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LONG-TERM PLANT-GROWING PERFORMANCE OF POROUS CONCRETE WITH VARYING AMOUNTS OF OYSTER SHELL AGGREGATE

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Oysters are produced in each district in Japan, and Hiroshima Prefecture is especially famous as a high producing district. Accordingly, the production of oysters has created oyster shells as a by-product. Oyster shell porous concrete (OyPoC) is porous concrete using crushed oyster shells as aggregates. In previous researches, it was found that OyPoC with finely crushed oyster shell had high plant-growing performance. However, all of the planting test periods were less than three months; the long-term plant-growing performance of OyPoC had not been clear. In this study, the plant-growing performance of OyPoC was investigated by conducting long-term planting tests over one year. OyPoC and hybrid porous concrete (HyPoC), which was combined with OyPoC and crushed stone porous concrete, were prepared for the planting tests. From the test results, the plant-growing performance of OyPoC was higher than that of HyPoC because OyPoC had much higher oyster shell aggregate than HyPoC. In contrast, there was a risk of the severe summer drought withering the grass on OyPoC and the watering in the summer was found to be important.

Keywords: By-product, Crushed oyster shell, Urban greening, Planting foundation, Long-term planting test, Water pumping performance.

1 INTRODUCTION

Japan is the fourth highest oyster producer in the world after China, South Korea, and the United States. Oysters are produced in each district in Japan, including Hiroshima Prefecture, where Kure College is located, which is especially famous as a high producing district. The production of oysters in Hiroshima in 2017 was 18,708 tons, which was 62.7% of the Japanese production of 29,846 tons (Hiroshima Prefectural Agriculture, Forestry and Fisheries Department 2019). Accordingly, the production of oysters has created oyster shells as a by-product. Untreated oyster shells in storage facilities emit a foul odor and lead to the destruction of the landscape. A few researchers have studied on the feasibility of crushed oyster shells as fine aggregate for mortar (Yoon *et al.* 2003) and concrete (Yang *et al*. 2010). However, oyster shells decreased the strength of the cementitious materials because of their porous microstructure.

Porous concrete is a special concrete wherein single-sized aggregates are bonded with cement or mortar, which is usually called "pervious concrete" in the United States (ACI Committee 522 2013). The authors have investigated the plant-growing performance of oyster shell porous concrete (OyPoC) containing crushed oyster shell aggregate. OyPoC is expected to apply a planting foundation, which is a low-strength structure for urban greening. Urban greening is one of the effective solutions for the mitigation of the urban heat island effect because the evapotranspiration of plants reduces atmospheric temperature. In previous researches, it was found that OyPoC with finely crushed oyster shell had high water pumping performance and high plant-growing performance (Horiguchi 2018). However, the weakness of oyster shell aggregates caused significantly low compressive strength of OyPoC. The oyster shell aggregates had 10% less crushing strength than crushed stone (Horiguchi and Takemura 2008). Additionally, all of the planting test periods were less than three months; the long-term plant-growing performance of OyPoC had not been clear.

In this study, the plant-growing performance of OyPoC was investigated by conducting long-term planting tests over one year. OyPoC and hybrid porous concrete (HyPoC), which was combined with OyPoC and crushed stone porous concrete, were prepared for the planting tests.

2 MATERIALS AND METHODS

2.1 Specimen Preparation

In this study, two kinds of porous concrete, OyPoC and HyPoC, were prepared. HyPoC was combined with OyPoC and crushed stone porous concrete, namely OyPoC, was filled into the voids of crushed stone porous concrete. The oyster shell aggregates were made of oyster shells collected from a storage facility in Kure, Hiroshima Prefecture. The oyster shells were crushed with a shell crusher and classified with 0.3 mm sieve. The particle size of oyster shell aggregates ranged from 0.3 to 5 mm, and the oven-dry density and the absorption were 1.67 g/cm^3 and 21.7% respectively. Crushed stone with a particle size of 13 to 20 mm, the oven-dry density of 2.66 g/cm^3 and the absorption of 0.85 %, was also used for HyPoC.

The plant-growing performance of the HyPoC depended on the amount of the OyPoC in the voids. In this study, the ratio of the OyPoC to the voids in crushed stone porous concrete by volume was defined as the OyPoC volume ratio. The volume ratios of 150 and 200% were employed for producing the specimens. Table 1 represents mixture proportions for OyPoC and crushed stone porous concrete. Portland blast-furnace slag cement type B, specified in JIS R 5211, was used. For both the OyPoC and crushed stone porous concrete, the water-cement ratio by mass (W/C) was kept at 25%. The ratio of cement paste to aggregate by volume (p/a) of the OyPoC was 30%, and that of crushed stone porous concrete was 20 %.

Table 1. Mixture proportions.

Aggregate type	W/C (%)	p/a (%)	Unit weight (kg/m^3)			
			W	C	A	Ad*
Oyster shell	25	30	69	277	1059	1.38
Crushed stone		20	49	196	1518	0.59

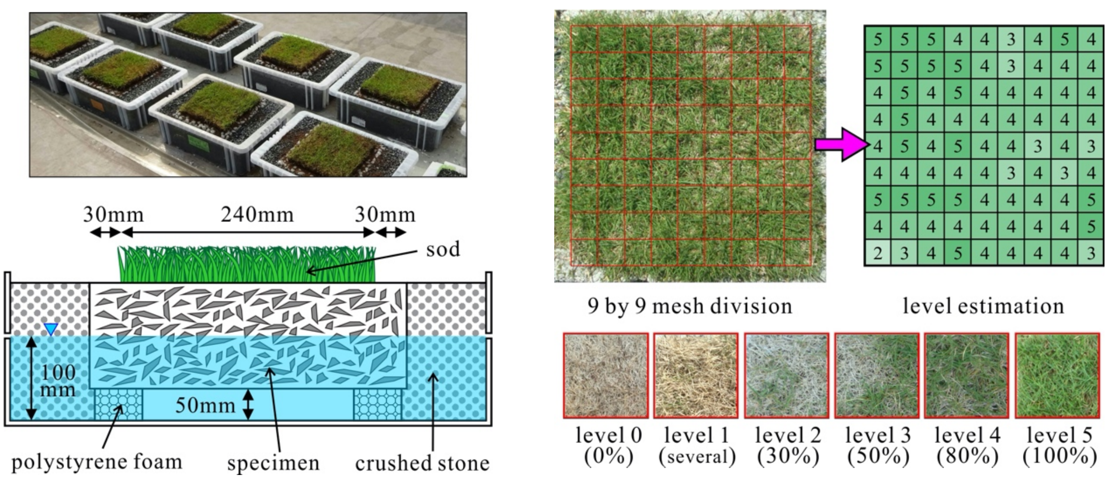
* Polycarboxylic acid-based air-entraining and high-range water reducing admixture

The specimens for the OyPoC were mixed with an omni mixer. In contrast, three mixers were used for mixing HyPoC. An omni mixer and a biaxial forced mixer were used for mixing the OyPoC and crushed stone porous concrete respectively, and two types of porous concrete were mixed in a drum mixer. The plate specimens of 300 × 300 × 100 mm were used for the planting test. The mixture was filled into a mold in two approximately equal layers and compacted each layer with the jigging method. In the jigging method, one side of a square section of the mold was raised about 30 mm and dropped in such a way as to slap a cement concrete floor. Each layer was compacted by dropping 20 times, five times on each side. A steel trowel was used to level the surface of the specimen. The specimen in the mold was covered with wet burlap and plastic sheets for 24 hours to prevent drying. All of the specimens were demolded 24 hours after casting and immersing in 20 ± 2 °C water for six days.

2.2 Planting Test

The planting tests were conducted on the rooftop of a four-story building located in Kure College. Figure 1(a) shows a schematic diagram of the planting test. The specimen was placed in a plastic container with two holes, each on four sides to keep the water level in the container less than 100 mm. *Zoysia japonica* sod was cut into 240 × 240 mm square and directly placed on the surface of the plate specimen. During the first week after setting sods, all plants were supplied with water daily. However, half of the specimens were not watered, and the remainder was watered about once a week. The planting tests were conducting for 445 days, from September 25, 2017 to December 14, 2018.

The grass cover level by the mesh method, the sod moisture content, and the water level in the container were measured to estimate the plant-growing performance of porous concrete. In the mesh method, a digital image of grass was divided into 81 areas using a 9 x 9 mesh as shown in Figure 1(b). The grass cover level in each area was evaluated on a scale of zero to five and averaged. A soil moisture meter was used to measure the sod moisture content, which could measure the moisture values of 12.1 to 58.1% via changes in the electrical resistance. The water level was measured outside of the translucent container with a ruler.



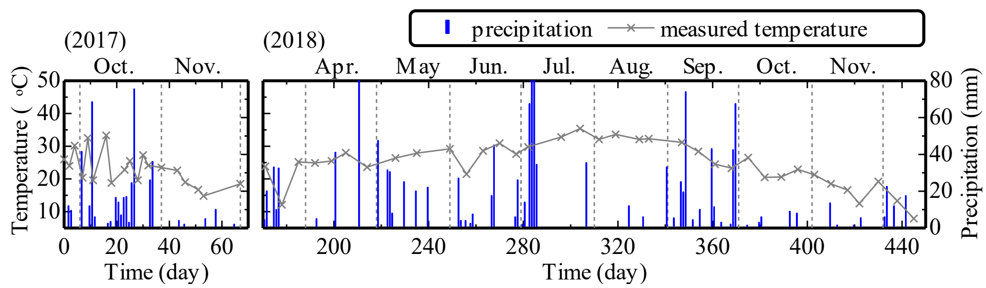
(a) Schematic diagram of planting test. (b) Grass cover level.

Figure 1. Planting test.

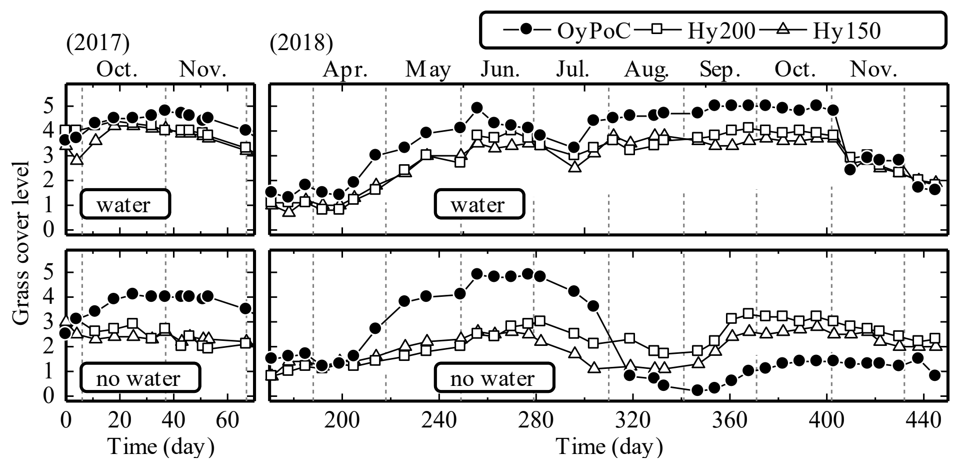
3 RESULTS AND DISCUSSION

Figure 2(a) shows the weather data at the test site from September 25, 2017 to December 14, 2018. The precipitation data at Kure, Hiroshima Prefecture was collected from the Japan Meteorological Agency (2020) and a thermometer was used for measuring the temperature at the site. The temperature decreases in the winter, withering all of the grass on the specimens, and the planting test was suspended from the beginning of December 2017. The test was resumed from the middle of March 2018 when the temperature was increasing.

Figure 2(b) shows the grass cover level of the OyPoC and HyPoC evaluated by the mesh method. Hy150 and Hy200 in the figure refer to HyPoC with the OyPoC volume ratios of 150 and 200%, respectively. As shown in Figure 2(b), the OyPoC had a higher grass cover level than the HyPoC during the entire test period in the test with watering. The results of the test without watering also showed that the grass cover level of OyPoC was higher than that of HyPoC, except for the data from August to December 2018. July and August had very little rain in 2018; the number of the days of rain with a rainfall amount of 0.5 mm or more was only three from the beginning of July to August 30. Most of the grass on the OyPoC died due to the shortage of rain and did not recover even when September had a lot of rain. Regardless of watering, Hy200 had a slightly higher grass cover level compared with Hy150. However, the differences between their values were small. In the planting test without watering, the grass cover level for both Hy200 and Hy150 decreased from July to August 2018, as well as the OyPoC. In contrast, the rainfall in September recovered some part of the sod on the HyPoC, and both of the HyPoC had higher grass cover level than the OyPoC from September 2018.



(a) Weather data at the test site.



(b) Grass cover level of OyPoC and HyPoC

Figure 2. Weather data at the test site and the grass cover level of OyPoC and HyPoC.

Figure 3 shows the moisture content of the sod on the OyPoC and HyPoC during the test period. According to Figure 3, it was found that the change in the moisture content of the sod was correlated with the plant growth on the porous concrete. The moisture content of the sod on the OyPoC was higher than that of the HyPoC during the entire test period in the planting test with or without watering. The sod of the OyPoC in the planting test without watering always had the lowest value from the beginning of July to August 30 when most of the grass on the OyPoC had died. Some of the data of Hy200 were higher compared with Hy150; however, most of their data had similar values.

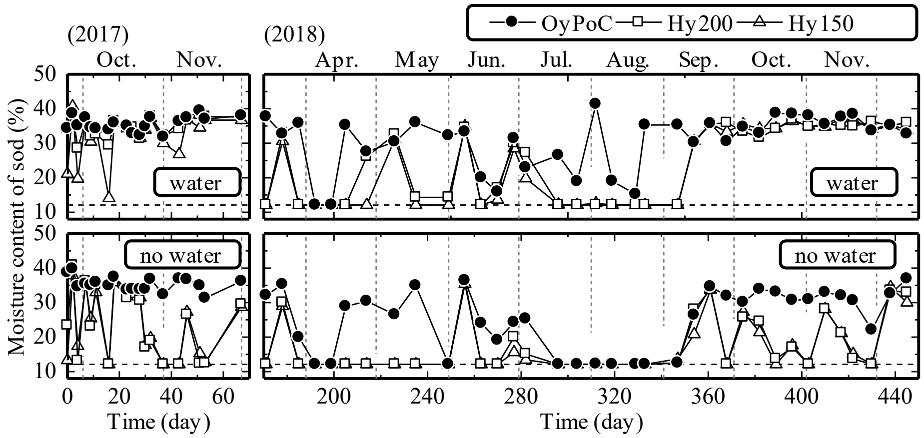


Figure 3. Moisture content of sod on OyPoC and HyPoC.

Figure 4 shows the change in the level of water in a container with the OyPoC and HyPoC. The water levels for both the OyPoC and HyPoC during the test period were usually lower than 100 mm regardless of watering, as seen in Figure 4. The result suggests that the porous concrete with oyster shell aggregates pumped water stored in the container to the grass on the specimens. The container with the OyPoC sometimes had slightly lower water levels than those of the HyPoC, and the water levels of containers with Hy150 and Hy200 were almost the same value.

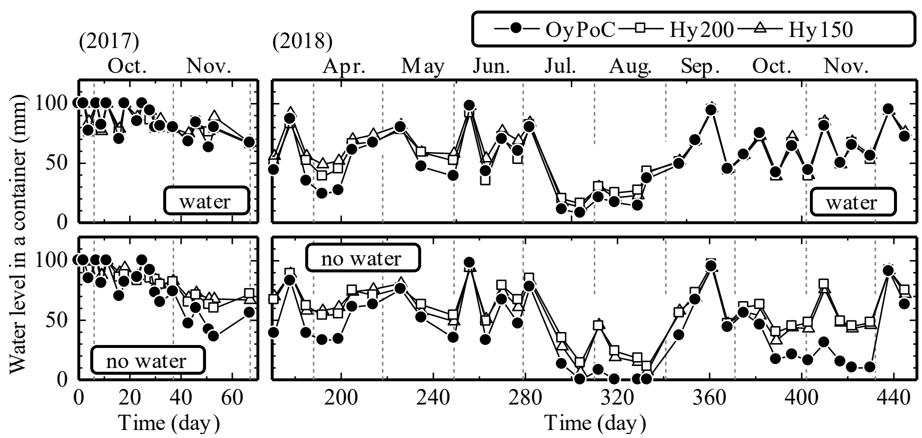
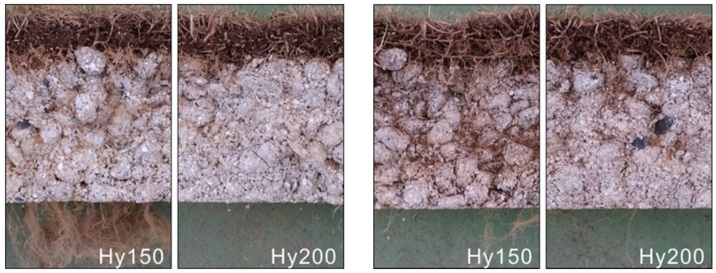


Figure 4. Level of water in the container with OyPoC and HyPoC.

All of the HyPoC were split in half after the end of the planting tests in the manner of the splitting tensile strength test. The cross sections were observed to investigate the root growth into the specimens during the test period. On the other hand, the planting test with the OyPoC was continued even after December 2018, and the observation on the cross section of the OyPoC was not made. Figure 5 shows the cross section of the HyPoC after the planting test. From the visual observations, most of the roots observed in the specimens were very thin, and Hy150, in the test with watering, had the most roots of four specimens. Many roots were found to penetrate Hy150 because the specimen had some larger voids due to the low OyPoC volume ratio.



(a) Water (b) No water

Figure 5. Cross section of HyPoC after the planting test.

4 CONCLUSIONS

In this study, the plant-growing performance of OyPoC was investigated by conducting long-term planting tests over one year. OyPoC and hybrid porous concrete (HyPoC), which was combined with OyPoC and crushed stone porous concrete, were prepared for the planting tests.

From the results of the planting test over one year, the long-term plant-growing performance of the OyPoC was higher than that of the HyPoC because the OyPoC had much higher oyster shell aggregate than the HyPoC. The OyPoC with finely crushed oyster shell could bring water upward in the specimen, and the water moistened the grass and helped the plant growth on the specimen. In contrast, there was a risk of the severe summer drought withering the grass on the OyPoC, and the watering in the summer was found to be important even if the OyPoC had high plant-growing performance. The OyPoC volume ratio had little effect on the plant-growing performance of the HyPoC even if the root growth into the specimens was different in each of the HyPoC.

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