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A study on the thermal conductivity of resilient materials☆

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ABSTRACT

The floor system of apartments must have a certain level of floor impact sound performance (light-weight impact sound is 58 dB or less, heavy-weight impact sound is 50 dB or less), and comply with the building energy code to prevent energy loss in residential buildings in Korea. In this study, expanded polystyrene (EPS), expanded polypropylene (EPP), ethylene-vinyl acetate copolymer (EVA), polyethylene (PE) and urethane foam, which are widely used in Korea as resilient materials for floating floor system of apartments, were measured. Their thermal conductivity and apparent density were measured to analyze their thermal properties and their relation was analyzed by material. In case of resilient materials made of EPS and EPP, thermal conductivity tended to decrease as apparent density increased, whereas in case of resilient materials made of EVA and PE, as apparent density increased, thermal conductivity tended to increase as well.

1. Introduction

1.1. Background and purpose of study

In Korea, the floor structure system of apartment house must have a certain level of floor impact sound performance (light-weight impact sound is 58 dB or less, heavy-weight impact sound is 50 dB or less) to solve the problem of inter-floor noise due to the floor impact sound. Currently, the floating floor system with resilient materials is generally used to a great extent to reduce floor impact sound. The relevant laws and regulations [1] stipulate the physical properties of the resilient materials used for the floating floor structure.

This floor structure system complies with the reinforced building energy code [2] to prevent energy loss in residential buildings. The Korea's building energy code required the additional installation of 20 mm or more resilient materials (or insulating materials) on top of the floor concrete slab structure for strengthening thermal performance of buildings. The insulating performance of the floor structure system is based on the thermal transmittance. So the thermal conductivity of the resilient materials in use has to be measured to calculate the thermal transmittance of the entire floor system.

At present, in the Korean residential construction market, several different types of resilient products made of different materials are applied and developed. In addition, several studies on methods of testing the acoustic and elastic properties and impact sound prevention performance of these materials and their physical properties have been conducted [3–5]. Very few attempts have been made at the investigation of and studies on the thermal property of resilient materials.

This study measured the thermal conductivity and apparent density of the resilient materials used in Korea to analyze their relation and properties.

1.2. Current status of resilient materials for apartment house in Korea

In Korean apartments, a number of households are living next door to each other separated by a wall or floor. So there are many problems related to soundproofing.

The reinforced concrete structure used in most apartment houses has the properties of heavy and tight materials. For this reason, it has better sound insulation performance against the airborne sound caused by voices and TV sound than other structural materials of the same thickness, but easily transmits the impact sound generated by footsteps or the drop of heavy objects to neighboring households.

As a solution to this floor impact sound problem, anti-vibration resilient materials are installed on top of the floor concrete slab. This floating floor structure, which lessens the vibration caused by impact and insulates sound, is used as the floor structure for apartments.

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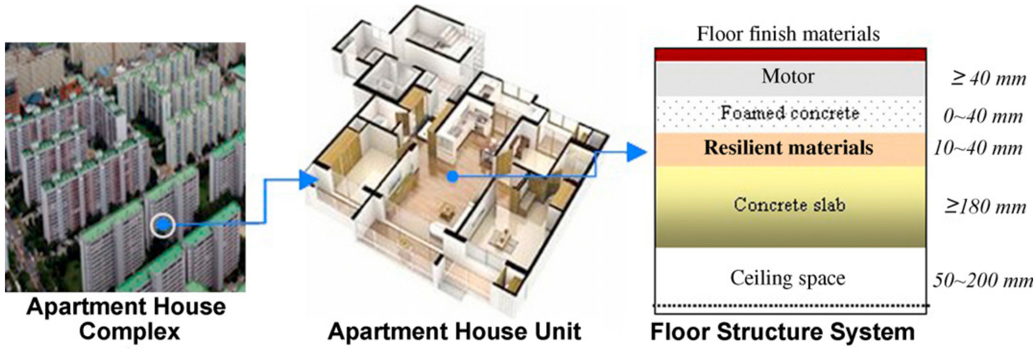

Fig. 1. The standard floor structure system of apartment house with resilient materials.

Table 1
Properties of resilient materials.

Designation	Density (kg/m^3)	Compressive strength (kPa)	Dimensional stability (%)	Water absorption (%, v/v)
EPS	15–30	50–250	5	6–2
PE	20–120	≥147	7	–
Urethane	25–45	30–150	5	3–4

The table was the physical properties of resilient materials. The mechanical properties of EPP and EVA have a wide-ranging value.

The resilient materials, currently used in Korean apartments or was under development, include expanded polystyrene (EPS), expanded polypropylene (EPP), urethane ranges, ethylene-vinyl acetate copolymer (EVA), polyethylene (PE), glass wool (GW) and mineral wool (MW), extruded polystyrene (XPS), extruded polyester fiber, recycling rubber tire chip and other composite materials [3].

The floor structure for apartments consists of the ceiling structure, the reinforced concrete slab, the insulation layer including resilient materials, the Ondol layer, the heat storage layer and floor finishing materials. In general, the thickness of resilient materials is 10–20 mm, and most living rooms have a thickness of 15 mm. Resilient materials are generally selected by measuring the dynamic stiffness, one of the physical properties of the materials in accordance with the Korean Industrial Standard [6,7]. The dynamic stiffness of many domestic resilient materials ranges between 10 and 30 MN/m^3 [8] (Fig. 1).

2. Experimental procedure

The test standards applied to the test of thermal conductivity in this study are KS L 9016 method for measuring thermal conductivity of insulation and ISO 8301 thermal insulation—determination of steady-state thermal resistance and related properties—heat flow meter apparatus. As the above standards stipulate that the temperature difference between both sides of the test specimen should be 10 °C or greater for measurement of thermal conductivity, the high-temperature side was 33 °C, the low-temperature side was 7 °C, while the temperature difference was 26 °C and the mean temperature was 20 ± 1 °C in this study. Measurements were taken with the heat flow meter method [9,10]. The thermal conductivity measuring device was ±2% to ±5% accuracy of measurement and the reproducibility was ±2%. The expanded uncertainty in test value was estimated to be a maximum possible error of 3.0% at a confidence level of roughly 95%.

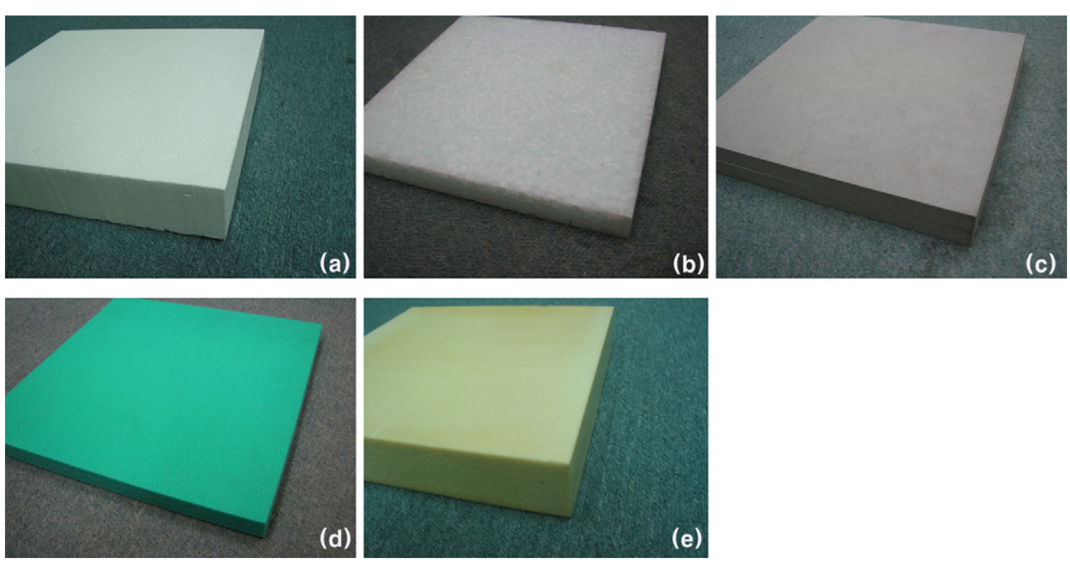

Fig. 2. Photographs of resilient materials for floor impact sound insulation: (a) expanded polystyrene (thickness 50 mm), (b) expanded polypropylene (thickness 20 mm), (c) ethylene-vinyl acetate copolymer (thickness 40 mm), (d) polyethylene (thickness 20 mm), and (e) urethane foam (thickness 50 mm).

The measurement specimens were 300 mm × 300 mm in size, and 20–50 mm in thickness. They were in the form of a rectangular plate. The volume and weight of the specimens were measured by means of digital Vernier calipers with 0.001 mm resolution and a digital scale with 0.001 g resolution for the apparent density [11]. As for the environmental conditions of the measurement location and the measurement specimen, the temperature and the relative humidity were kept constant at 23 ± 2 °C and 50 ± 5% RH.

The test samples were EPS, EPP, EVA, PE, and urethane foam. The test samples were random sampling of commercial products for sales, which were widely used in Korea as floor impact resilient materials for apartments. Table 1 summarizes the mechanical specification of resilient materials.

Fig. 2 shows the resilient materials by material for reducing floor impact sound.

3. Results

Resilient materials or insulating materials, used as part of the floor structure of apartments, must have a certain level of insulating performance to satisfy the thermal insulation codes for building elements [2]. As generally known, the thermal conductivity of insulating materials for buildings varies depending on density.

The thermal conductivity and apparent density of resilient materials made of EPS are shown in Fig. 3.

The apparent density ranged between 9.5 and 36.9 kg/m^3, the maximum thermal conductivity was 0.0461 W/(m K) and the minimum thermal conductivity was 0.0297 W/(m K). Fig. 3 tells us that thermal conductivity tended to decrease as apparent density increased. Particularly, in the low apparent density range between 9.5 and 20 kg/m^3, as apparent density increased, thermal conductivity tended to decrease abruptly, but in higher ranges of apparent density, thermal conductivity tended to drop gently, or ranged between 0.030 and 0.035 W/(m K). This leads to the prediction that, when apparent density exceeds 20 kg/m^3, thermal conductivity was influenced by the structural properties of the material, not only apparent density but also the structural properties of the material, such as the physical structure of the cells of the material.

The apparent density of resilient materials made of EPP ranged between 10.9 and 20.8 kg/m^3. Their thermal conductivity ranged between 0.0378 and 0.0443 W/(m K). Resilient materials made of EPP had a lower apparent density than those made of EPS as a whole. Resilient materials made of EPP were more difficult to form and cost more to make if they had a high apparent density. Accordingly, they were seldom used, and had poor dynamic stiffness, which is the most important property of resilient materials.

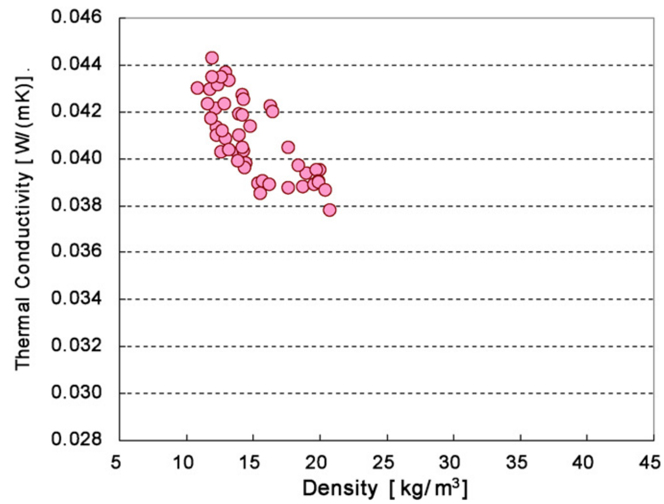

Fig. 4. Relation between the apparent density and thermal conductivity of EPP resilient materials.

With respect to the relation between apparent density and thermal conductivity, like resilient materials made of EPS, thermal conductivity tended to decrease as apparent density increased. The relationship between the two properties of resilient materials made of EPP, i.e. apparent density and thermal conductivity appears in Fig. 4.

Resilient materials made of EVA have a high elasticity and are widely used. According to the measurements in this study, the apparent density of resilient materials made of EVA ranged between 40.1 and 157.2 kg/m^3. Their thermal conductivity ranged between 0.0377 and 0.0573 W/(m K). With respect to the relation between apparent density and thermal conductivity, as Fig. 5 indicates, thermal conductivity tended to increase as apparent density increased. In particular, apparent density was concentrated in the 40.1–86.5 kg/m^3 range, whereas thermal conductivity ranged between 0.038 and 0.044 W/(m K). When the apparent density was the same, the amount of variation in thermal conductivity was 0.0048 W/(m K). This is thought to be attributed to the number and size of air gaps in the material, the foaming properties of the material during production, etc.

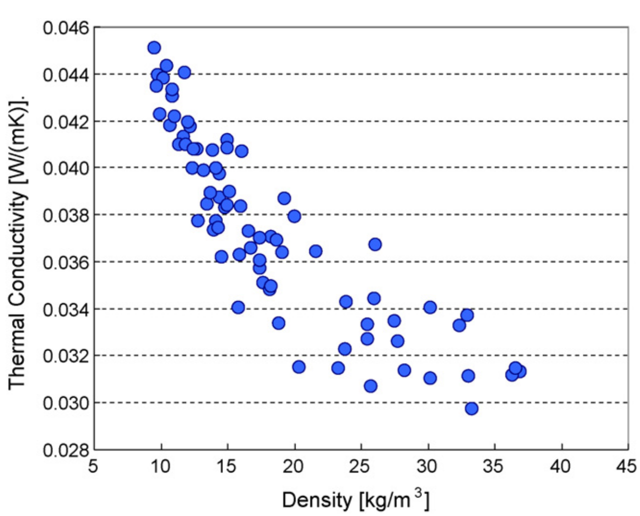

Fig. 3. Relation between the apparent density and thermal conductivity of EPS resilient materials.

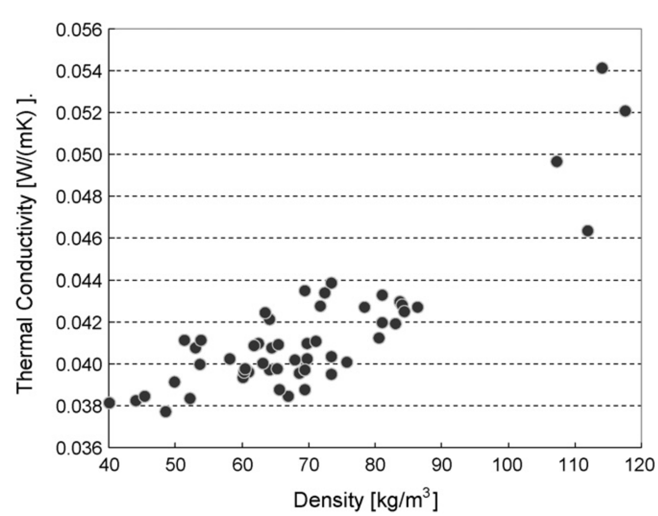

Fig. 5. Relation between the apparent density and thermal conductivity of EVA resilient materials.

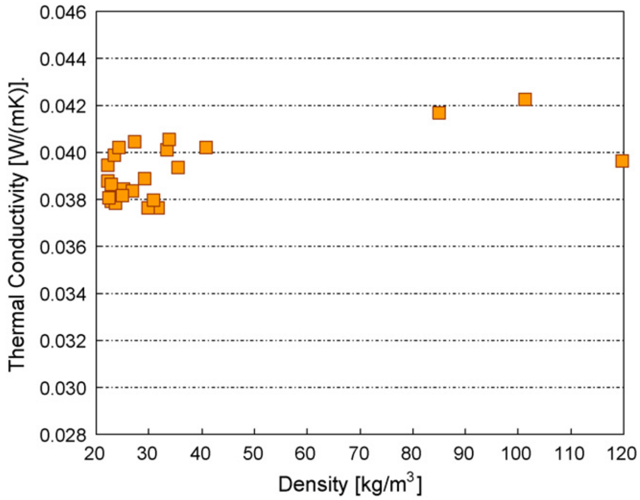

Fig. 6. Relation between the apparent density and thermal conductivity of PE resilient materials.

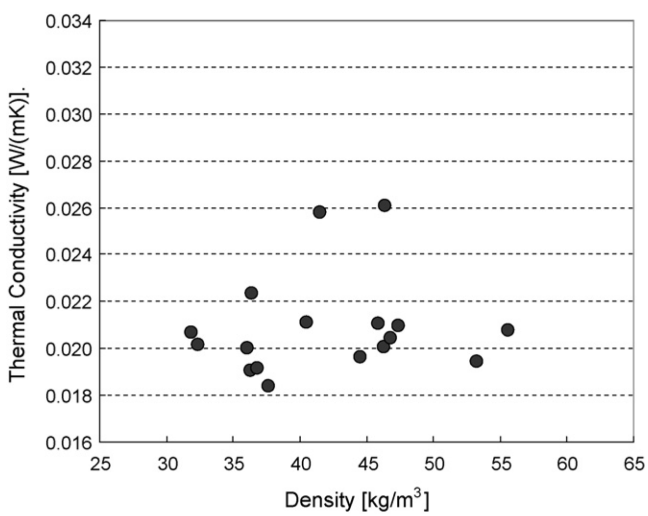

Fig. 7. Relation between the apparent density and thermal conductivity of urethane foam resilient materials.

Resilient materials made of PE showed thermal properties characterized by the increase of thermal conductivity according to the increase of apparent density. Fig. 6 illustrates the graph indicating the relationship between the apparent density and thermal conductivity of PE resilient materials. Apparent density ranged between 12.8 and 119.7 kg/m^3. Thermal conductivity ranged between 0.0355 and 0.0423 W/(m K). PE resilient materials have a wider range of apparent density than other resilient materials and their thermal conductivities varied little according to apparent density.

As illustrated by Fig. 7, the apparent density of urethane foam ranged between 12.7 and 55.6 kg/m^3, whereas thermal conductivity ranged between 0.0184 and 0.0529 W/(m K). The thermal conductivity of urethane foam resilient materials had a lower thermal conductivity than resilient materials made of other materials.

Urethane foam resilient materials are different from other materials of this study in that the relation between apparent density and thermal conductivity was not clear. We could not find a link between apparent density and thermal conductivity of urethane foam resilient materials.

4. Conclusion

Thermal conductivity and apparent density of the representative resilient materials of Korea were measured to analyze their thermal properties and their relationship was analyzed by material. The thermal conductivity of resilient materials was measured at the mean temperature of 20 °C with heat flow meter (HFM) method.

In case of resilient materials made of EPS and EPP, thermal conductivity tended to decrease as apparent density increased, whereas in case of resilient materials made of EVA and PE, as apparent density increased, thermal conductivity tended to increase as well. Meanwhile, there was no relation between the thermal conductivity and apparent density of urethane foam resilient materials.

At the same density thermal conductivity varied because of other factors affecting thermal properties, that is, the physical structure of the cells of the materials varying depending on the manufacturing method, the size and type of internal air gaps, radiant heat flow rate, etc.

When resilient materials are installed in the floor of each household for the purpose of preventing inter-floor noise in apartments and of improving the insulating performance of a residential building, apartments, materials with excellent insulating performance must be used in consideration of not only the elastic properties and structural properties of the materials, but also their thermal properties.

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