Applied Acoustics 138 (2018) 171–178

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

# Acoustic characteristics of sound absorbable high performance concrete

Heeae Kim, Jiyoung Hong, Sukhoon Pyo*

*Korea Railroad Research Institute, 176 Railroad Museum Road, Uiwang-si, Gyeonggi-do 16105, South Korea*

A R T I C L E  I N F O

*Keywords:*
Acoustic absorption
Porosity
Analytical modeling
High performance concrete
Fibers
PU test

A B S T R A C T

In order to effectively control ambient noise from transportation, this experimental study aims to develop sound absorbable high performance concrete. The main parameters evaluated include porosity, acoustic absorption coefficient, noise reduction coefficient, compressive strength, and freeze-thaw resistance. The PU test setup is adopted to characterize the acoustic absorption coefficients of concrete in a frequency range from 0 to 3000 Hz. The experimental control variables of the mix design in this research are the void ratio, by using various foam agents including aluminum powder, and acoustic characteristics, by using cellulose fiber and zeolite. It is proven that aluminum powder and cellulous fiber are effective to promote greater porosity and enhance the sound absorption capacity, respectively. A multi-layered perforated panel model is adopted to simulate acoustic absorption characteristics of the developed concrete. The comparison between the model and experiments highlights that the model can fairly predict the acoustic characteristics of the developed concrete.

## 1. Introduction

The growing need for transportation, especially for railways and roads, are inevitable in urban areas due to high population density; however, it generates undesirable noise problems, which even could cause serious health problems to humans. In addition, noise from high speed railways and highway traffic could lead to health risks to wildlife and livestock in rural areas [1]. Therefore, noise control from the ambient environment has become an imperative engineering field in modern society, not only because of recent recognition of noise as a serious health hazard but also because the standard of living and the quality of life are getting more important [2].

One of the effective solutions to dampen noise issues is the usage of porous media, such that various studies have been conducted to understand the noise reducing mechanism within porous media. The major sound absorbing mechanism of porous media is that sound wave energy can change its form to thermal energy through internal friction while a sound wave propagates in open voids (continuous voids) [3]. Therefore, it is important to adequately control the following factors for proper design sound absorption materials: void ratio, pore size, pore aperture size, and thickness of porous layer [4].

The most widely used construction materials, concrete and steel, are, however, sound shielding materials showing acoustic reflection behavior, which could worsen the noise issue both in urban and rural areas. For the sake of reducing noise using construction materials, various attempts have been carried out to develop sound absorbable cement based composites [5–12]. For example, Tiwari et al. [5] reported that by adding 40% volume of cenosphere to the cement matrix, the noise reduction coefficient (NRC) becomes twofold greater compared to that without cenosphere. Sukontasukkul [6] reported that by adopting 20% crumb rubber to replace aggregates in a pre-cast concrete panel, NRC can be increased by about 46%, but the compressive strength decreased by about 78% compared to the control case without crumb rubber. Kim and Lee [7] investigated the influence of flow and aggregate types on mechanical and acoustic characteristics of porous concrete, and they also reported that the total void ratio of porous concrete with aggregates sized 4–8 mm is higher compared to that of other concrete with larger sized aggregates such as 8–12 and 12–19 mm. They also concluded that the compressive strength of porous concrete is not directly proportional to the acoustic absorption performance. Zhang et al. [8] synthesized geopolymer foam concrete (GFC) and tested the acoustic absorption rate of GFC using a modified impedance tube with a specimen thickness of 20–25 mm. They reported that the GFC showed acoustic absorption coefficients of 0.7–1.0 at 40–150 Hz and 0.1–0.3 at 800–1600 Hz with compressive strength of about 12 MPa.

Some important guidelines for the design of sound absorbable concrete from the literature are adopted in this research when designing the mix proportion of sound absorbable high strength concrete. For example, Gerharz [9] recommended using aggregate size of 4–8 mm and a water-cement ratio less than 0.30 for porous concrete with effective sound absorption capacity without a significant loss in compressive strength. Neithalath et al. [10] concluded that cellulose fibers in cementitious composites have the potential for sound absorption

* Corresponding author.
*E-mail address:* shpyo@krri.re.kr (S. Pyo).

https://doi.org/10.1016/j.apacoust.2018.04.002
Received 24 October 2017; Received in revised form 30 March 2018; Accepted 2 April 2018


(a) (b)

**Fig. 1.** Materials used in the study: (a) Zeolite; (b) Cellulose fiber.

with the generation of an increased number of fibers interconnecting porous channels in the matrix. Cuiyun et al. [11] reported that properly sintered zeolite showed better acoustic absorption than glass wool due to their macro-pores and large specific areas.

This research developed and characterized sound absorbable high performance concrete by adopting various foaming agents, cellulose fiber, and high strength concrete design for concrete with high compressive strength and acoustic absorption capacity. To investigate the performance of the developed concrete, void ratios, compressive strength, freeze-thaw resistance, and acoustic absorption coefficient using the PU test setup were quantified.

## 2. Materials and experimental methodology

### 2.1. Raw materials

This experimental program was designed to develop sound absorbable high strength concrete. In order to effectively enhance the sound absorbability of high strength concrete, some important guidelines from the literature were followed as aforementioned in the introduction. For example, the water-to-cement ratio was set as low as 0.25. Two different sizes (3–5 mm and 5–7 mm) of zeolite with density of 2.2 g/cm$^3$ were used as coarser aggregates, as shown in Fig. 1(a). Cellulose fibers were also selected to test their sound absorbability (see Fig. 1(b)). The detailed properties of the cellulose fiber are listed in Table 1. Furthermore, in order to promote additional porosity in concrete, three types of foaming agents and aluminum powder were tested, and their properties are summarized in Table 2. At the same time, the mix design concept of ultra high performance concrete (UHPC) that typically has more than 150 MPa compressive strength (e.g., [13,14]

**Table 1**
Properties of cellulous fiber.

| Index | Averaged length (mm) | Effective diameter (μm) | Elastic modulus (GPa) | Tensile strength (MPa) | Specific gravity |
|---|---|---|---|---|---|
| | 2.92 | 15 | 5.98 | 500 | 1.38 |

**Table 2**
Properties of foaming agents.

| Type | Appearance | Density (g/cm$^3$) | pH |
|---|---|---|---|
| Foam Agent A | Dark brown liquid | 1.19 ± 0.01 | 6.6 ± 0.3 |
| Foam Agent B | Clear liquid | 1.05 ± 0.05 | 7.53 |
| Foam Agent C | Light brown liquid | 1.0 ± 0.05 | 7.0 ± 0.5 |
| Aluminum poweder | Silver-colored powder | 2.7 | – |

**Table 3**
Chemical compositions.

| | | Cement | Silica fume | Silica powder |
|---|---|---|---|---|
| Chemical composition (%) | CaO | 60.6 | 0.27 | 0.20 |
| | $SiO_2$ | 23.0 | 95.03 | 97.2 |
| | $Al_2O_3$ | 3.41 | 0.0 | 0.0 |
| | $Fe_2O_3$ | 3.13 | 0.31 | 0.23 |
| | MgO | 3.68 | 0.64 | 0.31 |
| | $TiO_2$ | 0.0 | 0.67 | 0.77 |
| | MnO | 0.08 | 0.15 | 0.13 |
| | L.O.I. | 2.24 | 2.19 | 0.91 |

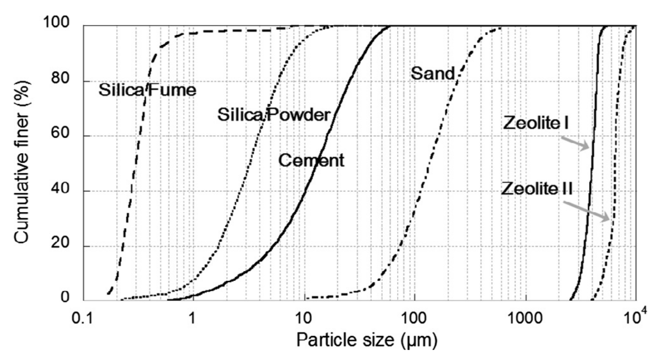


**Fig. 2.** Particle size distribution of the used solid materials.

was incorporated in this research to adequately increase the compressive strength of sound absorbable concrete. Consequently, the following materials typically used in the UHPC mixture were adopted in this research: undensified silica fume containing about 95% of $SiO_2$, ordinary Portland cement, silica powder with a median diameter of 3.15 μm, silica sand with a median diameter of 0.15 mm, and polycarboxylate-based superplasticizer with 25% solid content by weight. Table 3 shows the oxide compositions of cement, silica fume, and silica powder. In addition, the particle size distributions of solid materials used in this study are shown in Fig. 2.

### 2.2. Mix design and mixing procedure

The mix proportions of the developed sound absorbable concrete in this research are given in Table 4. The amount of cement, silica fume, silica power, water, and superplasticizer were fixed for sound absorbable concrete from the series of S-I to S-VII. S-II and S-III were designed to evaluate the effect of foam agent A and the cellulose fiber, respectively, compared to the control case, S-I. Furthermore, the S-IV series was prepared to enhance the compressive strength by replacing the