DOI: 10.61782/fa.2023.1276

FLOOR-IMPACT SOUND INSULATION PERFORMANCE OF ACOUSTIC METAMATERIAL CEILING

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ABSTRACT

Floor impact noise in apartment houses is a noise source that needs to be reduced first among the noise generated in residential spaces. Among the floor impact sound reduction methods, a plan that a downstairs resident can apply to his or her house is to improve the ceiling structure. In order to improve the performance of the floor impact sound isolation of the ceiling, a vibration-isolation hanger, sound-absorbing material and sound-insulating material were applied. In this study, a structure that effectively reduces the main frequency of floor impact sound is periodically arranged in the ceiling of an apartment building, and an acoustic metamaterial made of lightweight material is applied and compared in laboratory conditions. The light-weight impact sound and the rubber ball impact sound were measured and compared, and it was confirmed that the floor impact sound was reduced when the acoustic metamaterial was applied inside the ceiling.

Keywords: *acoustic metamaterial, floor impact sound, ceiling*

1. INTRODUCTION

In Korea, a system for improving the performance of floor-impact sound insulation in apartments has been implemented since 2005. In 2022, the building regulation for the floor impact sound isolation performance of apartments were revised for apartments built after 2022 by necessitating the measurement and disclosure of the performance of isolating floor impact noise after the construction is completed. If the floor impact sound isolation performance does not meet the building regulations, supplementary construction or compensation should be stipulated. In addition, methods for remodeling and using existing apartments are becoming increasingly active.

As apartment housing systems and markets change, the need for a plan that can easily improve the floor-impact sound isolation performance of existing apartments arises. One way to improve the floor-impact sound isolation performance of apartments is to enhance the ceiling surface finish and internal spaces. Therefore, in this study, considering the characteristics of floor-impact sound propagation in apartments, acoustic metamaterial for ceilings with arrays of shapes designed to effectively reduce sound were applied inside the ceiling; subsequently, the impact sound isolation performance was compared under laboratory conditions.

2. REDUCTION OF FLOOR IMPACT SOUND THROUGH CEILING

Research on reducing floor-impact noise by incorporating ceiling improvements began in the early 2000s. Kim et al. [1,2] applied a membrane-type sound absorber to a test room by applying a PE sound absorber to a damping iron plate to isolate heavy-impact sounds. Lee et al. [3] devised and applied a wall-supported ceiling system that was not connected to the bottom of the slab to reduce the vibrations transmitted from the slab to the ceiling finishing material. Shin et al. [4] reduced the weight impact sound by drilling a hole in a part of the ceiling finishing gypsum board to improve the low-frequency resonance generated in the interior space of the ceiling owing to floor impact. In addition, a previous study [5] applied glass wool density to improve the sound absorption performance inside the ceiling. A study on the performance of floor impact sound isolation based on

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the construction method of a lightweight steel frame constituting a ceiling frame [6].
In Japan, Tanaka et al. [7] examined the effects of air permeability inside the ceiling and whether air layers and sound-absorbing materials were installed in double ceilings to reduce floor impact noise. Ryota [8] applied a dynamic absorber to the ceiling surface. Taisei Construction applies a method of arranging materials such as charcoal, recycled resin, and zeolite (mineral combined with earth metal), which are effective in damping the ceiling, in the form of a bag inside the ceiling to reduce the sound of weight impact.

3. ACOUSTIC METAMATERIAL CEILING

This study was based on a plan to effectively isolate the impact sound transmitted to the lower floor through the ceiling interior. For application to the ceiling of an existing apartment buildings, an acoustic metamaterial ceiling material was devised and applied to a light and thin material. Acoustic metamaterials effectively isolate frequency noise in the area that is the main cause of noise between floors and walls and reduce the weight of soundproof panels by using a metastructure that can overcome the mass law and control the effective density. The metamaterial used in this study was designed and manufactured based on the aforementioned technologies and an example of the acoustic metamaterial ceiling shown in Figure 1.

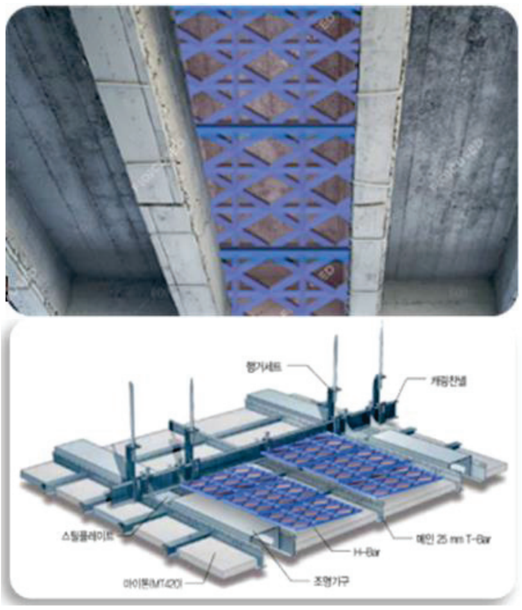

Figure 1. Examples of acoustic metamaterial ceiling materials to reduce floor impact noise

For the acoustic metamaterial ceiling, a standard concrete slab was installed in a reverberation room connected up and down, and a wooden ceiling frame was constructed and applied in the space below the slab.
The concrete slab used in the experiment was 210 mm thick, based on the concrete slab specifications used in most Korean apartment houses. In the experiment, the floor-impact sound isolation performance of a concrete slab was measured and used as a reference value. The case where only the gypsum board was installed after constructing the wooden ceiling frame with a depth of 200 mm and the case where the gypsum board and acoustic metamaterial ceiling were installed together were compared. To check the floor-impact sound isolation performance of the ceiling material, only the acoustic metamaterial was applied to the wooden ceiling frame and measured. The floor-impact sound isolation performance was measured using lightweight and rubber ball impact sources based on ISO 10140-3. A single number quantities of the floor-impact sound-isolation performance was evaluated according to ISO 717-2:2020.

Table 1. Single numerical evaluation of lightweight impact sound for each experimental condition.

Condition	Tapping ($L_{n,T,W}$)
1. Concrete slab 210 mm	73 dB
2. Concrete slab + gypsum board	60 dB
3. Concrete slab + metamaterial + gypsum board	53 dB
4. Concrete slab + metamaterial	63 dB

Table 2. Single numerical evaluation of rubber ball impact sound for each experimental condition.

Case	Rubber ball ($L_{iA,Fmax}$)
1. Concrete c slab 210 mm	54 dB
2. Concrete c slab + gypsum board	52 dB
3. Concrete slab + metamaterial + gypsum board	48 dB
4. Concrete slab + metamaterial	52 dB

Table 1 summarizes the changes in the single number quantities of lightweight impact sound isolation performance for each experimental condition. For a concrete slab of 210 mm, the $L_{nT,w}$ value was 73 dB, but when a 200 mm air gap was installed with gypsum board finishing, lightweight impact sound level decreased to 60 dB. When acoustic metamaterial was applied inside the ceiling along with gypsum board, the lightweight impact noise reduction performance decreased to 53 dB. The lightweight impact noise reduction performance was improved by 7 dB due to the application of acoustic metamaterial ceiling material. When only acoustic metamaterial ceiling material was applied to the concrete slab, the lightweight impact noise reduction performance was 63 dB, which was less effective in reducing lightweight impact noise compared to gypsum board. However, considering the thickness and weight, it can be considered quite effective in terms of blocking performance.

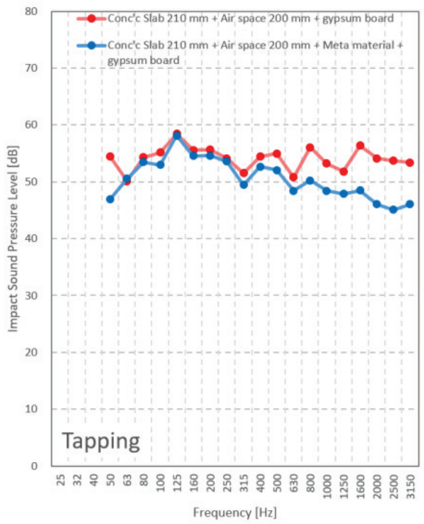

Figure 2. Changes in lightweight impact noise reduction performance due to the application of acoustic metamaterials.

Table 2 shows the changes in rubber ball impact noise level for each experimental condition. The rubber ball impact noise reduction performance for a concrete slab of 210 mm was 54 dB in terms of $L_{iA,Fmax}$. When a 200 mm air gap was formed and only gypsum board was applied, the rubber ball impact noise level decreased to 52 dB, which was 2 dB lower than the concrete slab. The rubber ball impact noise level also showed 52 dB when only acoustic metamaterial was applied instead of gypsum board. When acoustic metamaterial was applied inside the ceiling along with gypsum board, the rubber ball impact noise reduction performance decreased to 48 dB. It was confirmed that the application of acoustic metamaterial ceiling material improved the rubber ball impact noise reduction performance by 4 dB.

Figure 2 shows the frequency characteristics of the lightweight impact sound level for the case where a 200 mm air layer was formed underneath a concrete slab of 210 mm and finished with gypsum board, and for the case where gypsum board and acoustic metamaterial were applied together. The red line in the figure represents the case with only gypsum board, and the blue line represents the case with gypsum board and acoustic metamaterial applied together. Due to the application of acoustic metamaterial on the gypsum board ceiling material, the lightweight impact sound level was reduced for all frequency ranges except for the 63 Hz band. It can be seen that the reduction in lightweight impact sound level by the acoustic metamaterial is more pronounced as the frequency gets higher.

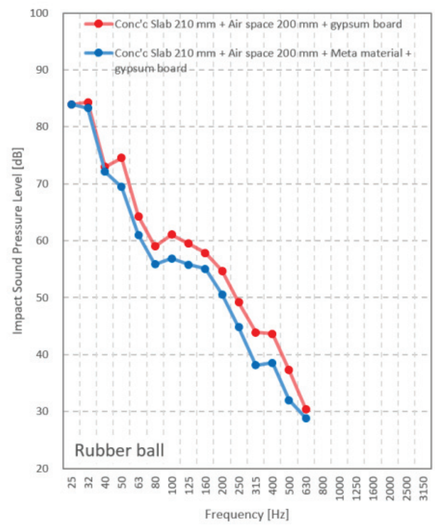

Figure 3. Changes in rubber ball impact noise reduction performance due to the application of acoustic metamaterials.

Figure 3 shows the frequency characteristics of the rubber ball impact sound level due to the application of acoustic metamaterial. To compare the rubber ball impact sound level, measurements were conducted from the 25 Hz band to confirm the characteristics of the low-frequency band.

As a result of comparing the rubber ball impact sound levels, it was found that the sound level decreased in all frequency bands when the acoustic metamaterial ceiling material was applied together with the gypsum board. Especially, the phenomenon of relatively high levels in the 50 Hz and 100 Hz bands observed when only the gypsum board was applied was mitigated. It was found that the rubber ball impact sound with high impact in the low-frequency band was effectively reduced by the acoustic metamaterial ceiling material.

4. RESULTS & DISCUSSIONS

In 2022, the requirement of building regulation for both lightweight impact sound and rubber ball impact sound in Korea were strengthened to 49 dB. In addition, the evaluation of isolation performance was also changed to follow ISO standards after all apartment buildings are built. Therefore, ways to improve the isolation performance of floor impact sound even after all apartment buildings are built are needed. In this study, we experimented with applying acoustic metamaterial ceiling materials in the ceiling space of mock-up in laboratory condition to improve the isolation performance of floor impact sound. As a result of applying the acoustic metamaterial on the gypsum board finishing, lightweight impact sound was reduced by 7 dB and rubber ball impact sound by 4 dB. In the future, we plan to verify and apply various acoustic metamaterial ceiling materials in actual multi-unit dwellings after testing them under laboratory conditions.

5. ACKNOWLEDGMENTS

This work is supported by the Korea Agency for Infrastructure Technology Advancemen(KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant RS-2022-00144050).

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