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RECYCLING OF FISHERY WASTE AS PLANTING BASE POROUS CONCRETE AIMED AT ACHIEVING CARBON NEUTRALITY

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ABSTRACT: The Paris Agreement was adopted as the international framework against global warming, and the global movement to reduce greenhouse gas emissions is progressing. On the other hand, the final disposal amount will be reduced to 13 million tons in 2025 with considering the situation of waste disposal in Japan. Concrete, which is a typical recycled civil engineering material, is a very useful material for drastically reducing waste, while its constituent material, cement, emits a large amount of CO_2 in its manufacturing process. Additionally, due to the Japanese eating habits, a large amount of fishery waste including fish residues and shellfish are discharged. Although these are recycled, only about 30% of them are recycled. In this study, because the hydroxyapatite can contribute to reduction of the amount of cement and the plant growth promoted by phosphorus content, the hydroxyapatite produced from fish bones (Fishbone Powder: FbP), which is a fishery waste, is adopted as an alternative material to cement of planting base porous concrete. In addition, from the viewpoints of various physical properties (porosity, permeability and compressive strength), plant growth conditions and CO_2 emission reduction, the potential of recycling FbP as a binder for planting base porous concrete is also examined. As the result, CO_2 emission of about 2.6 kg per 1 m^3 of porous concrete can be reduced by using FbP as a binder for planting base porous concrete. Additionally, the plant growth ability is also improved while the compressive strength is maintained above 10 N/mm^2.

Keywords: Carbon neutrality, FbP, Recycling, Planting base porous concrete, CO_2 emission reduction

1. INTRODUCTION

The current global average temperature is approximately 1°C higher than that before the industrial revolution. In Japan, the average temperature in 2020 is the highest since records began in 1898, and the global warming is still becoming unstoppable. In response to serious global warming, “The Paris Agreement” was adopted as a new initiative to replace the Kyoto Protocol in order to reduce greenhouse gas emissions after 2020 at the 21st Conference of Parties (COP21) to the United Nations Framework Convention on Climate Change which was held in Paris, 2015. The global movement to achieve carbon neutrality is progressing with the adoption of the agreement. In 2020, Japanese government declared that “Greenhouse gas emissions would be reduced to zero as a whole by 2050”. On the other hand, in the 12th goal "Sustainable consumption and production" of the Sustainable Development Goals (SDGs), it is aimed that "Dramatic reduction of waste generation through prevention, reduction, recycling and reuse of waste by 2030" in response to the increase of the waste quantity with the global economic development. In Japan, the final disposal amount of Japan will be reduced to 13 million tons in 2025 with considering the situation of waste disposal in recent years [1]. As an effective means to reduce the amount of final disposal, construction wastes, industrial by-products, general wastes (incinerated ash, molten slag, etc.) and sewage sludge are used as recycled civil engineering materials. Concrete, which is a typical recycled civil engineering material, is a very useful material for drastically reducing waste, while its constituent material, cement, emits a large amount of CO_2 in its manufacturing process. In order to reduce the environmental load and CO_2 emission, “Low-carbon concrete”, in which industrial waste and by-products such as fly ash, blast furnace slag and silica fume instead of cement are used, is noticed [2-7].

In addition to the wastes mentioned above, due to the Japanese eating habits, approximately 3.86 million tons of fishery waste, including fish residues such as bony parts of fish and shellfish such as scallops and oysters excluding those discharged by households, are discharged annually. Although these are recycled into feed and fertilizer, only approximately 30% of them are recycled [8]. Against this background, in order to reuse fish bones, which are discarded drastically at fish farms and fisheries processing plants, the hydroxyapatite produced from fish bones was developed by some of the authors, and its use as an adsorbent was proposed. In previous studies, the authors have clarified that the hydroxyapatite produced from fish bones has ability to adsorb for heavy metals such as zinc (Zn^{2+}), cadmium (Cd^{2+}), mercury (Hg^{2+}) and manganese (Mn^{2+}), and radioactive substances such as strontium (Sr^{2+}) in solution [9-11]. However, the use of adsorbents alone will not lead to a significant reduction in fishery waste. Additionally, the main component of hydroxyapatite produced from fish bones is calcium phosphate containing phosphorus which is one of the three major nutrients of plants.

2. RESEARCH SIGNIFICANCE

In this study, because the hydroxyapatite can contribute to the reduction of the amount of cement and the plant growth promoted by phosphorus, the hydroxyapatite produced from fish bones (Fishbone Powder: FbP), which is a fishery waste, is adopted as an alternative material to cement of planting base porous concrete. In addition, from the viewpoints of various physical properties (porosity, permeability and compressive strength), plant growth conditions and CO_2 emission reduction, the potential of recycling FbP as a binder for planting base porous concrete is also examined.

3. FISHBONE POWDER (FbP)

Hydroxyapatite is one of the typical apatites, that are a group of crystalline compounds with $M_{10}(ZO_4)_6X_2$ as a basic composition, and is a basic calcium phosphate represented by $Ca_{10}(PO_4)_6(OH)_2$ as chemical formula. The manufacturing method of the hydroxyapatite produced from fish bones (Fishbone Powder: FbP, see Fig. 1) is as follows. First, fish residues with organic matter adhering to fish bones are immersed and boiled in high-temperature water. Next, the organic matter residues are removed from the fish residues by spraying high-pressure water, and the fish bones from which organic matter residues are removed are forced to dry at 200°C. After that, the fish bones are burned at 700-900°C in a heating furnace, and the burned fish bones are pulverized with a ball mill [12]. Here, in order to calculate the reduction of CO_2 emission in porous concrete for planting base using FbP as a binder, it is necessary to take into account CO_2 emission in the manufacturing process of FbP. However, Wada *et al*. [13] report that the temperature for the combustion reaction of the solid component (carbide) is 400-540°C in the oxidative pyrolysis reaction of food waste such as carbohydrate, protein and fat. In other words, the temperature at which organic matter residues are burned and CO_2 is emitted is 400-540°C. The organic matter residues, such as fish meat, are removed from the fish bones in FbP production. Additionally, even if a small amount of organic matter residues adheres to the fish bones, the drying temperature before burning is lower than the combustion temperature at which the CO_2 is emitted. Furthermore, even though the fish bones are burned at 700-900°C, CO_2 is hardly emitted due to the small amount of organic matter residues. Therefore, in this study, CO_2 emission in the manufacturing process of FbP is almost zero, and the reduction of CO_2 emission in using FbP as a binder is calculated.

Fig. 1 Fishbone Powder (FbP)

4. TEST METHOD

4.1 Mix Design and Test Specimen Preparation

Table 1 shows the mix proportions of porous concrete in the test. The mix proportions are determined with reference to the study by Nakamura *et al*. [14]. The water-cement ratio is 25% and the target porosity is 26%. “BLANK” represents an ordinary porous concrete (porous concrete without FbP), and “FBP” represents porous concrete in which FbP is mixed as a binder (1% replacement of cement mass). Ordinary Portland cement is used for cement, No. 5 crushed stones of 13 mm to 20 mm in diameter is used for coarse aggregate, and polycarboxylic acid-based air entraining (AE) and water-reducing agent is used for chemical admixture. In addition, 1% is added to the cement mass as AE water reducing agent. Cement, FbP and crushed stones are mixed in a concrete mixer, and then water in which chemical admixture is dissolved is put into the mixer. Then, the mixer is rotated to mix the materials. After that, the materials are put into a cylindrical mold of 100 × 200 mm (diameter × height), and struck with rods and wooden hammers at each time. The size of the sample for the grass growth test is 100 × 180 mm. Five specimens are prepared for each physical property test and cured in water for 7 or 28 days. On

Table 1 Mix proportions (kg/m^3)

	W	Binder		G	A
		C	FbP		
BLANK	84	337		1547	3.37
FBP	84	333.63	3.37	1547	3.37

W: Water, C: Cement, G: Coarse Aggregate, A: Chemical admixture the other hand, four specimens are prepared for the grass growth test and cured in water for 28 days.

4.2 Physical Property Test

The porosity, permeability and compressive strength tests are conducted to confirm the physical property of porous concrete in which FbP is mixed as a binder. Porous concrete used as a planting base in the embankment is classified as "Strength emphasis type" or "Plant growth emphasis type". The porosity and strength for these two classifications are different. In the test, referring to "Plant growth emphasis type" of porous concrete, 21-30% of porosity, 2.5-5.0 cm/s of permeability, and 10 N/mm^2 of compressive strength are set as target values. As a reference to the report of the committee on the establishment of design and construction methods of porous concrete of the Japan Concrete Institute [15], the porosity test is conducted according to the volumetric method, and the constant head permeability test is conducted. In addition, the upper end surface of the specimen is covered with gypsum in order to smooth the loading surface (see Fig. 2), and the uniaxial compression test is conducted in compliance with the compressive strength test method of concrete (JIS A 1108).

4.3 Grass Growth Test

In order to examine the plant growth ability of porous concrete in which FbP is mixed, a growth test of western grass is conducted on porous concrete without FbP (BLANK) and porous concrete in which FbP is mixed as a binder (FBP). The test period is 42 days from November 17 to December 29, 2021, and the test is conducted in the vinyl greenhouse installed outdoors. The cylindrical porous concrete of 100 × 180mm (diameter ×height) is filled with peat moss in slurry type by a water-powder ratio of 1: 1 as the planting base (see Fig. 3). Fig. 4 shows the cross section of the planting base specimen. Since the test period is winter season, the blend of cold-district type turfgrass of Kentucky bluegrass, tall fescue, bent grass and others are selected as the test plant. The peat moss of 2 cm thickness is covered on the porous concrete. In order to make the western grass uniform, the seeds are added to the soil covering part at the ratio of 1 g per one porous concrete. Water is supplied once a day, around 11:00 a.m. after seeding. Leaf length is measured once a week from 14 days after seeding. Referring to the study by Tsukioka *et al*. [16], leaf length is measured at five places one per porous concrete specimen, and the average of five measured length is defined as the leaf length in the porous concrete specimen. The average of each leaf length in four porous concrete specimens is adopted as the test result for the whole case. In addition, the pH value of the soil cover and inside the porous concrete is measured after the grass growth test because it is considered that the soil pH value of the planting base influences the growth of the plant [17]. The mixture of soil 1 to distilled water 2.5 is shaken for 30 minutes. In the test, 6g of soil and 15mL of distilled water are used.

Fig. 2 The specimen on which the upper end surface is covered with gypsum

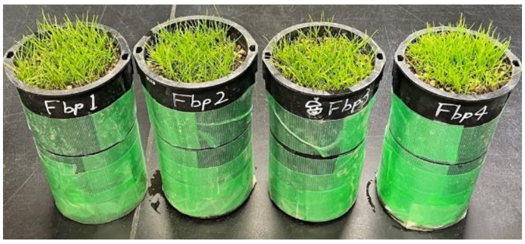

Fig. 3 Planting base used in grass growth test

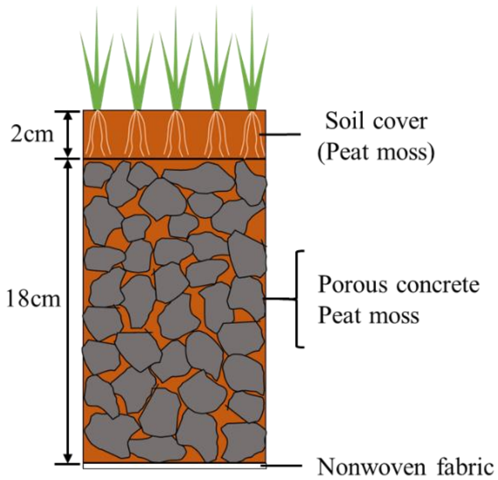

Fig. 4 Cross section of planting base specimen

After then, the measured pH of the supernatant is defined as the pH of the test soil.

5. RESULT AND DISCUSSION

5.1 Results of Physical Property Test

As the results of the porosity test, Fig. 5 and Fig. 6 show the total and continuous porosity, respectively. The horizontal and vertical axes in Fig. 5 and Fig. 6 are the curing period and porosity of the porous concrete, respectively. Fig. 5 and Fig. 6 show that the porosity of both BLANK and FBP are higher than 26% of the target porosity in the design, and the porosity at 28 days of curing is above 21-30% of the application range for the plant growth emphasis type, except for the BLANK of the continuous porosity. According to Saito *et al*. [18], it is indicated that in the porous concrete filled in the mold, the continuous porosity in the vicinity of the mold increases, because the filling property of coarse aggregate is deteriorated near the form surface. It is considered that the measured values exceed the target value due to the wall effect of the mold. On the other hand, Koshi *et al*. [19] state that the porosity is affected by the specimen size, and the larger the aggregate size, that the larger the void size near the surface in contact with the mold, and that the continuous existence of voids also increases the porosity. In this study, the No. 5 crushed stones are selected to ensure suitable voids for the growth of plant roots in porous concrete. However, the No. 5 crushed stones are slightly larger than the specimen size of porous concrete. This is also considered to be the cause of the actual porosity exceeding the target one. In general, the porosity of porous concrete tends to decrease as the curing days pass because cement hydration products become dense, while, the results obtained in the test differ from the general tendency. Further investigation is needed to obtain more detailed information on the porosity of porous concrete. Furthermore, the ratio of the continuous voids to total voids is calculated and the ratio of both BLANK and FBP exceeds 99%.

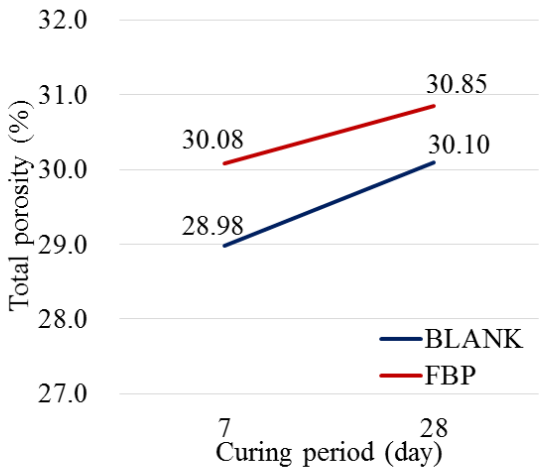

Fig. 5 Total porosity results

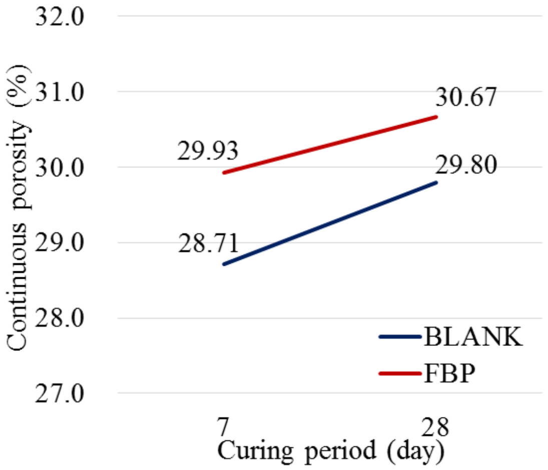

Fig. 6 Continuous porosity results

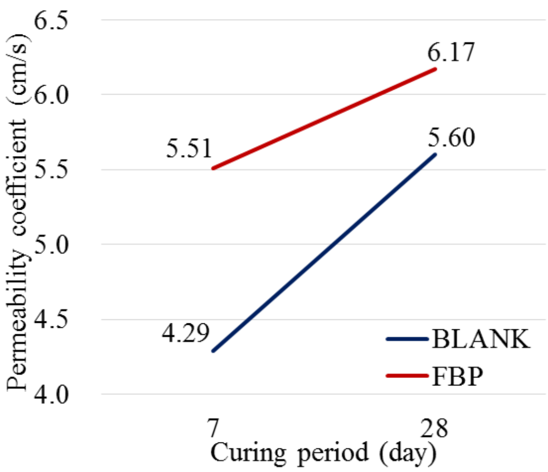

Fig. 7 Permeability test results

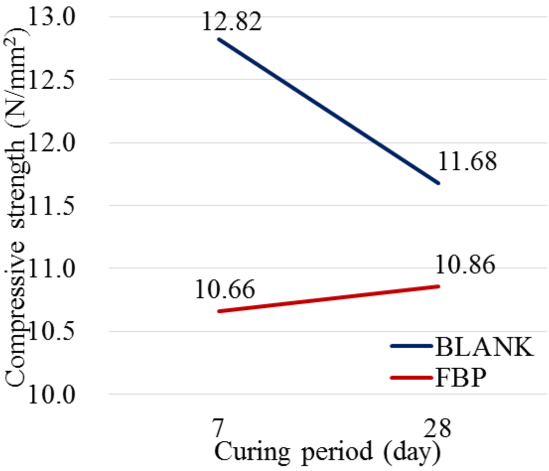

Fig. 8 Uniaxial compression test results

It is confirmed that most of the voids in those porous concrete are continuous voids. It can be said that both BLANK and FBP are the porous concrete suitable for plant growth.

Fig. 7 shows the results of the permeability test. The horizontal and vertical axes in Fig. 7 are the curing period and permeability coefficient of the porous concrete, respectively. Fig. 7 shows that the permeability coefficient in the test deviates from 2.5-5.0 cm/s of the target range, except for the BLANK which is cured for 7 days. As with the porosity, it is considered that the results are due to the wall effect. Additionally, the permeability coefficients of both BLANK and FBP increase with the curing period. The permeability coefficient is strongly affected by the porosity. As the porosity in the test increases with the curing period, the permeability coefficient is also presumed to increase.

Fig. 8 shows the results of the uniaxial compression test. The horizontal and vertical axes in Fig. 8 are the curing period and compressive strength of the porous concrete, respectively. Fig. 8 shows that both BLANK and FBP are satisfied with 10 N/mm^2 of the target compressive strength, while the compressive strength of FBP is slightly lower than that of BLANK. This may be attributed to the fact that the amount of cement in the FBP is less than in the BLANK. In addition, the compressive strength of BLANK decreases with the curing period. Since the compressive strength is affected by the porosity as with the permeability coefficient, it is presumed that the results are due to an increase in the porosity. On the other hand, the compressive strength of FBP is maintained above 10 N/mm^2 despite an increase in porosity as the curing period progresses. It is necessary to examine the extent to which FbP contributes to strength from the relationship between the replacement ratio of FbP and the strength of porous concrete by changing the replacement ratio of FbP to cement mass.

5.2 Results of Grass Growth Test

The measurement result of the leaf length of grass growth and the condition of each specimen at the end of grass growth test are shown in Fig. 9 and in Fig. 10, respectively. The horizontal and vertical axes in Fig. 9 are the elapsed period and leaf length, respectively. Fig. 9 shows that the leaf length of FBP is longer than that of BLANK consistently from the beginning to the end of the measurement of leaf length. In addition, the growth rate of leaf length in FBP is higher than that in BLANK. FbP contains phosphorus that is one of the three major nutrients of the plant. It is suggested that the phosphorus in FbP mixed in the porous concrete is supplied to it, which brings about a positive effect on the grass growth. It is necessary to analyze the amount of phosphorus contained in the grass growth test in which porous concretes mixed with and without FbP as planting base so as to confirm that the phosphorus in FbP is supplied to porous concrete. Additionally, Fig. 10 seems that FBP is slightly superior to BLANK regarding the root thickness, root length and root quantity of the grass comparing BLANK and FBP. Yoneyama *et al*. [20] report that there is a proportional relationship between the root mass of plant and the absorbed amount of phosphorus. The growth of roots is presumed to be promoted by the supply of phosphorus contained in FbP. In the future, it is

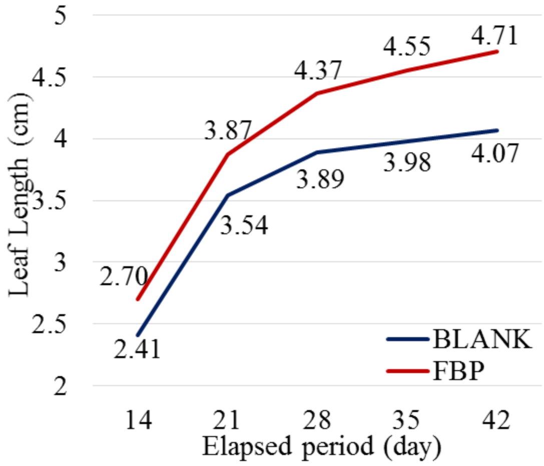

Fig. 9 Grass growth test results

Fig. 10 Planting base specimens at the end of grass growth test (left: BLANK, right: FBP)

Table 2 Measuring soil pH value test results

	BLANK	FBP
Soil cover	8.00	7.99
Inside of concrete	8.00	8.08
Peat moss (Original)	7.39	

needed to conduct the quantitative investigations such as measurement of root dry mass.

The results of the pH value in the soil is listed in Table 2. Table 2 shows that the pH value in the cover soil of FBP is almost the same as that of BLANK. In addition, there is only about 0.1% difference between soil pH inside the void of BLANK and that of FBP. The difference is a category of error. Calcium phosphate, the main component of FbP, is from neutral to weakly alkaline, and it is presumed that the soil pH of BLANK and FBP is almost the same due to the use of FbP. Yokozeki *et al*. [21] indicates that there is a relatively high correlation between the soil pH and the volume of plant growth, and that the lower the pH, the better for plant growth. In order to further improve the growth amount of plant, it is necessary to examine a method of decreasing pH.

5.3 Calculation of CO_2 Emission Reduction

By applying FbP mixed in porous concrete to an actual revetment, CO_2 emission reduction is calculated. Here, the Aizawa river embankment repair work in Yamagata Prefecture [22] is referred. CO_2 emission in manufacturing FbP is not considered, as described in Chapter 2. By substituting 1% of FbP for cement mass, it is possible to reduce cement content by 3.37 kg per 1 m^3 of porous concrete. According to the Japan Federation of Construction Contractors [23], roughly 770 kg of CO_2 is emitted in the production per 1 ton of cement. Compared with conventional porous concrete, CO_2 emission by approximately 2.6 kg per 1 m^3 of porous concrete can be reduced when FbP is used as a binder. The volume of the porous concrete used in the repair work is estimated to be 900 m^3 considering the construction scale and thickness of the embankment. Thus, CO_2 emission by approximately 2,335 kg can be reduced. Mishina *et al*. [24] states that a gasoline automobile emits 2.32 kg of CO_2 per 1 L of gasoline. Applying this to the repair work mentioned above, the amount of CO_2 emission reduced by substituting cement for FbP in porous concrete is equivalent to the amount of CO_2 produced when about 1,006 L of gasoline is consumed in a gasoline automobile. In the case of the automobile which runs 20 km per 1 L of gasoline, it can run approximately 20,120 km with 1,006 L of gasoline. This is equivalent to half a world's circumference. Therefore, it is expected that the use of FbP as a binder for the planting base porous concrete brings useful results toward achieving carbon neutrality.

6. CONCLUSIONS

In this study, because the hydroxyapatite can contribute to the reduction of the amount of cement and the plant growth promoted by phosphorus,the hydroxyapatite produced from fish bones (Fishbone Powder: FbP), which is a fishery waste, was focused on an alternative material to the cement of planting base porous concrete, and the potential of recycling FbP as a binder for planting base porous concrete was examined. The findings obtained are as follows.

- Porous concrete in which FbP was mixed has the physical properties required for "Plant growth emphasis porous concrete" used as a planting base in a revetment.

- The compressive strength of porous concrete in which FbP was mixed as a binder was lower than that of porous concrete without FbP. Although the compressive strength of porous concrete without FbP decreased with the curing period, that of the porous concrete in which FbP was mixed did not decrease and was maintained above 10 N/mm^2.

- The leaf length of grass in the porous concrete in which FbP was mixed was longer than that in porous concrete without FbP. It is suggested that phosphorus in the FbP mixed in the porous concrete has a positive effect on the grass growth.

- CO_2 emission by approximately 2.6 kg per 1 m^3 of porous concrete can be reduced by using FbP as a binder. When porous concrete in which FbP is mixed is applied to the Aizawa river embankment repair work in Yamagata Prefecture, it is expected to reduce CO_2 emission by approximately 2,335 kg.

In the future, in order to investigate the effect of FbP on the strength of porous concrete, it is necessary to examine the relationship between the replacement rate of FbP to cement and its strength. Additionally, it is needed to analyze the amount supplied of phosphorus in the grass and measure the dry mass of the leaves and roots of the grass so as to quantitatively evaluate that FbP influences plant growth.

7. ACKNOWLEDGMENTS

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