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Development of a New Type of Environmentally Friendly Porous Concrete

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ABSTRACT

In this study, two concepts for the sustainable use of porous concrete (PoC) were developed using two different approaches. First, the potential for coexistence between PoC and plants was tested. Previous studies have indicated that the strength and durability of ordinary PoC prevents plant roots from growing. Therefore, this research aimed to create a PoC that could be fractured by roots to support plant growth. The possibility of fracturing was investigated by comparing the PoC strength and striped bamboo root-enlargement strength. Second, the effect of water purification was examined using a PoC sphere containing zeolite. PoC specimens (25) were hung in a large water tank. Total phosphorus (T-P) and total nitrogen (T-N) concentrations of water from Lake Biwa were measured for 3 months. The amount of T-N and T-P dramatically decreased in the first 7 days. The water purification effect of the PoC sphere containing zeolite was confirmed.

Keywords. porous concrete, coexistence with plants, fracture by plant roots, water purification, zeolite

INTRODUCTION

The sustainability of porous concrete (PoC) has been studied since the 1990s in Japan. PoC's porous structure of continuous voids, which comprise 20-40% of PoC volume, contributes to "green" concrete, ecosystem conservation, water purification and absorption, sound absorption and insulation, permeable drainage, and landscape (Okamoto and Takeda, 2008). PoC has successfully been applied in Japan, especially in pavements and vegetation beds. New usage and applications for this material should be developed. This study focuses especially on PoC as a sustainable concrete that contributes to conservation of the ecosystem. Sustainability was evaluated using two approaches: (1) The fracture potential of PoC due to plant roots, and (2) the water purification effects of PoC.

The idea of the coexistence of concrete and natural environments has developed with increasing use of PoC for vegetation beds in river or on lakesides (Takeda *et al.*, 2011) (committee report, 2003). In this study, coexistence indicates the fracture of PoC by plant roots as they grow. Therefore, in the first study, the possibility of fracture was studied by comparing the PoC strength and the strength of roots as they grow. In the second study, potential water purification effects were investigated using PoC spheres containing zeolite. This study aimed to develop a new water purification system that conserves hydrological ecosystems. PoC has a highly porous structure; thus, small living creatures and microorganisms can live inside its voids. Additionally, zeolite has an absorptive effect on organic molecules. Both PoC alone and in combination with zeolite were studied using PoC spheres. The experiment was carried out to investigate the changes in total phosphorus (T-P) and total nitrogen (T-N) of water from Lake Biwa, Japan.

FRACTURE POTENTIAL OF POC BY PLANT ROOTS

Overview

In this study, typical material science concerns related to strength and durability can be ignored because the focus is on the coexistence of concrete and natural environments. Strength and durability hinder the growth of plants in many cases. Therefore, the fracture of PoC by plant roots was suggested to be a positive process; the initial strength of PoC protects plants, but as plant roots grow, PoC is fractured by their roots, consequently promoting plant survival and growth. The objective of the experiment was to create a PoC that can be fractured by plant roots and to examine the possibility of fracture. A mix proportion was determined, and material tests were carried out to obtain a lower strength and durability compared with ordinary PoC.

Materials

To create environmentally friendly concrete, decreasing the pH value is one challenge that must be overcome. Therefore, slag was used to decrease the pH value, and artificial lightweight aggregate was applied to achieve a lower strength. The materials used are listed

Table 1. Materials

Materials		Properties
Binder	C	Normal Portland Cement, Density: 3.16 g/cm^3, Fineness: 3340 cm^2/g
	BS	Blast Furnace Slag Cement B, Density: 3.02 g/cm^3, Fineness: 3750 cm^2/g
	BFS	Ground Granulated Blast-Furnace Slag, Density: 2.89 g/cm^3, Fineness: 4180 cm^2/g
	L	Slaked Lime, (Mixed in BFS)
Coarse aggregate	G1	Crushed Stone, 13-20 mm, Density (face dry): 2.68 g/cm^3
	G2	Crushed Stone, 5-13 mm, Density (face dry): 2.68 g/cm^3
	LA	Artificial Lightweight Aggregate, 10-25 mm, Specific gravity: 0.3-0.6, Absorption: 30% or above
Admixture	SP1	Super Plasticizer
	Ad1	Admixture for Porous Concrete
	Ad2	Surfactant Thickener
	Af	Antifoaming Agent (Mixed in Ad2)

in Table 1. Specimens with a Water cement ratio (W/C) of 25%, 50%, and 75% (without water absorption correction) were prepared according to the JCI standard (JCI: Japan Concrete Institute) (Okamoto *et al*., 1998).

Strength tests

Both the binder strength (φ50×100 mm) test and the compressive strength test (φ100×200 mm) were carried out according to JIS A 1108; the splitting tensile strength test (φ100 × 100 mm) was also carried out according to JIS A 1113. The results are shown in Fig. 1 and Fig. 2. The binder strength of BS-Ad2 and BFS-Ad2 (Fig. 1) decreased with increases in the W/C. However, the compressive strength and splitting tensile strength of artificial lightweight aggregate PoC did not show increases with changes in the W/C (Fig. 2). Moreover, artificial lightweight aggregate PoC showed remarkably low strength. The compressive strength was below 1.0 N/mm^2, and the splitting tensile strength was below 0.3 N/mm^2. Therefore, it can be said that the strength of artificial lightweight aggregate PoC was dependent on aggregate strength rather than binder strength.

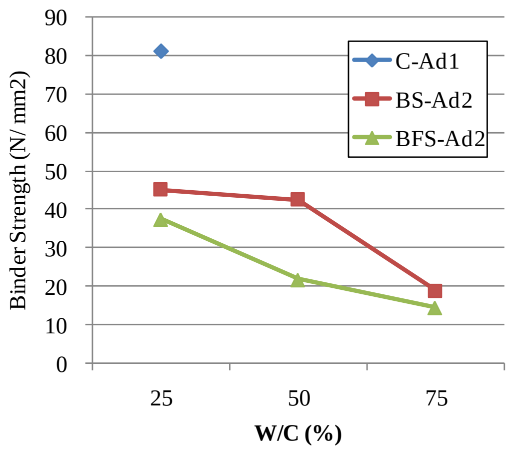

Fig. 1. Binder strength results

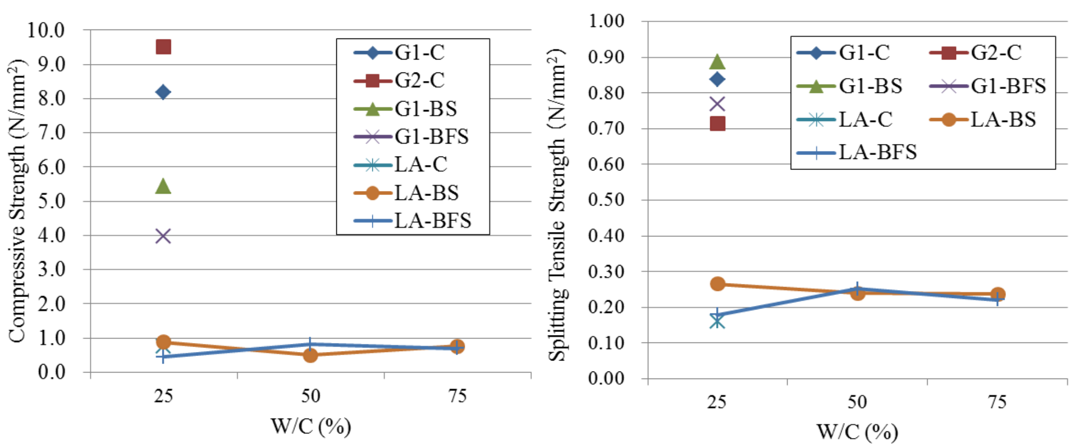

Fig. 2. Compressive strength and splitting tensile strength results

Internal Pressure Test

Two types of hollow, cylinder-shaped specimens (outside: φ100×200 mm; inside: φ26×200 mm) were prepared: (a) W/C= 28%, LA, C and Ad1, and (b) W/C=48%, LA, BFS and Ad2. A silicon tube was inserted into each specimen, and the PoC was fractured by the expansion of the silicon tube using water pressure (Fig. 3). This test defined the internal pressure strength as the maximum pressure before the PoC specimen was fractured. The average internal pressure strengths of (a) and (b) were 0.51 (N/mm^2) and 0.47 (N/mm^2), respectively. These values are shown in Fig. 4.

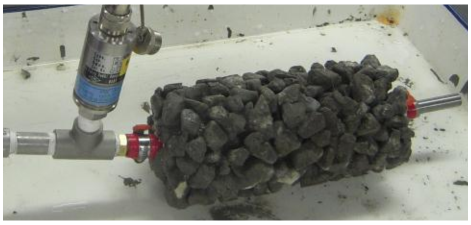

Fig. 3. Internal pressure test

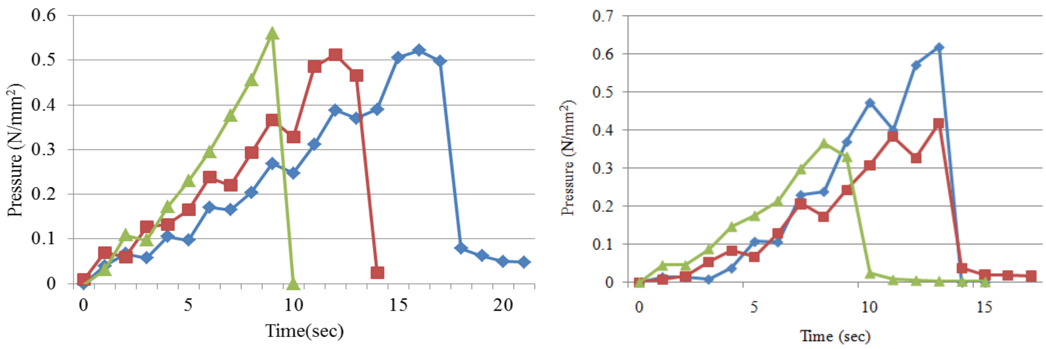

Fig. 4. Internal pressure strength result of (a), at left, and (b), at right

Fracture Patterns of PoC

The fracture patterns of PoC are classified as aggregate fractures, binder fractures, and interface fractures (Maegawa *et al.*, 2005) (Fig. 5). Fig. 6 shows the sections that were destroyed by the strength tests. The picture on the left is the specimen made of crushed stone aggregate, whereas the specimen in the picture on the right is made of artificial lightweight aggregate with the same binder as the former specimen. It was observed that PoC using artificial lightweight aggregate underwent aggregate fractures. By contrast, PoC using crushed stone underwent binder fractures or interface fractures.

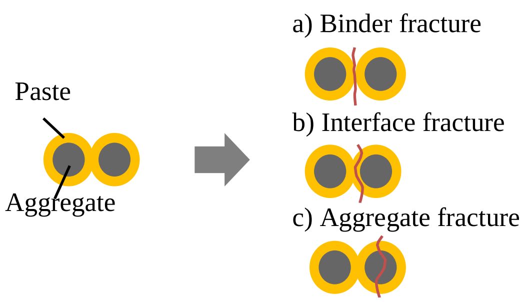

Fig. 5. Fracture patterns

Fig. 6. sections that were destroyed by the strength tests

Evaluation of the fracture of PoC by roots

Overview

The possibility of fracturing artificial lightweight aggregate PoC was investigated by comparing internal pressure strength (Fig. 4) and the strength during the enlargement process of striped bamboo roots.

Measurement enlargement force exerted by the root growth of striped bamboo

A device used to measure the enlargement force exerted by a root during growth in the diametrical direction is shown in Fig. 7 (Ishihara and Tanaka, 2008). This device measures the force of an underground stem as it pushes the receiving section upward. An underground stem is placed between the force-receiving sections, to which a load cell is attached. The result of the enlargement force of the striped bamboo is shown in Fig. 9 (Ishihara and Tanaka, 2008). The enlargement force increased up to approximately 25 N/cm within 12 days.

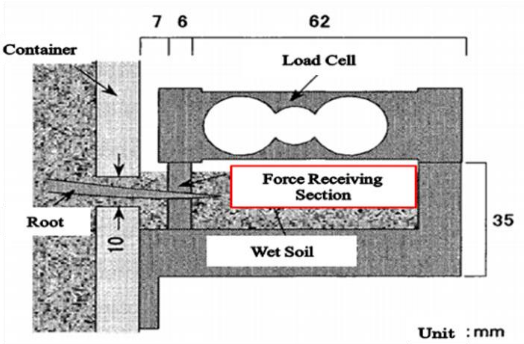

Fig. 7. Device used to measure root enlargement force (Ishihara and Tanaka, 2008)

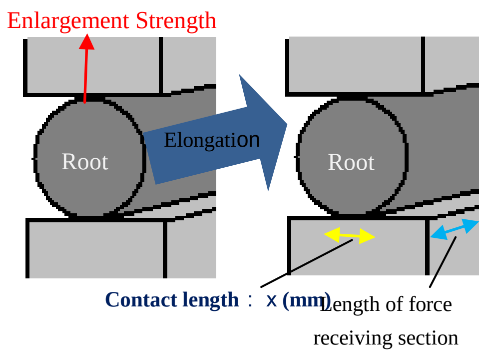

Fig. 8. Force-receiving section

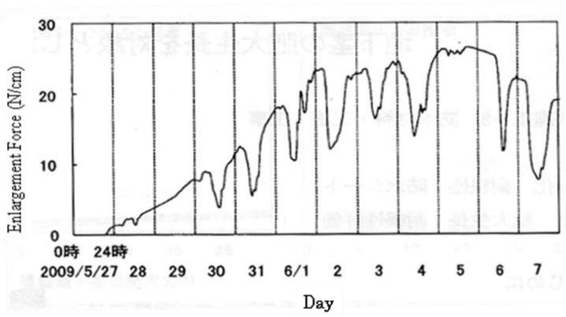

Fig. 9. Enlargement force of striped bamboo (Ishihara and Tanaka 2008)

Evaluation of fracture potential by comparing PoC strength and root enlargement strength

Fig. 8 shows a sectional view of the force-receiving section. The left-side diagram shows the enlargement direction and the elongation direction, whereas the right-side diagram shows the contact length and the length of the force-receiving section. To compare the internal strength of PoC and root enlargement, it was necessary to set the contact length as x mm. When a root pushes up on the force-receiving section, it cannot be shaped properly as a circle. Thus, because the diameter of striped bamboo is approximately 2 to 5 mm (Ishihara and Tanaka, 2008), it was assumed that x=1 to 3 mm. When x=1 mm, the striped bamboo enlargement strength is slightly less than approximately 2.5 N/mm^2, whereas when x=3 mm, the strength is lower, approximately 0.83 N/mm^2. The average internal pressure of (a) was 0.51 N/mm^2, and that of (b) was 0.47 N/mm^2 (Fig. 4); both values were lower than 0.83 N/mm^2 (striped bamboo enlargement strength). Therefore, the artificial lightweight aggregate PoC can be expected to be fractured by striped bamboo.

WATER PURIFICATION EFFECT USING POROUS CONCRETE

Overview

In this study, the removal of (T-P) and (T-N) by PoC spheres was investigated. Previous studies have demonstrated the T-P and T-N removal effect using PoC. Fig. 10 shows a decrease of T-P and T-N concentrations within a month. An additional experiment was carried out by placing zeolite inside PoC spheres to determine whether the removal effect would increase. Zeolite contributes absorbing nutritive salts (Oki *et al*., 1995), and PoC becomes a habitat for small living creatures and microorganisms because of its porous structure. The experiment was conducted following the previous experimental conditions. Spherical PoC specimens (25) containing zeolite were hung in a large water tank (560×375, height: 80 cm) that held 16,800 liters of water (Fig. 11). The test water was taken from the southern, most contaminated part of Lake Biwa in Japan. The test tank was simulated to replicate some of the conditions at Lake Biwa. Thus, the cover was not placed on top of the tank so that the water could be exposed to air and rain. The experiment started in June, 2012 and ran for over 7 weeks. The T-P and T-N levels were examined every 7 days.

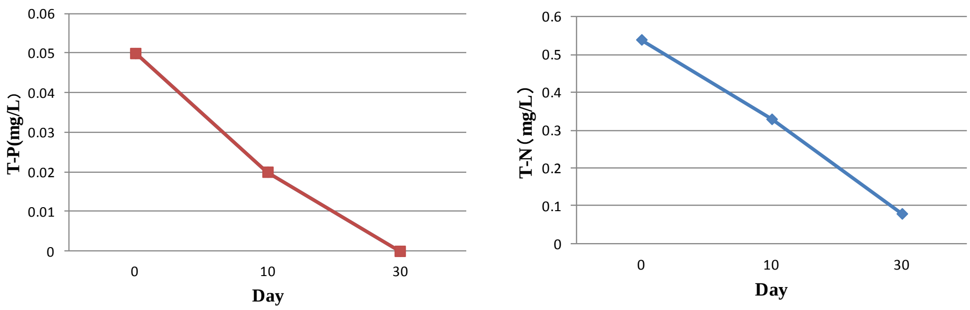

Fig. 10. Changes in T-P and T-N concentrations in a previous study (November 2011)

Materials

Spherical PoC specimens were prepared, and natural zeolite was placed into the nucleus of the concrete (Fig. 12). The materials used were Normal Portland cement, coarse aggregate (grain diameter: 5-13 mm; density: 2.68 g/cm^2), and super plasticizer. Table 2 shows the proportions of the mixture.

Table 2. Mixture proportion

W/C (%)	Porosity (%)	Unit weight (kg/m^3)			
		W	C	G	SP
20.5	25	72	352	1518	3.74

Fig. 11 PoC spheres in water tank

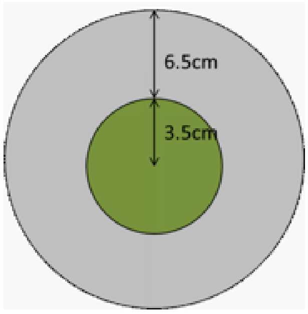

Fig. 12. Model of PoC spheres

Results of the water quality analysis

Fig. 13 shows the changes of T-P and T-N concentrations each week. Both the T-P and T-N concentrations dramatically decreased within a week, but afterward, the values remained constant. Absorption appeared to reach its maximum in approximately 7 days. In the previous experiment using PoC without zeolite (Fig. 10), the T-P and T-N concentrations reached 0.01 mg/L and 0.20 mg/L, respectively, within 20 days. However, the PoC containing zeolite reached the same concentration within a week, suggesting that spherical PoC containing zeolite has a greater effect on water purification than PoC without zeolite.

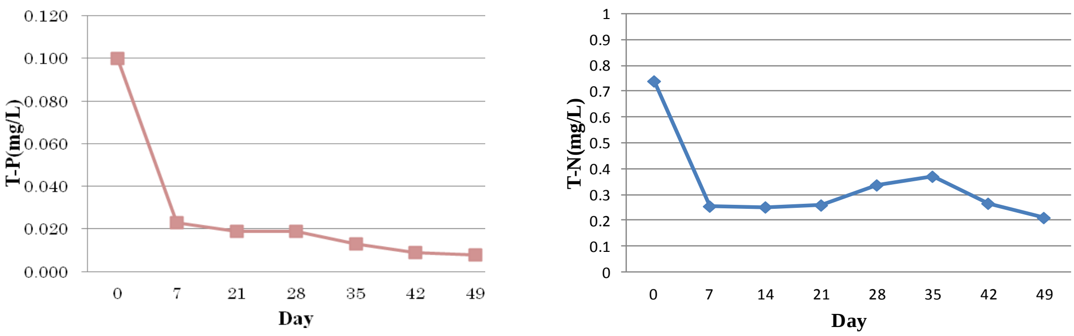

Fig. 13. T-P and T-N concentrations (Since June 2012)

CONCLUSIONS

From this study, the following conclusions can be made:

(1) The potential for coexistence between PoC and plants was discussed. The aim was to create a PoC that could be fractured by roots. In addition, the fracture potential of PoC was analyzed by comparing PoC strength and the strength of roots under growth conditions (Ishihara and Tanaka, 2008). PoC that contains artificial lightweight aggregate is expected to be fractured by striped bamboo roots.

(2) Among the various fracture patterns observed in the PoC (i.e., aggregate fracture, binder fracture, and interface fracture), this study focused on aggregate fractures. Artificial

lightweight aggregate PoC showed remarkably low strength in this study, regardless of W/C. The PoC caused aggregate fractures because its strength was dependent on aggregate strength rather than binder strength.

(3) The water purification capacity of PoC spheres containing zeolite was investigated. By using PoC without zeolite, T-P and T-N concentrations reached 0.01 mg/L and 0.2 mg/L, respectively, within 20 days. However, PoC containing zeolite reached the same concentration within a week. Therefore, PoC containing zeolite demonstrated a more efficient water purification effect compared with PoC without zeolite.

(4) This study proposed new types of environmentally friendly PoC applications using two approaches: research on the fracture possibility of PoC by plant roots and research on water purification effects using PoC.

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