# 論文 An Experimental Study on Greening Porous Concrete

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**ABSTRACT:** The effects of mix proportions on the properties of porous concrete, referred to herein as POC, and its coexistence with plants are discussed in this paper. The use of available volcanic coarse aggregate with high water absorption for greening POC products is evaluated. Moreover, the influence of the thickness of both greening concrete blocks and topsoil on plants growth was explored. According to this investigation, it is recommended for greening POC products to use: a) aggregates with higher water absorption; and b) a mix proportions with aggregate-cement ratio by volume equal to 8 and water-cement ratio of about 35%.
**KEYWORDS:** mix proportions, greening porous concrete, water absorption, strength, permeability, blocks thickness, topsoil thickness, plants

## 1. INTRODUCTION

For the last two decades, the use of porous concrete (POC) was introduced into Japan as an ecological material. All over the country, efforts are increasingly intensified to evaluate POC with the aim of establishing design specifications and developing pertinent design methodologies, compatible with climatic conditions and materials availability. POC is diversely used as permeable concrete material, greening concrete material, and so on.

Several methods for producing POC have been reported. In one method, lightweight aggregate is used [1]. In another one, air bubbles are introduced into the fresh concrete or mortar mass to produce a material with a cellular structure [2, 3]. In one more, the fine aggregates are omitted from the mixture so that a large number of interstitial voids are present [4-8]. In this case POC is known as no-fines concrete and contains pores of large size. The narrow range of aggregate particle sizes ensures a high interstitial void content that approaches 50% in the loose state. The last method is mostly used to produce greening POC [6, 7] because of the ease with which a POC can be finished. However, up to date the influence of mix proportions upon porous concrete properties and its coexistence with plants is not fully understood. For such a reason, the present study was carried out to develop and produce an "adequate" greening POC for road and riverbank sides. The efficiency of the use of high-water absorbing volcanic coarse aggregate for greening POC products is evaluated. The effects of void content, aggregate types, gradation as well as water-cement ratio on the properties of POC are discussed. The study was extended to examine the influence of the thickness of planting POC blocks and topsoil on the growth of plants.

## 2. EXPERIMENTAL WORK

### 2.1 MATERIALS

Ordinary portland cement (specific gravity of 3.15 and blaine of 3290 $cm^2/g$) was used to bind the coarse aggregates that are pumice (P), scoria (S) and crushed limestone (CL). The physi-

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cal properties of coarse aggregates were measured according to the relevant Japanese Industrial Standard. The volcanic coarse aggregates, pumice and scoria, have very high water absorption that varies between 87~109% and 35~40% respectively.

### 2.2 MIX PROPORTIONS AND PROCEDURES

The mix proportions prerequisite was set to a minimum void content of 20% and a minimum compressive strength of 3 MPa [6]. Example of mix proportions with a constant water-cement ratio of 25% is given in Table 1. The mixing procedure, workability inspection and specimens casting were the same as that in our previous work [8]. Briefly, the aggregate content was maintained constant to that of its saturated surface dry bulk density and the cement content was changed. Example, for CL 5-10, the aggregate content was 1647 kg/m$^3$ and the cement contents were 323, 242 and 161 kg/m$^3$ for aggregate-cement ratio by volume, A/C=6, 8 and 12 respectively. The water-cement ratio ranged between 25% and 55%. POC was mixed in a pan-type forced circulating 50 liters' mixer operated at 75% capacity for nearly 3 minutes. The workability of fresh POC was visually inspected to insure that cement paste coats the aggregates, without being too dry to form the necessary fillet nor being so wet as to produce drip off. It was confirmed using a bucket with holes in the bottom described elsewhere [5]. The concrete was placed in the molds in layers of about 10 cm. POC was carefully light hand rammed to ensure its uniform distribution and to avoid aggregate fracture. Rectangular wooden tamper was used to provide for uniform compaction in the corners of greening concrete blocks. Exposed surfaces were finished with trowel. After demolding, specimens were cured in water at 20 ± 2°C. POC blocks were cured on open-air without any special precautions for about 2 months to carbonize theirs exposed surface area.

### 2.3 TESTING METHODS

(1) Test for porous concrete

Void content that accounts for the total volume through which grass's roots can reach the natural soil under the concrete and water can flow inside the sample, was assumed to be a very important content in the experiments. Its values were calculated following the procedure proposed by eco-concrete research committee [9].

Compressive strength tests were performed according to the JIS A 1108 on cylindrical specimens of 10 x 20 cm. Double face capping with sulfur was used.

Coefficient of permeability was measured by using a constant head permeameter at head loss of 12 cm. Cylindrical specimens of 10 x 10 cm were used for POC with maximum coarse aggregate size of 25 mm or finer, and cylindrical specimens of 15 x 15 cm were used for POC with maximum coarse aggregate size exceeding 25 mm.

Capillary rise tests were conducted at 20 ± 2°C and 80% (RH) on specimens previously tested for permeability. The specimens were oven dried and immersed to a depth of about 2 cm in water.

Water absorption tests were carried out on specimens previously tested for permeability and oven dried. The specimens were weighed before and after immersion in water for 24 hours.

(2) Vegetation

The vegetation study was carried out in two steps: a) First, the coexistence of commercially available turf grass with POC was investigated. POC blocks were made from several mixes of different crushed limestone gradations and constant water-cement ratio of 25%. POC blocks were covered with a loam of 3 cm of thickness. The present loam is the usually used soil for roadsides' vegetation because of its satisfactory moisture content and permeability qualities. The POC blocks had 33 cm of width, 38 cm of length and 5 cm of thickness. b) Second, the thicknesses of planting concrete blocks and topsoil were varied. Planting concrete blocks had 5, 10, 15 and 20 cm of thickness and the thin cover of topsoil had 3, 6 and 10 cm of thickness. The pores in POC were filled with mixture of peat moss, soil, fertilizer and water. The fresh concrete had a pH of about 12 and the mixture had pH of 4.75.

Tall fescue (*Festuca arundinacea* L., Schreb) and perennial ryegrass (*lolium perenne L.*, Manhattan II) were used as plants. Such plants were most frequently used for roadsides to be aesthetically acceptable because of increased public awareness of environment quality dictation.

In this study, the growth of the plants was evaluated by measuring the length of plants in 5 predetermined locations on the top of each block. It was confirmed by measuring the density of the plants in term of their weight.

## 3. RESULTS AND DISCUSSION

### 3.1 MECHANICAL PROPERTIES OF POC

The large pores in POC are among the most important factors that affect its properties [5] and applications [7]. To understand the influence of this factor, quantitative estimation of pores' diameter was done by circular transformation from photos of cut concrete cross-section. Table 1 summarizes the properties of POC using crushed limestone with various gradations, and with different cement contents. These results clearly show that the number of pores decreases with an increase in aggregate gradation. The thickness of cement paste coating the aggregate is inversely proportional to the aggregate-cement ratio. When the thickness of cement paste decreases, the diameter of pore is increased and the POC becomes weaker and more permeable. For a given aggregate-cement ratio, permeability increment with an increase in aggregate gradation is recorded.

The maximum compressive strength of POC made with volcanic aggregate did not exceed 3 MPa. It was comparatively lower than that of POC made with crushed limestone.

Fig.1 presents a relationship between capillary rise and equivalent spherical diameter of aggregate used for various POCs of the same A/C and W/C. Capillary rise, mean for the rise for three specimens, increases with a decrease in aggregate diameter. Capillary rise for POC made with volcanic aggregates is higher than that made with crushed limestone of the same equivalent spherical diameter. That of POC made with crushed limestone varies between 30 and 56 mm.

The water absorption, reported to be lower for POC made with conventional aggregate [2], is about 3%, 22% and 50% for that made with crushed limestone, scoria and pumice respectively.

**Table 1 Mix proportions and properties of POC using crushed limestone**

| Mixture No. | R.a.s (mm) | A/C | C (kg/m$^3$) | W/C (%) | d (mm) | N | $\phi$ (mm) | t ($\mu$m) | Vc (%) | f'c28 (MPa) | k (cm/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 6 | 323 | | | 100 | 1.68 | 293 | 27.10 | 10.55 | 1.48 |
| 2 | 5-10 | 8 | 242 | | 8.98 | 103 | 1.73 | 220 | 33.00 | 5.62 | 2.37 |
| 3 | | 12 | 161 | | | 113 | 1.70 | 146 | 35.10 | 3.30 | 2.60 |
| 4 | | 6 | 310 | | | 69 | 2.32 | 514 | 29.50 | 10.87 | 1.56 |
| 5 | 10-15 | 8 | 233 | | 15.54 | 58 | 2.64 | 387 | 34.90 | 5.06 | 2.89 |
| 6 | | 12 | 155 | | | 65 | 2.85 | 257 | 35.00 | 4.26 | 3.80 |
| 7 | | 6 | 308 | | | 45 | 3.26 | 673 | 29.20 | 11.15 | 2.45 |
| 8 | 15-20 | 8 | 231 | | 20.00 | 43 | 3.44 | 505 | 34.60 | 5.68 | 3.75 |
| 9 | | 12 | 154 | 25 | | 47 | 3.60 | 336 | 36.70 | 3.77 | 4.85 |
| 10 | | 6 | 309 | | | 30 | 4.59 | 801 | 29.80 | 11.05 | 1.30 |
| 11 | 20-25 | 8 | 232 | | 23.36 | 33 | 5.06 | 602 | 34.60 | 4.10 | 3.21 |
| 12 | | 12 | 154 | | | 33 | 5.31 | 399 | 37.80 | 3.63 | 3.51 |
| 13 | | 6 | 318 | | | 40 | 2.75 | 460 | 25.80 | 12.48 | 1.22 |
| 14 | 5-20 | 8 | 239 | | 15.27 | 45 | 3.02 | 346 | 33.80 | 6.21 | 2.70 |
| 15 | | 12 | 159 | | | 47 | 3.17 | 230 | 35.50 | 4.19 | 3.58 |
| 16 | | 6 | 311 | | | 53 | 9.28 | 957 | 29.37 | 6.72 | 4.98 |
| 17 | 20-40 | 8 | 233 | | 29.70 | 39 | 10.61 | 717 | 34.68 | 4.33 | 8.26 |
| 18 | | 12 | 156 | | | 52 | 9.77 | 480 | 30.38 | 2.83 | 6.65 |

R.a.s: Range of aggregate size, A/C: aggregate-cement ratio by volume, C: cement content, W/C: water-cement ratio, d: equivalent spherical diameter of aggregate, N: Number of pores per 100 cm$^2$, $\phi$: Average diameter of pore, t: Average thickness of cement paste as binder, Vc: experimental void content, f'c28: compressive strength (28 days) and k: permeability.

## 3.2 COEXISTENCE OF POROUS CONCRETE WITH PLANTS

The smallest mean pore diameter (1.68 mm) of POC shown in Table 1 exceeds sufficiently the maximum root diameter (0.72 mm) measured for roots from several carefully crushed blocks.

Fig.2 shows turf grass length and weight versus aggregate-cement ratio. Up to 5 months the growth of grass is almost indistinguishable for all aggregate-cement ratios. However, after that time the grass growth decreases significantly for any aggregate gradation in the case of A/C=6. Therefore, the decrease of grass growth could be due to the higher pH of the surface of POC and very low capillary rise for POC made with higher cement content. Moreover, as shown in Table 1, for an aggregate-cement ratio equal to 8, compressive strength and total void content of all POCs fulfill the required conditions of greening concrete. For such a reason, a medium cement content is adopted. Also an increase in water-cement ratio and an injection of a mixture of peat moss, soil and fertilizer to reduce the pH at the surface of POC and to improve its capillary rise was done.

Fig.3 shows a relationship between water-cement ratio (W/C) and compressive strength of POC using crushed limestone with the size range of 5 to 20 mm. As illustrated graphically, an increment in W/C by 10% increases the compressive strength significantly. An increase in W/C by 10% reduces the void content of about 2.5% and slightly the pH of the fresh concrete to 11.6. No significant effect on the continuity of voids was noticed. Consequently, on the following part of vegetation, a W/C of 35% is adopted for all mixtures.

Fig.4 depicts the effects of aggregate type, aggregate gradation and POC thickness on tall fescue growth at 23 weeks after planting. Herein POC is covered with a topsoil of 6 cm of thickness. Regardless of the aggregate type, the thickness of POC blocks influences the growth of plants. The thinner blocks give the better growth of grass.

Fig. 5 depicts the influence of aggregate gradation on POC texture and tall fescue growth in POC using crushed limestone. This influence is expressed in term of POC average pore diameter and variation of grass weight and length. Fig. 5 was plotted using the results presented in Table 1 since an increase in W/C by 10% does not reduce the average pore size significantly. The use of bigger coarse aggregates gives the larger pores and the better grass growth. However by increasing the average pore diameter from 5 to 10 mm, no significant amelioration in the growth of grass is noticed.

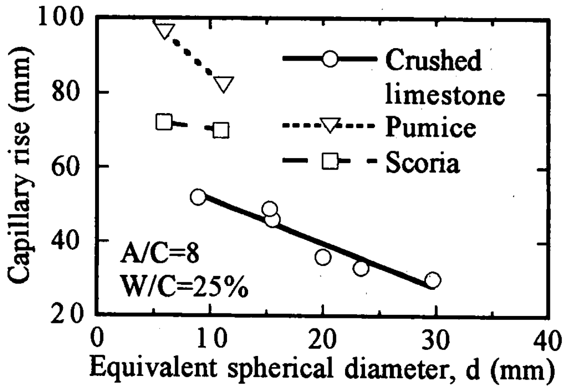



Fig.1 Relationship between capillary rise and equivalent spherical diameter of aggregate used for POC with A/C = 8.

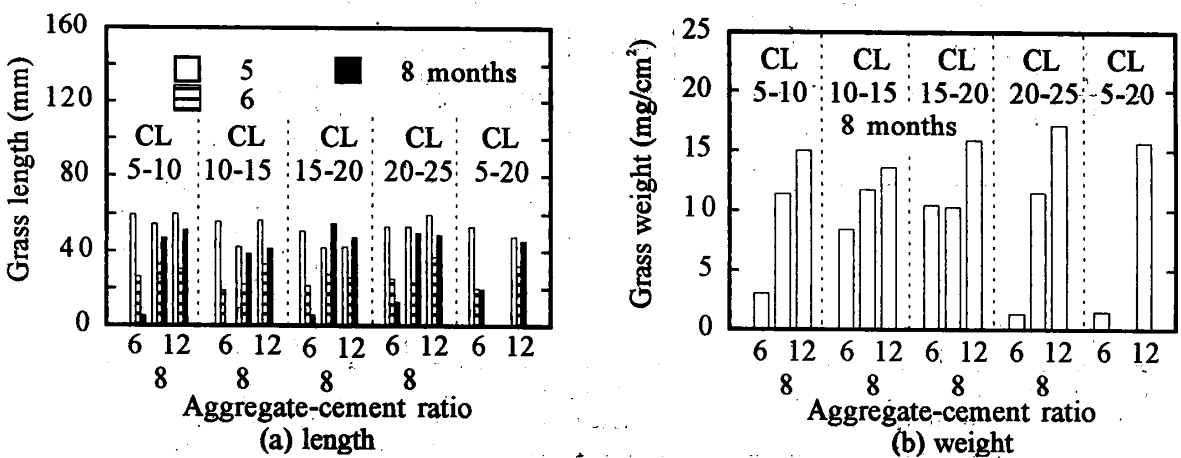



Fig.2 Effect of aggregate-cement ratio on turf grass growth in POC using crushed limestone.

Fig.6 reports the effects of POC and topsoil thicknesses on Manhattan II growth. Herein, typical results of plant growth for 3 different POCs at 23 weeks after planting are plotted. Clearly for comparable topsoil thickness, the coexistence of Manhattan II with POC made with volcanic aggregates is better than that with POC made with crushed limestone of identical aggregate gradation. This could be a result of the high water absorption and capillary rise for POC made with volcanic aggregates. Furthermore, for POC blocks of the same thickness, the grass growth is better for blocks covered with thicker layer of soil.

Fig.7 shows a relationship between Manhattan II growth at 23 weeks after planting and ag-

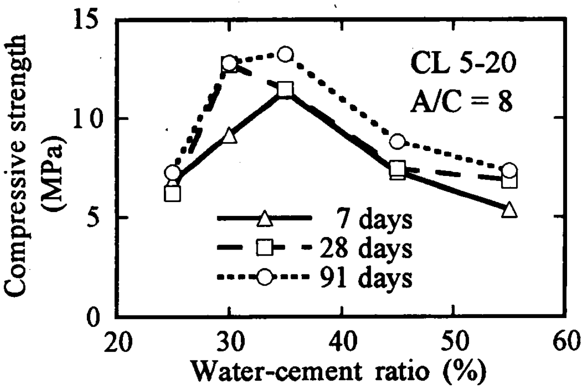



Fig.3 Relationship between water-cement ratio and compressive strength of POC using crushed limestone with size range of 5 to 20 mm.

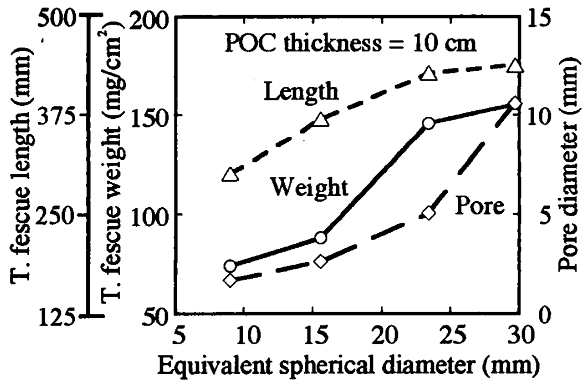
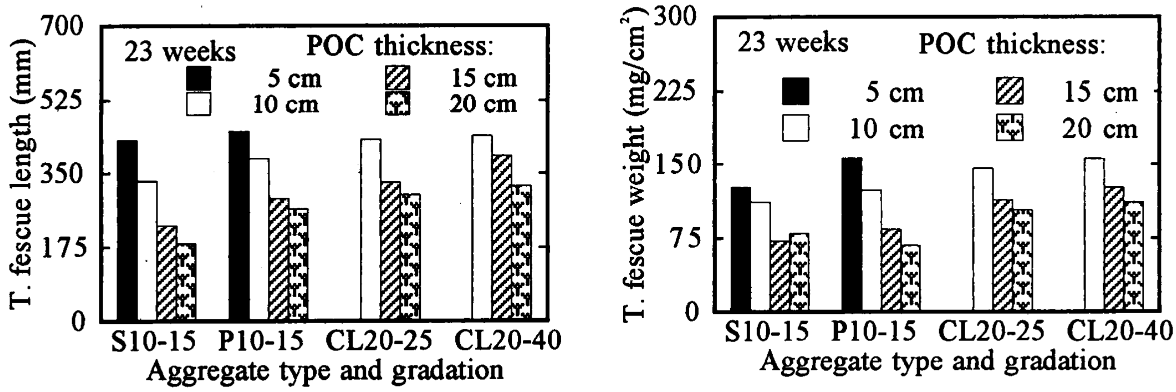



Fig.5 Influence of aggregate gradation on POC texture and tall fescue growth in POC using crushed limestone.




(a) length (b) weight

Fig.4 Effect of aggregate type, gradation and POC thickness on tall fescue growth at 23 weeks after planting.

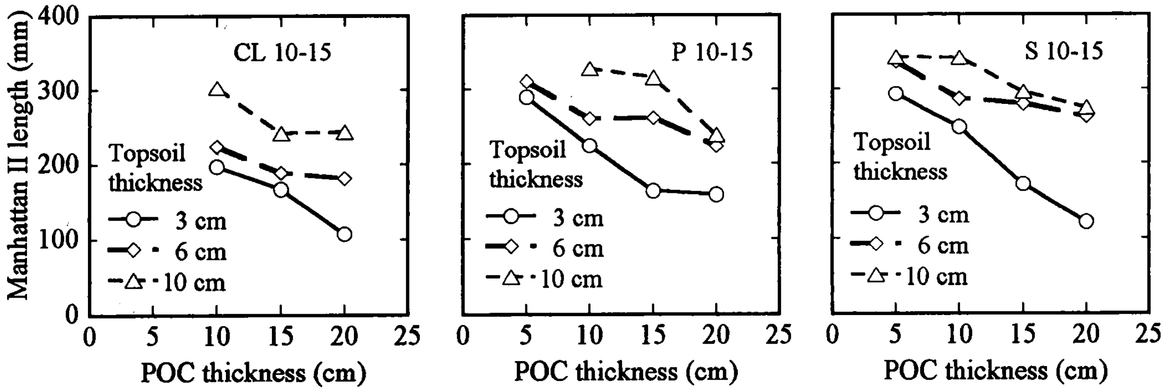



Fig.6 Influences of POC and topsoil thicknesses on the growth of Manhattan II at 23 weeks after planting in POC using various aggregates.

gregate gradation of POC made with crushed limestone and covered with soil of different thicknesses. As illustrated here, the effect of topsoil thickness on Manhattan II growth is significant only for smaller aggregate gradation. An increase in topsoil thickness does not lead to a better growth of plants for POC made with larger aggregate gradation. In addition for 6 cm of topsoil, no considerable difference on plants growth is noticed. Further, it is of interest to notice that color change tendency of plants from green to yellow is depended on aggregate type, POC thickness and topsoil thickness. It is faster for POC made with crushed limestone. It is increased with an increase in POC thickness and a decrease in topsoil thickness.

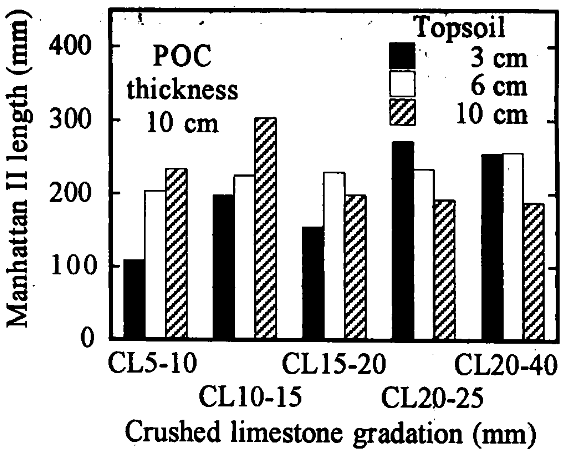



Fig.7 Relationship between Manhattan II growth at 23 weeks after planting and aggregate gradation of POC using crushed limestone.

## 4. CONCLUSIONS

The present study investigating the effect of mix proportions on properties of POC and its coexistence with plants is extended to evaluate the effect of concrete blocks and topsoil thicknesses on the plant growth, and led to the following conclusions:

1. The strength of POC is governed simultaneously by the water-cement ratio and cement content. For identical cement content and water-cement ratio, compressive strength of POC made with volcanic aggregate is very lower than that of POC with crushed limestone.
2. Permeability is increased with any increment in aggregate gradation and any decrease in cement paste content.
3. Aggregate gradation, cement content, and water-cement ratio influence the texture of porous concrete and hence significantly its coexistence with plants. Aggregate-cement ratio equal to 8 and water-cement ratio of about 35% are recommended for greening POC products.
4. Capillary rise is proportional to the equivalent spherical diameter of the various POC. It increases with a decrease in aggregate size. Thus voids within the body of POC should be filled with water retention material to ensure better growth of plants.
5. Aggregates of higher water absorption are highly recommended to produce greening POC, if they can fulfill the condition of strength requirement.
6. The thicknesses of concrete blocks and topsoil affect the growth of plants.

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