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STUDY ON PHYSICAL PROPERTIES AND GRASS GROWTH CAPACITY OF POROUS CONCRETE

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ABSTRACT: In Japan, sufficient consideration is required for the natural ecosystem and landscape in the plan of river revetment. The current Rivers Act, in which the environment was recently added to conventional flood control and water use as an objective of river management, was applied in 1997. Furthermore, the basic guideline of Nature-oriented River Management was presented in 2006, and the good environment of rivers was recovered from river planning, considering the natural ecosystem and landscape, and the relationship between man and river would be rebuilt. Due to the backgrounds has mentioned above, river revetments using porous concrete have been focused on. Porous concrete is green concrete in which plant roots, water, and air can pass through the pores, and organisms can grow. It is required to have the strength necessary for safety as a revetment and have many pores. In this study, when the condition of "Low cost" was added to these conditions, hydroxyapatite (FbP) of the fishbone derivation was noticed to clear all these conditions. Also, physical property (strength, permeability, and porosity) tests and western turf grass growth tests are carried out for the FbP mixed porous concrete. According to the test results, the target values for the physical properties of the FbP mixed porous concrete are achieved. Furthermore, the FbP has a function to improve the plant growth environment of porous concrete since the leaf length of the germinated western turf in the FbP mixed specimens is longer than that in the non-FbP mixed specimens.

Keywords: Porous concrete, Green concrete, FbP, Grass growth Capacity, Western turf grass

1. INTRODUCTION

In Japan, sufficient consideration is required for the natural ecosystem condition of flora and fauna inhabiting and growing in rivers and the landscape of rivers in the plan of river revetment. The current Rivers Act, in which the environment was recently added to conventional flood control and water use as an objective of river management, was applied in 1997. Furthermore, the basic guideline of Nature-oriented River Management was presented in 2006, and the good environment of rivers was recovered from river planning, considering the natural ecosystem and landscape, and the relationship between man and river would be rebuilt.

Due to the backgrounds has mentioned above, river revetments using a new material called porous concrete in which the plants can grow have been focused. Porous concrete is green concrete in which plant roots, water, and air can pass through the pores, and organisms can grow. Porous concrete was developed in Western Europe around the middle of the 19th century, and it was introduced to Japan via the USA. The main application of porous concrete in Western Europe and the USA was pavement. When porous concrete was introduced to Japan, it has been used not only as pavement, but also as environmentally friendly concrete, such as flood control, water purification, sound absorption, acoustic isolation, plant growth, and especially the planting base [1].

It is necessary for porous concrete as the planting base to satisfy the contradictory condition, the high strength condition necessary for the safety as a river revetment, and the high porosity condition. While porous concrete, which has the strength necessary for the safety as a river revetment and has many pores is the most ideal, the strength of porous concrete generally tends to decrease with an increase in voids. Therefore, it is difficult to satisfy the conditions that porous concrete has at the same time enough strength and many pores. The valid technology for achieving both conditions is the carbonation curing of concrete. Generally, the carbonation reaction of concrete is regarded as a cause of deterioration of concrete since it destroys nonconductive coating film for protecting steel. However, it has been reported to significantly density concrete by carbonation reaction according to curing method and reaction period, besides it has already been revealed to increase concrete strength by carbonation curing while adding special admixture [2,3]. Furthermore, it has been revealed to secure nitrate-nitrogen necessary for growing plants by lowering the pH value of porous concrete to near neutral due to carbonation curing [4]. As has been stated above, carbonation curing is being considered the most effective method for the production of porous concrete, which simultaneously achieves both purposes of enough strength and maintenance pores and, has excellent plant growth capacity. However, to stably supply a large amount of carbon dioxide gas, a gas supply source such as a carbon dioxide bombe is required, so the production of carbonation curing concrete requires a high cost.

To solve the above issue, in this study, hydroxyapatite (hereafter, FbP) of the fishbone derivation is noticed. The physical property (strength, permeability, and porosity) tests and western turf grass growth tests are carried out for the FbP mixed porous concrete. Through the tests, the property of the application of the FbP mixed porous concrete for revetment facilities is verified.

2. FISHBONE POWDER (FBP)

Hydroxyapatite is a representative apatite having a basic structure of $M_{10}(ZO_4)_6X_2$, and it is basic calcium phosphate whose chemical formula is $Ca_{10}(PO_4)_6(OH)_2$. Hydroxyapatite has many characteristics such as high adsorption property, ion exchange property, catalytic, and ion electric conductivity [5-7]. In this study, fishbone hydroxyapatite (Fishbone Powder: FbP, Fig.1) developed by a part of the author is adopted as an admixture of porous concrete. The FbP is manufactured by burning and crushing fishbones discarded at fishing ports.

Previous studies have reported that the strength of concrete increases when calcium ions dissolved in water combine with cement components [8,9]. Additionally, it is revealed that phosphorous-adsorbed concrete has a plant growth-promoting function [10]. Furthermore, it is confirmed that there is a strong correlation between the amount of phosphorus absorbed and the root volume of plants [11]. Therefore, it is expected that the improvement of plant growth capacity and the strength of porous concrete is increased by the mixing FbP of which the main component is calcium phosphate in porous concrete since the FbP supplies phosphorus and calcium (Fig.2). Also, it is possible to realize the coexistence of sufficient strength and excellent plant growth capacity at low cost, because the FbP is manufactured from fishbone which is food waste.

3. TEST METHOD

3.1 Physical Property Tests

To determine the physical property of the FbP mixed porous concrete, strength, permeability, and porosity test are conducted on the specimens. Preparation of specimens, permeability test, and porosity test are conducted following the report of the committee on the establishment of design and

Fig.1 Fishbone Powder (FbP)

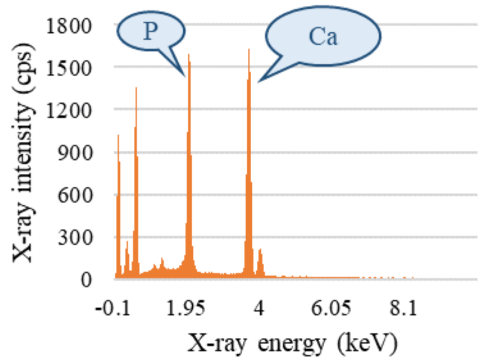

Fig.2 Spectrum of FbP by EDS

construction methods of porous concrete of the Japan Concrete Institute [12]. Materials such as cement and admixtures are mixed according to the mixing conditions by concrete mixer, poured into a cylindrical mold of ϕ 10 × 20 cm, and placed in 3 layers using a rod and a hammer. Five specimens are prepared for each case and cured in water for 7 or 28 days. The mixed proportion of porous concrete produced in this study is shown in Table 1. Also, Crushed stone No. 5 (Particle size 13 ~ 20 mm) is adopted as coarse aggregate, and ordinary Portland cement is adopted as cement.

Table 1 Mix proportion

Materials	Mixing ID	
	Blank	FbP
W/C (%)	25	25
Water (kg/m^3)	84	84
Cement (kg/m^3)	337	337
Coarse aggregate (kg/m^3)	1547	1547
Admixture* (% cement)	1	1
FbP (% cement)	0	1

It is a polycarboxylic acid-based water-reducing admixture.

The design porosity is 26 % and the water-cement ratio is 25 %. The admixture amount of the FbP is 1 % substitution for the cement mass. In addition, the uniaxial compression test is conducted according to the compression test method of concrete (JIS A 1108). Also, the porous concrete adopts either “revetment type, emphasizing strength” or “revetment type, emphasizing vegetation” according to the design flow velocity of the place where the porous concrete is installed. In both types, prescribed strength and porosity are respectively determined. In this study, the target values are as follows: porosity 21 ~ 30 %, coefficient permeability 2.5 ~ 5.0 cm/s, compressive strength 10 N/mm^2 referring to the porous concrete of revetment type emphasizing vegetation.

3.2 Grass Growth Test

To verify the plant growth capacity of the FbP mixed porous concrete, the growth of the western turf grass test is conducted on the specimens. The test period is from December 1, 2020, to February 1, 2021, and it is conducted in the plastic greenhouse installed outdoors. The aspect of the grass growth test is shown in Fig.3.

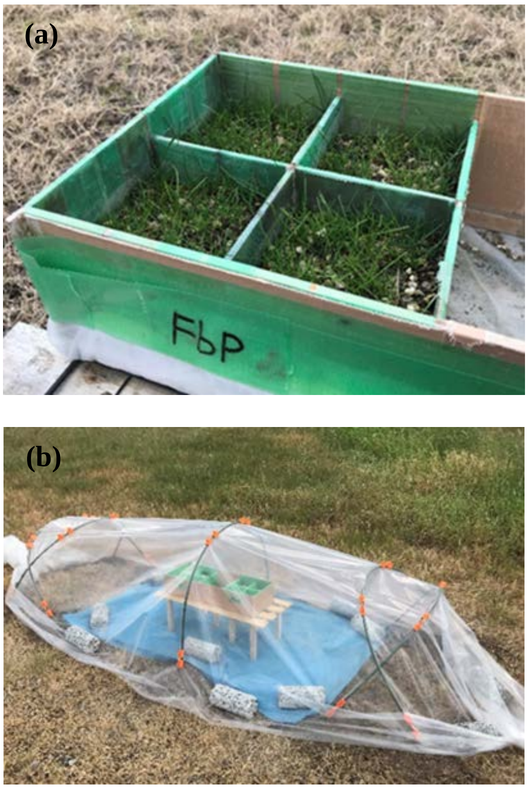

Fig.3 Grass growth test ((a) is a close-range view, (b) is a distant view)

Peat moss slurry (water powder mass ratio = 1: 1) is filled on the pore of the porous concrete placed on a square column 10 cm in length, 10 cm, in width, and 6 cm in thickness. The outline of the specimens is shown in Fig.4. The material age of the porous concrete for the grass growth test is 7 days, and 5 specimens are prepared in each case. In this study, the test plant in which 3 species; Kentucky bluegrass, Perennial ryegrass, and Creeping red Fescue is employed as a test plant with considering the test period. The cover soil is carried out with peat moss of 2 cm on the specimen, and the seeds of the western turf grass are uniformly disseminated on it. Water is supplied once a day before germination and once every two days after germination. From 14 days after sowing, the leaf length is measured once a week with referring to Tsukioka and Yonemoto [13]. The leaf length is measured at 5 places for one test-peace, and the mean leaf length measured at 5 places is adopted as the test result. It is noted that the withered leaf is excluded from measuring objects. Additionally, the soil pH value of the covering soil and the inside of the specimens is measured since the soil pH value of the planting base seems to affect the growth of plants [14].

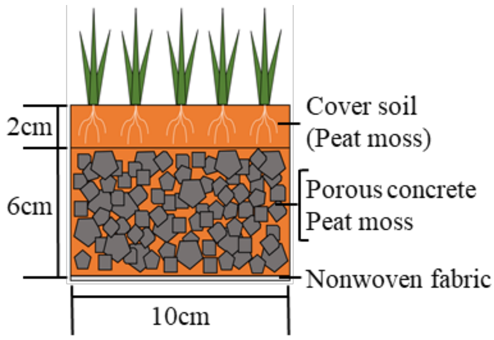

Fig.4 Cross-section of specimen for grass growth test

4. RESULTS AND DISCUSSION

The results of the physical property test and grass growth test for each specimen are summarized in graphs. Five specimens for the physical property test and four specimens for the grass growth test are prepared to ensure reproducibility. Therefore, the values in the figure are the average of each.

4.1 Physical Property Tests

The results of the porosity test are shown in Fig.5 (Total porosity) and Fig.6 (Continuance porosity). “Blank” is the specimen to which FbP is not mixed. The porosity and curing period of porous concrete is shown in the vertical and horizontal axes, respectively. According to the test results, the porosity of both “Blank” and the FbP mixed specimens satisfies the target value (21 ~ 30 %). The porosity in the design is 26 %, but the porosity of produced porous concrete exceeds this value. The reason for this is that it seems that the filling property of the part which contacts the form in specimen molding is hindered by the wall effect [15]. Also, the general tendency that the porosity decrease in proportion to the curing days is confirmed. In addition, the proportion of continuous porosity occupied in total porosity of the "Blank" specimen or the FbP mixed one is about 99 %, and it can be said that porous concrete produced in this study is suitable for the growth of plants.

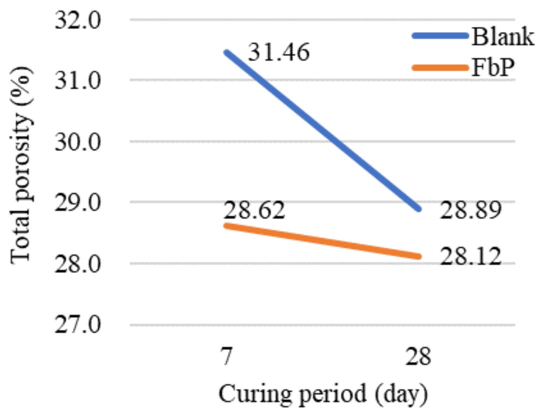

Fig.5 Porosity test results (Total porosity)

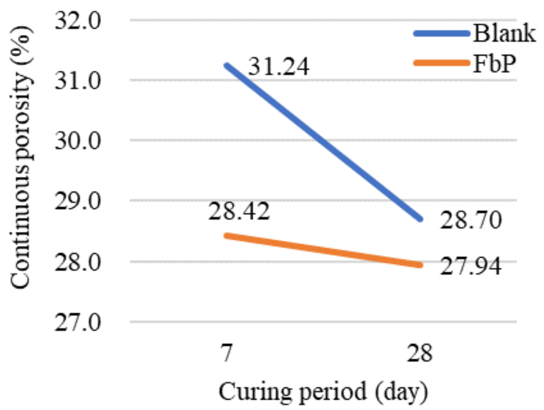

Fig.6 Porosity test results (Continuance porosity)

The results of the permeability test are shown in Fig.7. The coefficient of permeability of both the "Blank" specimen and the FbP mixed specimen satisfies the target value (2.5 ~ 5.0 cm/sec). Generally, the coefficient of permeability tends to decrease as the curing period becomes longer, but such a tendency is not observed in this study. It is considered that the porosity distribution in a specimen affects permeability. Therefore, it is necessary to investigate the state of porosity in detail by X-ray photography.

The results of the uniaxial compression test are shown in Fig.8. The compressive strength of both the "Blank" specimen and the FbP mixed specimen after 28 days of curing exceeds the target value (10 N/mm²). The strength of the FbP mixed specimen is almost the same as that of the "Blank" one despite the reduction of cement. It is considered that calcium is supplied with porous concrete by mixing FbP. In the future, it is necessary to examine the relation between the amount of FbP mixing and the strength of porous concrete by adjusting the amount of FbP is mixing.

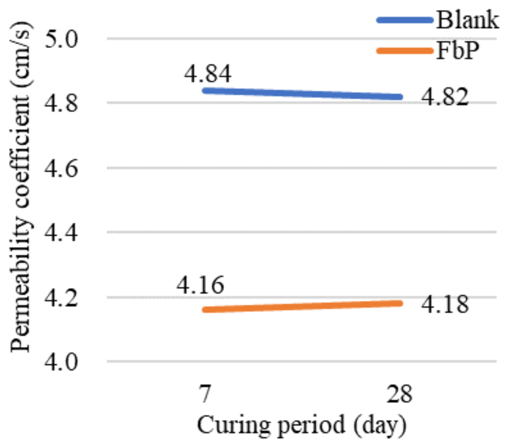

Fig.7 Permeability test results

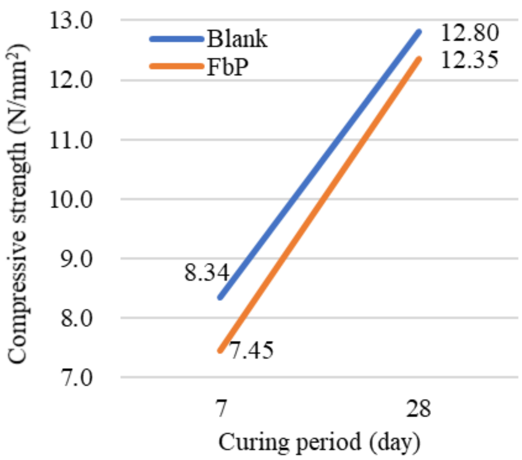

Fig.8 Uniaxial compressive test results

4.2 Grass Growth Test

The results of the grass growth test are shown in Fig. 9. The leaf length and elapsed days are shown in the vertical and horizontal axes, respectively. Also, the results of the measuring soil pH value are shown in Fig.10. From the test results, it is proven that the leaf length of the FbP mixed specimen is longer than that of the "Blank" one from the start to the end of the measurement. Additionally, it is confirmed that the growth period of western turf grass on the FbP mixed specimen is longer than that of the "Blank" one since the FbP mixed specimen does not show the growth lowering of the leaf length after 42 days. Comparing the soil pH value of the "Blank" specimen and that of the FbP mixed specimen, the soil pH value of the FbP mixed specimen is lower than that of the "Blank" one. It is considered that the growth of grass is improved since the soil pH value became more neutral by the reduction of cement content and the mixture of FbP. In addition, phosphorus which is one of the three elements of fertilizer is supplied to the grasses by the mixture of FbP, which may support the growth of grasses. To verify this, it is necessary to analyze the phosphorus content of the test plant in the future.

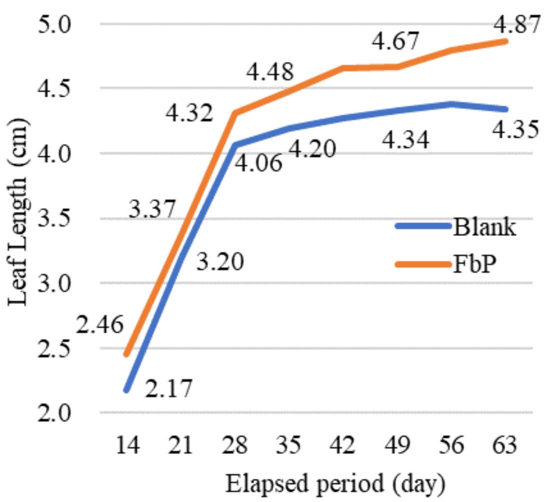

Fig.9 Leaf length in grass growth test

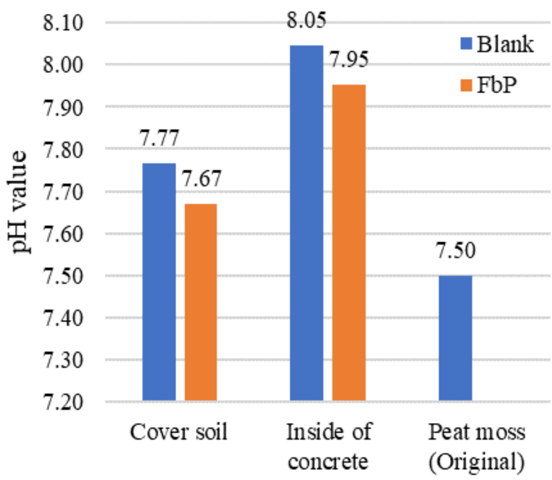

Fig.10 Soil pH value in grass growth test

5. CONCLUSIONS

・ The FbP mixed porous concrete has physical properties required as river revetment.
・ The compressive strength of the FbP mixed porous concrete was almost the same as that of the "Blank" one despite the reduction of cement.
・The soil pH value on FbP mixed porous concrete is lower than that of the "Blank" one.
・The leaf length and growth period of grasses on the FbP mixed porous concrete are better than that of the "Blank" one. Phosphate acid which is one of the main components of FbP may affect the growth of grass. Thus, it is necessary to analyze the phosphorus content of the test plant.
・In this study, only the case in which the FbP was mixed with the porous concrete at a rate of 1 % of the cement amount was conducted. In the future, it is necessary to examine physical properties and the plant growth capacity when the mixing amount of FbP is changed.
・In this study, the test period was short, 9 weeks. In the future, it is necessary to extend the test period to annual units to examine long-term effects on physical properties and the plant growth capacity.

6. ACKNOWLEDGMENTS

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