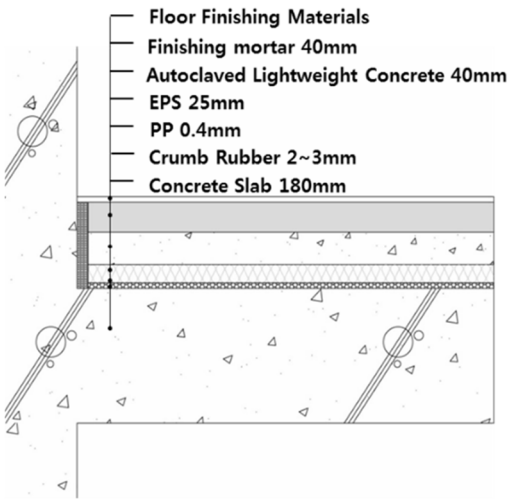


Figure 4. Section of Type 2 floor (crumb rubber 2~3 mm; EPS 28 mm).

3. Experiment

3.1. Classification of Standard Test Room

In order to evaluate the reduction performance of resilient materials for floor impact noise, an experiment was conducted in the standard floor impact noise test room, which was designed to simulate the living room of an actual apartment building. The floor structure in this test room was equivalent to that of an apartment located at KCL (Korea Conformity Laboratories).

The standard test room for the floor impact noise consists of a total of sixteen sound-receiving rooms on the first floor and sound source rooms on the second floor with equal-sized spaces. The inner size of each room has a rectangular space of 4.5 m × 5.1 m, and the thickness of every floor slab is 180 mm. The sound-receiving room is required to have a plaster ceiling with a 100 mm air space thickness. Table 3, as follows, shows the summary of building dimensions of the standard test room for the floor impact noise.

3.2. Methods of Experiment

The floor impact noise was measured and evaluated in accordance with KS F 2810-1,2 for the measurement method and KS F 2863-1,2 for the evaluation method, using the standard onsite measurement procedure [27–30]. The specifications of the measurement instruments used in this study are summarized in Table 4. The impact sources listed in the table are designed to simulate typical floor impact noises encountered in residential settings such as footsteps, dropped objects, and children running or jumping. The impact noise generated in the source room by each device was recorded in the receiving room using microphones, and the data were collected and analyzed through a real-time sound and vibration analyzer. The background noise during the onsite experiment was maintained below 30 dB(A), as the test was conducted in a building managed by the testing institution, where surrounding noise is properly controlled.

In Figure 5, as follows, the outline diagram of the experiment is illustrated. Five sites were selected for the installation of the impact source in the sound source room, including the center point. It was installed at a distance of 0.75 m from the surrounding walls of the room, and it is shown in Figure 6. Five sites were selected for the installation position of microphones, including the center point of the receiving room. These positions were equivalent to the installation position of the impact source in the sound source room. It was installed at a height of 1.2 m from the floor at sites 0.75 m away from the walls of the surrounding room.

Table 4. Specifications of measurement instruments.

Category	Equipment	Specification/Description
Impact Sources	Tapping Machine	Light-weight impact source (KS F 2810-1)
	Bang Machine	Heavy-weight impact source (KS F 2810-2)
	Impact Ball	Heavy-weight impact source (KS F 2810-2)
Microphones	0.5-inch Condenser Microphone	Ref. sensitivity: 54.23 mV/Pa Frequency range: 3.15 Hz–30 kHz
Calibrator	Acoustic Calibrator	94 dB at 1 kHz
Analyzer	Real-Time Sound and Vibration Analyzer	Frequency range: 20 Hz–20 kHz Up to 12-channel simultaneous acquisition
Loudspeaker	Omnidirectional Loudspeaker	Max output: 125 dB
Amplifier	Power Amplifier	Output range: 220–700 W

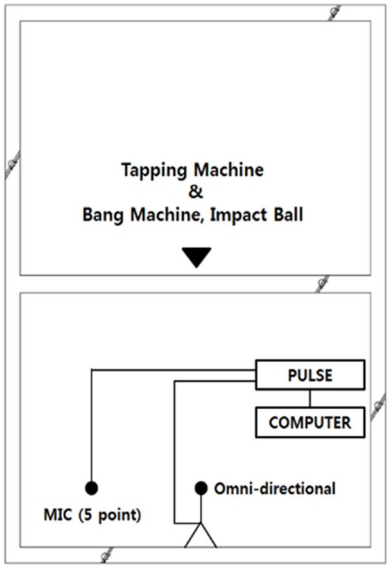


Figure 5. Experiment setup apparatus.

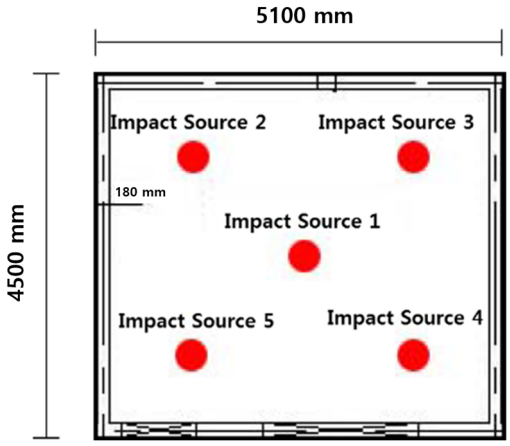


Figure 6. Points of floor impact source.

3.3. Floor Impact Noise Standards of Korea

Table 5 shows the floor impact noise standards of Korea for light-weight and heavy-weight impact noise with four different grades that have been implemented since 2006 [31]. These standards have been implemented to ensure acceptable levels of noise within residential buildings, improving the quality of living by mitigating floor impact noise.

Table 5. The floor impact noise standards of Korea [31].

Classification	Light-Weight Impact Noise ($L'_{nT,w}$)	Heavy-Weight Impact Noise ($L'_{I,Fmax}$)
1st grade	$L'_{nT,w} \leq 37$	$L'_{I,Fmax} \leq 37$
2nd grade	$37 < L'_{nT,w} \leq 41$	$37 < L'_{I,Fmax} \leq 41$
3rd grade	$41 < L'_{nT,w} \leq 45$	$41 < L'_{I,Fmax} \leq 45$
4th grade	$45 < L'_{nT,w} \leq 49$	$45 < L'_{I,Fmax} \leq 49$

4. Results and Discussions

4.1. Floor Impact Noise Levels by Standard Light-Weight Impact Source (Tapping Machine)

The floor impact noise levels measured using the standard light-weight impact source were calculated in 1/3 octave bands after background noise correction. A comparison graph for the light impact noise level according to the frequency for each floor type is shown in Figure 7. As shown in Figure 5, based on the measured light impact noise levels for Type 2 floors, the reduction performance for the light impact noise was improved. For this reason, according to the study result by K.W. Kim, it was found that, as the thickness of resilient material increased, the reduction performance of the light impact noise increased [4]. Although the total thickness of the resilient layer was 30 mm in both floor types, the effective EPS thickness contributing to light impact noise reduction in Type 2 was estimated to be 3 mm greater than that in Type 1. On the other hand, it was shown from the study result that, if the dynamic stiffness of resilient material increased, the reduction performance of the light impact noise also decreased. However, it was shown that, although the dynamic stiffness in Type 2 floors was higher than that of Type 1 floors, the reduction performance of the light impact noise was excellent.

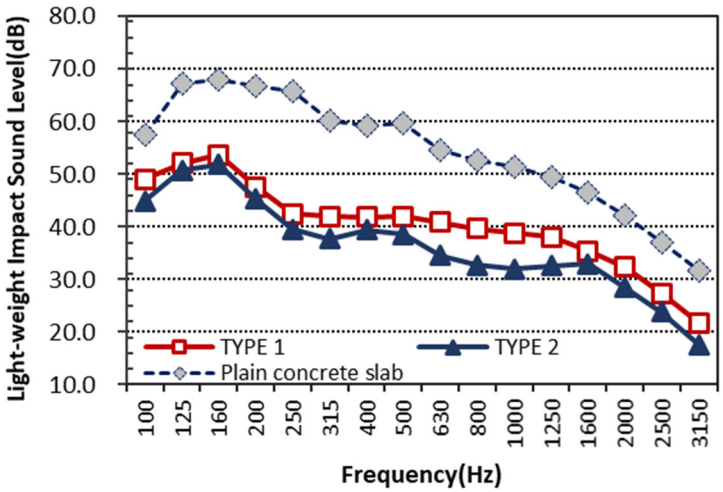


Figure 7. Comparison of light-weight impact noise level of Type 1 and 2 floors with plain concrete slab.

When the light-weight impact noise levels of Type 1 and 2 floors per frequency were compared, it was observed that in both types, as commonly observed in EPS-based resilient materials, the light impact noise level became lower toward the middle- and high-frequency bands.

4.2. Floor Impact Noise Levels by Standard Heavy-Weight Impact Sources

The value of the floor impact noise level by the standard heavy impact source was computed for the 1/3 octave band after background noise correction. In particular, the reduction characteristics of the heavy impact noise level of resilient materials utilizing crumb

rubber were compared to those measured on the heavy impact noise level measured at concrete slabs only.

4.2.1. Bang Machine

The value of the floor impact noise level by Bang Machine was computed for the 1/3 octave band after background noise correction. The measured heavy impact noise levels are shown in Figure 8. As shown in Figure 6, the resilient material of Type 2 floors demonstrated a higher reduction in heavy impact noise, as measured using the Bang Machine, compared to that of Type 1 floors. In addition, the reduction performance of heavy impact noise was outstanding in the low-frequency band, which is the major cause of the noise between floors due to the heavy impact noise. In the previous studies of this thesis, it was shown that the lower the dynamic stiffness was, the higher the reduction performance was. However, based on the results of the actual installation of the resilient materials in the standard test room for floor impact noise, it was shown that the reduction performance of Type 2 floors with a higher dynamic stiffness was superior. It is assumed that the difference in dynamic stiffness between the two floor types was minimal. Therefore, the variation in crumb rubber particle size may have influenced the heavy impact noise reduction performance. When the sound insulation of heavy impact noise per frequency was compared, it was verified that at 50 Hz, the heavy impact noise level was higher when resilient materials were installed than when only the slabs were used. In the case of the concrete slab, it appeared that the inherent vibration frequency of the resilient material excited by the heavy impact source in the 63 Hz band (40 Hz~80 Hz) was located at 50 Hz, causing resonance and increasing the heavy impact noise level.

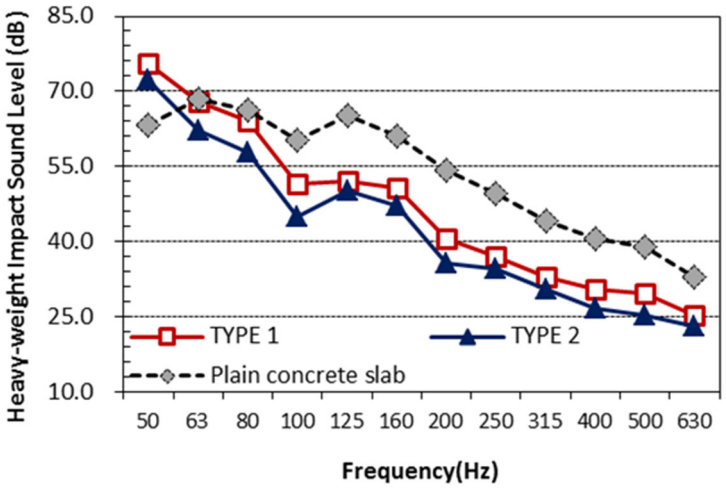


Figure 8. Comparison of heavy-weight impact noise level of Type 1 and 2 floors with plain concrete slab (Bang Machine).

4.2.2. Impact Ball

The value of the floor impact noise level by Impact Ball was computed for the 1/3 octave band after background noise correction. The measured results of the heavy impact noise levels for each floor type were compared by frequency and are shown in Figure 9.

It was shown in Figure 7 that, through the value of heavy impact noise level by Impact Ball among the standard heavy impact sources, the reduction performance of the heavy impact noise of Type 2 floors exceeded that of Type 1 floors, like the Bang Machine. In particular, the difference in the reduction amount of heavy impact noise in the 80 Hz band, excluding 50 Hz and lower, was greater than that in the frequency band above 125 Hz. In the frequency band of 125 Hz and higher, the reduction amounts of Type 1 floors and Type 2 floors were almost the same. Frequency-dependent analysis showed that at 50 Hz,

the heavy impact noise level was higher when the resilient material was installed compared to the case with the concrete slab alone. This level was similar to the heavy impact noise measured using the Bang Machine as the standard impact source.

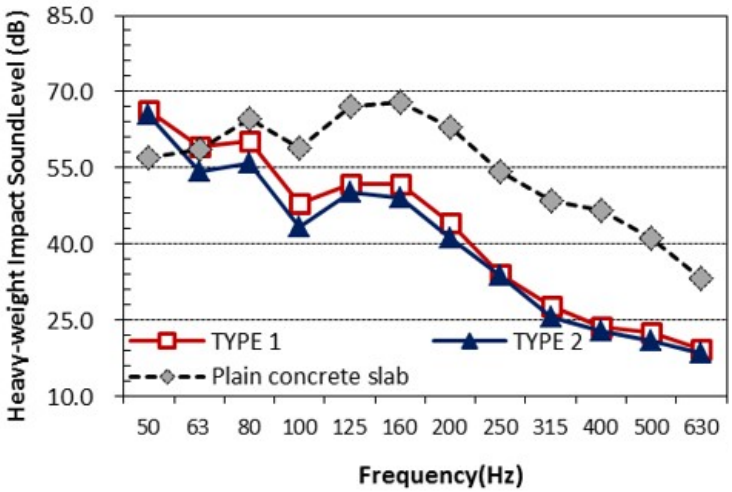


Figure 9. Comparison of heavy-weight impact noise level of Type 1 and 2 floors and plain concrete slab.

4.3. Performance Grade of Floor Impact Noise of Resilient Material Utilizing Crumb Rubber

The sound insulation performance of resilient materials incorporating crumb rubber was evaluated based on the grading criteria specified in the detailed measurement standards for floor impact noise. Table 5 shows the impact noise level evaluated for floor impact noise according to KS F 2863 [24,25], which was measured using the standard light impact source and heavy impact source.

Accordingly, the grade classification of the floor impact noise insulation is identified in Table 6. It was shown that for Type 1 floors, the sound insulation performance for resilient material utilizing crumb rubber corresponded to the first grade in the light impact noise, and among heavy impact noises, the third grade corresponded to excitation by the Bang Machine, and the second grade corresponded to excitation by the Impact Ball. For Type 2 floors, it was shown that the sound insulation was the first grade in the light impact noise, and in the case of exciting the Bang Machine and the Impact Ball, both showed the second grade.

Table 6. Floor impact noise insulation grade of floors using resilient material and crumb rubber.

Impact Source	Type 1		Type 2	
	Impact Noise Level (dB)	Class	Impact Noise Level (dB)	Class
Tapping machine	39	1	35	1
Bang machine	46	3	42	2
Impact ball	40	2	38	2

According to the study by Lee [32], the average floor impact noise insulation measured in four apartment units with a floor structure composed of a 210 mm concrete slab, 30 mm EPS, 40 mm autoclaved light-weight concrete, and 40 mm finishing mortar showed that the light-weight impact noise level was 46 dB, corresponding to Grade 2. However, the heavy-weight impact noise level measured using the Bang Machine was 51 dB, which exceeded the grade classification threshold. This corresponds to a difference of approximately 7~11 dB for light-weight impact noise and 5~9 dB for heavy-weight impact noise, when compared

with the results of Type 1 and Type 2 floors in this study. Accordingly, the 30 mm resilient material incorporating waste tire chips applied in this study is considered to exhibit superior floor impact noise insulation.

5. Conclusions

In this study, based on the resilient material designed for floor impact noise utilizing crumb rubber, the floor structure was constructed in the standard test room. The floor impact noises were measured, and the reduction performance was analyzed. The results of this study are summarized as follows:

(1) When the standard impact source was excited, the reduction performance of the resilient material of Type 2 floors exhibited the lowest measured levels for both the light and heavy impact noise, indicating superior sound insulation performance.
(2) Although the floor impact noise insulation of Type 1 floors, which has a lower dynamic stiffness, was initially expected to be superior to that of Type 2 floors, onsite measurement results showed that Type 2 floors exhibited better performance.
(3) In both Type 1 and 2 floors, a resonance was generated at 50 Hz so that the heavy impact noise was not reduced but rather increased.
(4) For Type 1 floors, the sound insulation in the light impact noise satisfied the first-grade standard; among the heavy impact noises, the third-grade standard was achieved when excited by the Bang Machine, and the second-grade standard was achieved when excited by the Impact Ball. For Type 2 floors, the sound insulation satisfied the first grade in the light impact noise, and the sound insulation in the heavy impact noise satisfied the second-grade standard when excited by both the Bang Machine and the Impact Ball.
(5) Regardless of the different characteristics of impact sources that the Bang Machine and the Impact Ball have as the standard heavy impact source, Type 2 floors showed a reduction in floor impact noise when examining two impact sources.

Through the present study, crumb rubber was applied as a resilient material for reducing floor impact noise, and it was found to be highly effective. To address the limited performance of resilient materials in reducing heavy-weight impact noise, an improved floor structure was developed to enhance sound insulation. In the future, further verification of the floor impact noise reduction performance will be needed through implementation in actual apartment buildings.

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