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Damping and mechanical properties of composite composed of polyurethane matrix and preplaced aggregates

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HIGHLIGHTS

- Two-stage manufacturing process and materials were proposed for high damping property.
- The new composite showed the damping ratio of 18.1%.
- The flexural strength of the composite is higher than that of normal concrete.
- The interfacial property between polyurethane matrix and aggregate was investigated by microscopic observation.

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ABSTRACT

This paper presents an experimental study of the damping and mechanical properties of a new composite produced by a two-stage casting process. Five mixtures according to the materials and manufacturing process were prepared. A series of experiments, including density, impact resonance, compressive strength, flexural strength, and uniaxial tension tests, were performed in order to characterize the damping and mechanical properties of the composite. The test results showed that the composite, which is composed of preplaced aggregate and polyurethane matrix, and produced by manufacturing process proposed in this study, showed significantly improved damping performance as well as better tensile behavior.

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1. Introduction

Reinforced concrete is a most common construction material in residential buildings such as multiplex housing or apartments, and the safety and serviceability specified in standards such as the design code, housing act, and regulation should be satisfied. The noise and vibration arising in floors of buildings are important factors in serviceability and residential satisfaction [1,2]. Therefore, these should be controlled and limited to a certain level. The magnitude of noise induced by impact on the building floors depends on the lifestyle of the residents, and the degree of disturbance by noise also depends on the sensitivity of the residents to the noise. Previous studies reported that noise-sensitive people were more bothered and less satisfied with their living environments than less sensitive people [1,3]. The sources of noise and vibration in building floors include floor impact sounds such as walking, running, jumping, moving chairs, and other activities performed on the floors or stairs [2]. The impact sounds partially emanate as structure borne sound into rooms.

A floor slab system is generally composed of a concrete slab which supports the load, light weight foamed concrete, and finishing mortar [4]. To reduce the floor impact noise, it is common to install a noise insulation layer made of soundproofing material between the concrete slab and light weight foamed concrete [5]. The resilient material or soundproofing material dissipates vibration energy in the form of friction, heat losses, and other resistance because floor impact noise occurs by the transmission of vibration energy applied to the structure through air in the form of sound [6]. Therefore, the material used for the anti-shock material or soundproofing material should have a high damping property.

Previous study reported that the damping ratio for concrete without cracks ranged from 0.32% to 0.64%, and for concrete with cracks, it ranged from 1.3% to 2.1% [7]. Other studies also reported that the damping ratio of concrete is below 5% [8,9]. Recently, many studies have been performed to investigate the mechanical

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properties of rubberized concrete, in which rubber crumb or recycled rubber crumb replace aggregates in concrete [10–16]. It was demonstrated that the deformability and ductility of concrete could be increased by the addition of rubber crumb. Although the damping ratio of rubberized concrete increased compared with normal concrete, the damping ratio of rubberized concrete was still same order of magnitude to that of normal concrete [12,14]. Therefore, a noise insulation layer made of soundproofing material is still necessary. However, additionally installed anti-shock material or soundproofing material is expensive or can show low durability because most anti-shock material or soundproofing material has lower strength and stiffness than concrete. Therefore, it is necessary to develop a material that has high damping and similar properties to concrete.

The purpose of this study is to propose a preplaced aggregate polyurethane matrix based composite that has a high damping property compared with cement based concrete and to investigate experimentally the damping and mechanical properties of composites.

2. Design framework and proposed manufacturing process

The main challenges are to achieve not only a high damping property compared with normal concrete, but also a low cost for use as a common construction material. This paper proposes a high damping composite produced by a two-stage casting process in order to maximize the damping property and to minimize the cost. The composite is composed of two types of materials: aggregate, which is one component of concrete, and matrix material, which is liquid in the fresh state and has high damping property in the hardened state. The two-stage casting process is as follows: A formwork is filled with interlocking aggregate for maximum packing density, then a liquid polyurethane paste having a high damping property is poured into the formwork until it completely fills the void between the aggregate. Fig. 1 shows the illustration of the proposed manufacturing process. The proposed manufacturing process and composition of materials can be applied to have a high damping property and cost effectiveness because the aggregates is much cheaper than the polyurethane matrix. Hardened polyurethane paste absorbs the vibration energy which is induced by external impacts or dynamic loads because it has a high damping property. Additionally, the vibration energy is dissipated by the interlocking friction between the aggregate and the interfacial damping between aggregate and polyurethane matrix. The energy dissipation capacity of interlocked aggregate without matrix decreases with increasing vibration due to the breakage and settlement of the aggregate. On the other hand, the energy dissipation capacity of interlocked aggregate with a polyurethane matrix can be maintained because the polyurethane paste, having high elastic and deformation capacity, keeps the aggregate where it was before vibration. Furthermore, the proposed manufacturing process enables the preplaced aggregate polyurethane based composite to be economical because the volume fraction of aggregate can be maximized by the preplacing process, and aggregate is relatively much cheaper than polyurethane.

3. Experimental program

3.1. Materials and test variables

The properties of the polyurethane resin and hardener used in this study are listed in Table 1. The ratio of polyurethane resin and hardener was 1.0. The viscosity and yield stress of polyurethane paste, which is the mixture of polyurethane resin and hardener, were 4290 mPa.s and 1.28 Pa, respectively. The mini-slump flow (which represents the flowability of material) of the polyurethane paste was 307 mm. Crushed granite with maximum size of 13 mm, fineness modulus of 6.37, and density of 2.66 g/cm^3 was used as coarse aggregate. The mixtures according to the materials and manufacturing process are listed in Table 2. The C-G-P mixture is a control mixture, in which cement paste and coarse aggregate were used and the water-to-cement ratio of C-G-P was 0.4. A high-range water-reducing admixture was added in the amount of 0.1% by weight of cement to improve the flowability of the cement paste. The C-G-P mixture was produced by applying the proposed manufacturing process: A formwork was filled with the coarse aggregate, and cement paste was poured into the mold which was filled with coarse aggregate until it completely filled the void between the aggregate. In order to measure the average packing density of the coarse aggregate, the volume fractions of the aggregate in the mold were measured ten times. The average volume fraction and standard deviation of the aggregate were 48.0% and 0.8%, respectively. The PU-P mixture is the polyurethane paste which was made in order to compare the damping property with the control mixture. The PU-G-P mixture is a composite composed of coarse aggregate and polyurethane paste matrix. It was produced by applying the proposed manufacturing process. The PU-G-M mixture was produced with the same materials and mixture proportion as the PU-G-P mixture, but it was produced by a normal mixing method. The coarse aggregate and polyurethane paste were mixed together and then placed in the mold. From this mixing process, the whole surface of the coarse aggregate of the PU-G-M mixture was coated and surrounded by a polyurethane matrix. Therefore, there is no direct surface contact between coarse aggregate in the PU-G-M mixture. The PU-G-S-M mixture is the same as the PU-G-M mixture except the polyurethane was replaced by fine aggregate 30% by weight. Quartz sand with fineness modulus of 2.09 was used as fine aggregate. After the entire manufacturing process, the mixture was cast into molds (three specimens for each mixture) for measuring the damping

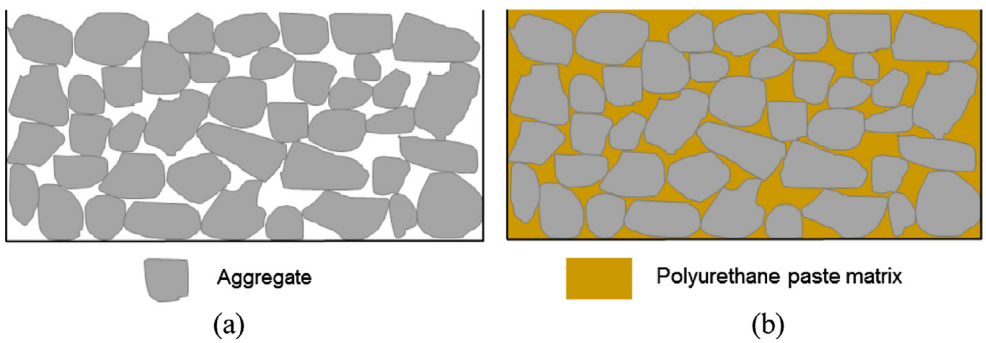

Fig. 1. Illustration of the two-stage casting process; (a) preplaced aggregate and (b) polyurethane paste injection.

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