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Damping property of prepacked concrete incorporating coarse aggregates coated with polyurethane

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ABSTRACT

This study proposes a new prepacked concrete incorporating coarse aggregates coated with polyurethane with high damping and investigates the mechanical properties and damping ratio of the proposed concrete. Two types of prepacked concretes, in this case new prepacked concrete produced with the materials and manufacturing process as proposed here and normal prepacked concrete were prepared. A series of experiments focusing on the density, strength, and impact test results of small-scale specimens and beam specimens as well as a modal analysis of a simply-supported beam were conducted in an effort to characterize the mechanical and damping properties of the new prepacked concrete. The test results showed that the damping ratio of the new prepacked concrete was as high as 10% in the range of 10 Hz to 200 Hz, which is approximately 10 times higher than that of normal prepacked concrete, with a decrease in the mechanical properties.

1. Introduction

Many types of residential buildings, such as multi-family and apartment buildings utilize reinforced concrete structures which must be designed and constructed to meet the safety and serviceability requirements specified in the relevant design codes, specifications, and/or laws. Recently, the noise generated by floor impacts is becoming more important with regard to serviceability and housing satisfaction [1,2]. Although these types of noise levels can be regulated by acts or laws and even when a proper floor system is adopted to control the noise, the magnitude and frequency of noise stemming from floor impacts typically depends on the lifestyle and circumstances of the residents involved and the degree of annoyance depends on the psychological state or sensitivity of those affected [2].

The sources of floor impact noise or vibration include falling objects, walking, jumping, running, moving furniture, and other activities performed on the floor [3]. The vibration energy induced by these sources is transmitted through air in the form of sound. This type of noise, considered to be structure-borne sound, is regarded as the most annoying type [3].

Although normal concrete has high compressive strength and high durability, it has a relatively low damping ratio which ranges from 1% to 2% [4–6]. Therefore, to mitigate floor impact noise, it is necessary to install a noise insulation layer which consists of sound-proofing or resilient materials in the floor system. These sound-proofing or resilient materials should have a high damping ratio to enable energy dissipation by internal friction, heat loss, inaudible sound, and other types of dissipation. However, sound-proofing or resilient materials have low compressive strength, low stiffness, and low durability compared to normal concrete. Therefore, it is necessary to develop a new type of concrete with a high damping ratio.

Many researchers have attempted to improve the deformability and damping properties of normal concrete by incorporating rubber crumbs or recycled rubber crumbs into the concrete [6–12]. The literature reports that the damping ratio and deformability of concrete can be improved by adding rubber particles to the concrete. Although the damping ratio of concrete with rubber particles is increased by up to 2.3 times relative to that of normal concrete without rubber particles, the damping ratio of concrete with rubber particles was still same order of magnitude to that of normal concrete [5,6,11]. Chung et al. [13–16] studied the damping capacity of cement paste and mortar with silica fume, latex, and methylcellulose as admixtures. It was found that the damping ratio of the cement-based composite is improved up to five times by adding silica fume and improved up to four times by adding latex. Wang and Chung [17] also found that the effect of silica fume is large when sand is present. Recently, Lee et al. [18] investigated the damping ratio of composites composed of preplaced aggregates and polyurethane matrix. Their experimental results showed that the

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damping ratio of the composite was approximately 12 times higher than that of cement-based concrete. Although the composite showed a high damping ratio, the volume of the polyurethane matrix was 50% of the total volume. This degrades the economic feasibility of such a composite given the high of polyurethane to the costs of the aggregate and cement.

Therefore, the purpose of the present study is to propose a new type of prepacked concrete which incorporates coarse aggregates coated with polyurethane in an effort to increase the damping ratio compared to that of normal prepacked concrete. An evaluation of the mechanical and damping characteristics of the new prepacked concrete is also conducted.

2. Design and manufacturing process

Here, a high-damping prepacked type of concrete produced by a three-stage casting process is proposed to increase the damping ratio of concrete and minimize the use of polyurethane. The concrete in this study is composed of three types of materials: coarse aggregate, polyurethane, and a matrix material. Normal coarse aggregate, a typical component of concrete, can be adopted. Polyurethane is a liquid with a proper viscosity in the fresh state and it is changed to a solid with a high damping in the hardened state. The matrix in this case can be cement paste or mortar. Any types of binding material, including cement, alkali-activated slag, and geopolymer can be used. Fig. 1 presents an illustration of the manufacturing process of the new prepacked concrete with a high damping ratio. The three-stage casting process is as follows: Aggregates are coated with polyurethane by mixing the two materials (Fig. 1(a)). A formwork is then formed with aggregates to ensure maximum packing density before the hardening of the polyurethane (Fig. 1(b)). Cement paste or mortar is then poured into the formwork until it completely fills the voids between aggregates after the hardening of the polyurethane (Fig. 1(c)).

The manufacturing process enables the polyurethane to become bonded chemically during the change from the liquid state to the hardened state, thus creating an integrated frame composed of coarse aggregates coated with polyurethane. Therefore, the distribution and structure of the material with a high damping ratio in concrete are wholly different those of rubber particles in normal rubberized concrete reported in previous studies. Vibration energy can be transmitted through the cement paste or mortar and through the aggregate in rubberized concrete because the rubber particles are not connected and are not percolated. On the other hand, the polyurethane coating the aggregates is inherently connected and is percolated. As shown in Fig. 1(c), the polyurethane layer coating the aggregates is fully percolated in all directions. Therefore, vibration waves cannot be transmitted only through the cement paste or mortar. The vibration wave starts at one surface and passes through the polyurethane layer to reach another surface, which results in higher dissipation of the vibration energy compared to that in normal rubberized concrete. The damping is derived from that of materials involved and from the interfacial slip damping between two different materials. Therefore, the damping mechanism of the proposed new prepacked concrete incorporating coarse aggregates coated with polyurethane are the damping inherent in the polyurethane and the interfacial damping of the polyurethane layer and aggregates or the cement paste.

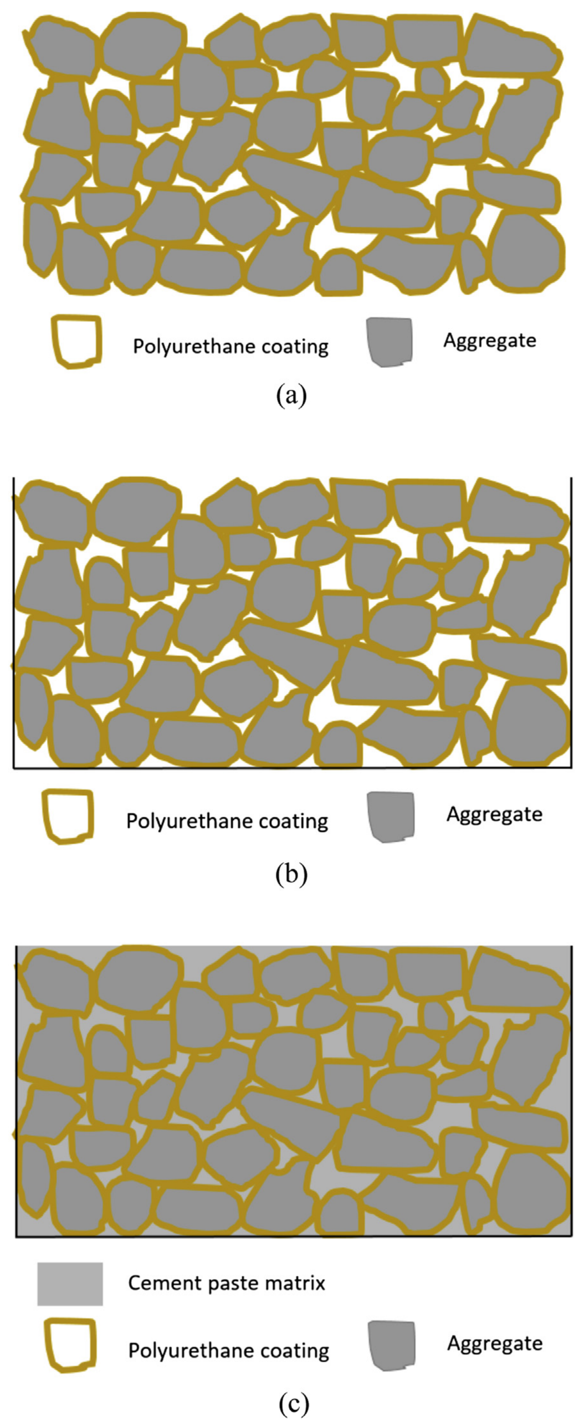

Fig. 1. Illustration of the manufacturing process: (a) coating aggregates with polyurethane, (b) preplaced aggregate, and (c) matrix injection.

3. Experimental program

3.1. Materials and test variables

Ordinary Portland cement was used as a binding materials and cement paste with a water-to-cement ratio of 0.4 was used as the matrix. The super-plasticizer was of 0.1 wt.% of the cement, and it was used to decrease the yield stress and viscosity of the paste to ensure high flowability and minimization of air voids in the matrix. The maximum size and density of the prepacked coarse aggregates were 13 mm and 2.66 g/cm^3, respectively. Table 1 lists the properties of the polyurethane resin and hardener used to coat the coarse aggregates. The working time of the polyurethane used in this study is approximately 1 h after the polyurethane resin is mixed with the hardener.

The mixtures according to the materials used are listed in Table 2. In the table, the PC-P mixture is the new prepacked concrete produced via the materials and manufacturing process proposed in this study. The coarse aggregates were coated with polyurethane through a mixing process, and the aggregates coated with polyurethane were prepacked into molds. After the hardening of the polyurethane and the formation