International Journal of GEOMATE, June, 2025 Vol.28, Issue 130, pp.112-122
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2025.130.g14237
Geotechnique, Construction Materials and Environment

DEVELOPMENT OF POROUS CONCRETE MIXED WITH HYDROXYAPATITE PRODUCED FROM FISH BONES

Taku Higashino[1], Ayane Yanaka[2], Yui Oyake[2], Shinichiro Okazaki[2], Yoshihiro Suenaga[2] and Hidenori Yoshida[2]

[1]Graduate School of Science for Creative Emergence, Kagawa University, Japan; [2]Faculty of Engineering and Design, Kagawa University, Japan

*Corresponding Author, Received: 26 March 2025, Revised: 31 March 2025, Accepted: 01 April 2025

ABSTRACT: In recent years, environmentally friendly vegetated porous concrete (hereinafter, PC) has been required for revetment reinforcement in rivers, lakes, and other water bodies. Vegetation prefers a substrate with a high void ratio. However, an increase in the void ratio of the substrate leads to a reduction in its strength. On the other hand, in concrete used as a foundation for embankment slopes, ensuring sufficient strength is desirable. However, this often results in a lower void ratio. As mentioned above, in PC, it is generally difficult to achieve both a high void ratio and sufficient strength simultaneously. Fishbone-derived hydroxyapatite (hereinafter, FH) is a material recycled from fish residues. Its main component is calcium phosphate; calcium enhances the strength of concrete, while phosphate promotes plant growth ability. Therefore, this study focuses on FH with these characteristics and aims to develop PC with partial cement replacement by FH. In this study, physical property tests and plant growth experiments were conducted on PC to examine the effects of the presence or absence of FH on the strength and vegetation growth of PC. As a result, it was found that sufficient strength in PC was maintained even when FH was mixed into PC, and that the inclusion of FH contributed to the vegetation growth of PC. Additionally, low-carbon PC was achieved by replacing cement with FH.

Keywords: Fishbone powder, Calcium phosphate, Porous concrete, Plant growth ability

1. INTRODUCTION

One of the goals in the Sustainable Development Goals (SDGs), Goal 12 “Responsible Consumption and Production.” It aims to achieve a “substantial reduction of waste generation through prevention, reduction, recycling, and reuse” by 2030. To achieve this goal, the “Circular Economy” effort has been attracting attention recently. In “Circular Economy,” the focus is on an overall approach to economic activities that minimizes waste generation by maximizing the value of resources and products and minimizing resource input and consumption. In Japan, approximately 3.86 million tons of fish residues are discarded annually due to the high consumption of seafood compared to other countries [1]. Here, the proportion of inedible parts in wholesale fresh food varies by category, with vegetables and fruits at 24.8%, meat at 85.1%, and seafood at the highest at 98.7% [2]. Furthermore, the recycling rate of fish residues in Japan is low, at about 30%. Much of the fish residues in Japan are reused in low-value products such as fish feed and livestock feed [1]. Against this background, it is required to maximize the value of fish residues and recycle them in Japan. Against these backdrops, fishbone-derived hydroxyapatite (hereinafter, FH) was developed. Here, hydroxyapatite refers to calcium hydroxy phosphate, which is the main component of tissues such as teeth and bones, and is represented by the chemical formula $Ca_{10}(PO_4)_6(OH)_2$. Characteristics of hydroxyapatite include its high biocompatibility, ion exchange properties, and ion adsorption properties [3-5]. Here, Fig.1 shows FH. FH is produced by extracting fish bones from discarded fish residues, then calcining them in a furnace at 900°C for 6 hours, and subsequently grinding them to a particle size of less than 0.1 μm using a ball mill [6]. Yanaka, Yoshida, Matsumoto and Suenaga [7] have investigated the reuse of FH as an adsorbent for heavy metals. Additionally, Yanaka, Ikeda, Suenaga, Matsumoto, and Yoshida have also investigated the reuse of FH as an adsorbent for fluoride [8]. These two methods are the current potential uses of FH, and it is necessary to expand the scope of its further utilization. Therefore, it is focused on the fact that the main component of FH is calcium phosphate to aim to the utilization of FH except for the adsorbent for heavy

Fig.1 Fishbone-derived hydroxyapatite (FH)

metal or fluoride in this study. Several previous studies have found that calcium contributes to the increase in compressive strength of concrete [9-11]. Furthermore, phosphorus is one of the three essential nutrients for plants. Also, phosphorus has the effect that promotes blooming, fruiting, root elongation, and flower bud formation. It is generally preferable for vegetation to have a substrate with a high void ratio, as plants need to establish roots in the soil or other substrates. However, an increased void ratio in the substrate leads to a reduction in its strength [12]. On the other hand, in the case of concrete used as the foundation for embankment slopes, ensuring sufficient strength is desirable. However, this results in a lower void ratio. In other words, it is generally difficult to achieve both an increase in void ratio and that in strength simultaneously. In recent years, environmentally friendly vegetated porous concrete (hereinafter PC) has been increasingly required for applications such as revetment reinforcement. Therefore, achieving both a high void ratio and sufficient strength is essential. Therefore, this study focuses on FH which has the aforementioned characteristics, and examines the development of PC with partial replacement of cement by FH. Thus, this study aims to develop vegetation-based PC that considers both strength and vegetation. In general, the strength of vegetation-oriented PC is above 10 N/mm², and the porosity ranges from 21 to 30%. To meet these requirements, test specimens containing FH were prepared in this study. Here, although FH is a porous material, its pore size distribution primarily ranges from angstroms to several hundred micrometers. Needless to say, the pore sizes of this magnitude are not expected to contribute to the void structure at the macro level as indicated above. Therefore, in this study, the chemical properties of FH, which is primarily composed of calcium phosphate, are focused on, and the FH is an attempt to be blended into PC not from the perspective of waste recycling but as a functional material. A similar study by Suda and Watanabe [13] can be cited, where scallop shells were mixed into PC as a cement substitution, primarily for the purpose of recycling scallop shells. According to the study by them, the physical properties of scallop shells, such as particle size, affect the compressive strength and other properties of PC. However, the study by them is not focused on vegetation, but rather on simply mixing waste materials into PC. In addition, cement, among concrete materials, emits a large amount of carbon dioxide during its manufacturing process. Furthermore, it is investigated in recent years that the development of low-carbon concrete which can reduce cement usage by replacing it with waste materials or additives as binders [14]. Therefore, in this study, the development of PC by replacing cement with fishbone-derived hydroxyapatite (FH), which is mainly composed of calcium phosphate is examined since the calcium component can be expected to maintain the strength of the concrete and the phosphate component can be expected to enhance plant growth.

In this paper, Chapter 2 describes the significance of the study conducted. In Chapter 3, the methods of various physical property tests conducted in this study, as well as the test results and discussions of the tests, are presented. In Chapter 4, the methods of various plant growth experiments conducted in this study, as well as the test results and discussions, are presented. In Chapter 5, the conclusions of this study are presented, while Chapter 6 discusses its future prospects of this study.

2. RESEARCH SIGNIFICANCE

This study focuses on calcium phosphate, the main component of FH, which is mixed into PC. This leads to a reduction in the amount of fish residues. Additionally, mixing FH into the PC is expected to increase in compressive strength along with plant growth of the PC. By utilizing the PC as a planting substrate, vigorous plant growth is expected. Moreover, in this study, a part of the cement used in the PC is replaced with FH. This reduction in cement usage leads to a reduction in CO_2 emissions. Therefore, this study can contribute to supporting carbon neutrality.

3. PHYSICAL PROPERTY TEST

3.1 Preparation of Test Specimens

Table 1 shows the mix design used in this study. The mix design was determined with reference to the study by Nakamura, Ishikawa, Yanagibashi and Ando, on the application of PC for reservoir embankments [15]. In the table, "Blank" represents PC without the addition of FH, "FH-1%" represents PC in which 1% of the cement mass is replaced with FH, and "FH-5%" represents PC in which 5% of the cement mass is replaced with FH. Here, only a substitution rate of 1% of FH relative to the cement mass is adopted in the study by Yanaka, Yoshida, Okazaki, Oyake and Suenaga [16]. Therefore, a substitution rate of 5% of FH relative to the cement mass is adopted in this study. In this study, φ100×200mm cylindrical

Table 1. Mix design

	C	FH	W	G	AE	
Blank	337	0	84	1547	3.37	kg/m^3
FH-1%	333.63	3.37	84	1547	3.37	kg/m^3
FH-5%	320.15	16.8	84	1547	4.381	kg/m^3

C : Cement, FH : Fishbone-derived hydroxyapatite, W : Water, G : Coarse Aggregate, AE : AE water-reducing agent specimens are prepared for three cases: Blank, FH-1% and FH-5%. For each case, five specimens are cured for 7 days and another five for 28 days, totaling 30 specimens are used for the tests. Additionally, No. 6 crushed stone is used as coarse aggregate, and ordinary Portland cement is used as cement. Furthermore, an AE water-reducing agent containing mainly lignosulfonate compounds and polycarboxylic acid ether complexes is used. Here, 1% of the cement mass of AE water-reducing agent is added to both Blank and FH-1%, while 1.3% of the cement mass of AE water-reducing agent is added to FH-5%. The procedure for creating the PC used in this study is as follows: First, coarse aggregate, cement, and FH are placed into a mixer, and then the mixed materials are dry-mixed for 30 seconds. After that, a mixture of water and AE water-reducing agent is added to the mixer, and the mixed materials are wet-mixed for 90 seconds. After mixing, the fresh concrete was transferred to a mixing vessel, mixed with a shovel, and then placed into the mold. After mixing, the fresh concrete is poured into a mold in three layers during this process. Each layer is tamped 25 times with a tamping rod, and the sides of the mold are tapped with a wooden mallet until the air bubbles on the surface of the specimen disappear. Subsequently, after 24 hours of formwork curing, the formwork is removed. After demolding, the PC is cured in water until the physical property tests are conducted.

3.2 The Methods of Physical Property Test

In this study, to evaluate the physical properties of PC as a verger substrate, physical property tests such as porosity test, permeability test, and compressive strength test are conducted. The specimens used in the porosity test are subsequently used in the permeability test, and then those are used in the compressive strength test. Additionally, the target physical property values in this study are set with reference to the PC used for vegetation-oriented embankments [17]. The target porosity value is 21-30%, the target compressive strength value is at least 10 N/mm^2, and the target permeability coefficient is 2.5-5.0 cm/s. For the porosity test, the volumetric method is employed, referencing "Proposed Method for Porosity Testing" outlined in "Report of the Research Committee on the Establishment of Design and Construction Methods for Porous Concrete" by the Japan Concrete Institute [18]. Furthermore, constant head permeability test is conducted for the permeability test, referencing to 'Proposed Method for Permeability Testing' outlined in "Report of the Research Committee on the Establishment of Design and Construction Methods for Porous Concrete" by the Japan Concrete Institute [18]. Fig.2 shows the permeability test apparatus used in this study. In addition, since the top surface of the prepared specimens was not smooth, it is finished smoothly with a gypsum capping as shown in Fig.3, before the compressive strength test.

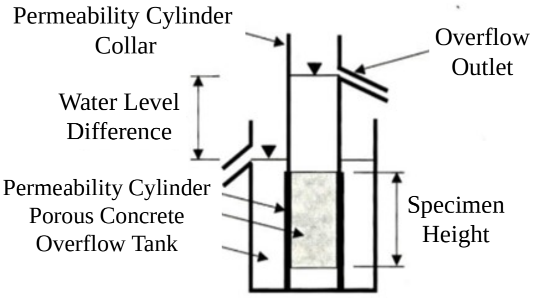

Fig.2 The permeability test apparatus

Fig.3 Capped Specimen

3.3 The Results of Physical Property Test

The results of the porosity tests are shown in Fig.4 (total porosity) and Fig.5 (continuous porosity). In this test, the target porosity for the mix designs of the three cases (Blank, FH-1%, FH-5%) is set at 26%. Fig.4 and Fig.5 show that the porosity values for all three cases, both for 7-day and 28-day curing, fall within the target range. Fig.4 and Fig.5 indicate that in all cases, the porosity after 7 days and 28 days of curing falls within the target range. This phenomenon is presumed to be due to the densification of cement around the aggregate as the curing period progresses. On the other hand, Fig.4 and Fig.5 show that the rate of decrease in porosity for Blank and FH-1% is almost the same, whereas that for FH-5% is greater than that of Blank and FH-1%. This is because the amount of cement in FH-5% is lower than that of Blank and FH-1%. As a result, the hardening due to the hydration reaction is slower in FH-5% in the initial stages, leading to a larger initial porosity. Furthermore, Fig.4 and Fig.5 show that the porosity

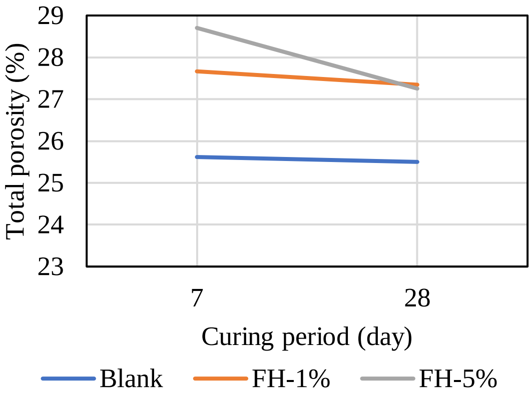

Fig.4 The results of the total porosity test

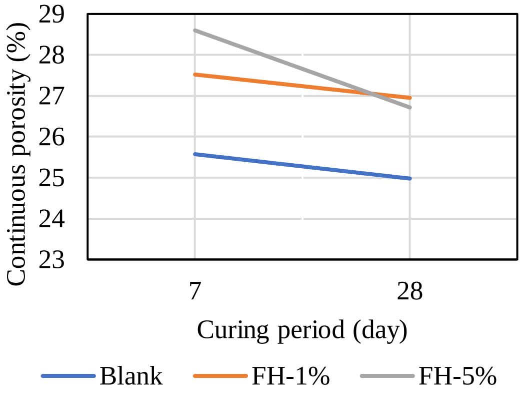

Fig.5 The results of the continuous porosity test

of the specimens with FH (FH-1% and FH-5%) is approximately 2% higher than those without FH (Blank). This is because the amount of cement usage is reduced when FH is mixed, leading to a relatively higher amount of water than cement. The water not consumed in the hydration reaction likely evaporates, resulting in the formation of more fine air bubbles. In addition, calculating the ratio of continuous porosity to total porosity from the values of total porosity and continuous porosity for all three cases reveals that most of the total porosity consists of continuous porosity. The high proportion of continuous porosity indicates an environmental conducive to plant root growth [19]. This suggests that the PC in all three cases of this test is suitable for use as a vegetation base.

Next, Fig.6 shows the results of the permeability test. Fig.6 shows that all cases except for Blank at the 28-day curing stage meet the target range for the permeability coefficient set for this test. This indicates that the permeability necessary for the healthy growth of plants can be ensured within the concrete by mixing FH. Additionally, Fig.6 suggests that the permeability increases by mixing FH. This is assumed to be the cause that mixing FH increases the continuous porosity as shown in Fig.5, like the study by Suda and Watanabe [13] in which scallop shells are mixed into PC. Moreover, Fig.6 shows that the permeability coefficient decreases with the passage of curing days as a general trend. The results shown in Fig.4 and Fig.6, where a decrease in porosity corresponds to a decrease in the permeability coefficient, are consistent with the findings of Okamoto, Yasuda, Masui, and Satoh [20]. This indicates a positive correlation between porosity and the permeability coefficient.

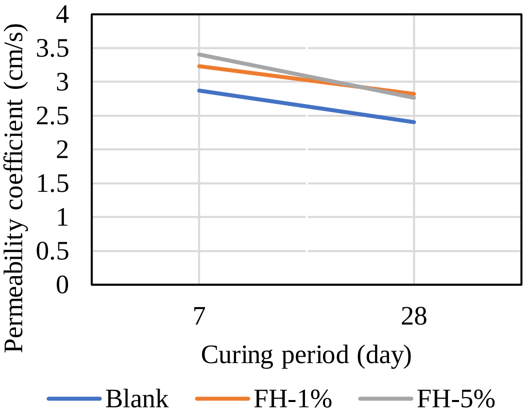

Fig.6 The results of the permeability test

Next, Fig.7 shows the results of the compressive strength test. Fig.7 shows that the compressive strength of all cases at the 28-day curing stage meets the target compressive strength of 10 N/mm² and that at the 7-day curing stage, only FH-5% does not meet the target compressive strength of 10 N/mm². This is assumed to be due to the lower amount of cement in FH-5%, which results in slower hardening in the initial stages due to the slower hydration reaction. Fig.7 also shows that at the curing stages of 7 days and 28 days, the compressive strength is highest for Blank, followed by FH-1%, and lowest for FH-5%. This result can be attributed to the fact that the

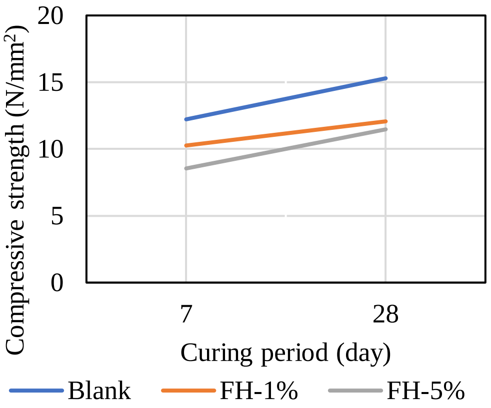

Fig.7 The results of compressive strength test

compressive strength of each case corresponds to the amount of cement usage. Therefore, the reduction in cement usage due to the substitution with FH is likely the cause of the lower compressive strength. On the other hand, the strength of the PC mixed with FH did not significantly decrease. This suggests the possibility that the calcium contained in FH contributes to maintaining the strength. Furthermore, Fig.7 shows that the compressive strength of all cases increases with the number of curing days. Here, calculating the daily strength increase rate from Fig.7 for FH-1% and FH-5%, the rate for FH-1% and FH-5% is approximately 8.6% and 13.9%, respectively. This data indicates that the increase rate for FH-5% which has a lower cement content exceeds that of FH-1%. This can be attributed to the decrease in porosity and the densification of the concrete for FH-5%, as seen in Fig.4 On the other hand, calcium is supplied from FH to PC by mixing FH into the concrete. Therefore, it is assumed that the continuous hydration reactions [21] contributing to the development of concrete strength contributes to the increase in strength.

The results of each test (Fig.4 to Fig.7) indicate a negative correlation between compressive strength and porosity, as well as between compressive strength and the permeability coefficient.

4. PLANT GROWTH EXPERIMENT

4.1 Preliminary Experiment

4.1.1 Experimental method

Nitrogen, phosphorus, and potassium are essential nutrients for plant growth and are commonly referred to as the "Three main fertilizer elements". Nitrogen is essential for the growth of leaves and stems, phosphorus is crucial for energy metabolism, photosynthesis, root development, and the formation of flowers and fruits. In addition, potassium is necessary for root growth. Phosphorus is an indispensable nutrient for fundamental plant growth processes, and an adequate supply of phosphorus directly contributes to healthy growth and quality improvement. Specifically, energy metabolism is disrupted when phosphorus is deficient, leading to an energy shortage in the plant. As a result, plant growth is inhibited. Phosphorus is also required to store and utilize the energy generated by photosynthesis efficiently. Therefore, a lack of phosphorus reduces photosynthesis efficiency and reduces the plant's ability to produce sugars and starch. Moreover, phosphorus is needed to promote root development and ensure that plants efficiently absorb water and nutrients from the soil. Therefore, adequate phosphorus allows roots to grow rapidly, supporting stable and healthy plant growth. Additionally, phosphorus is involved in plant reproductive growth and is particularly important for fruit trees and ornamental plant cultivation. Thus, a lack of phosphorus leads to poor flower and fruit formation. In addition, it leads to reduction in yield. FH is hydroxyapatite derived from fish bones, and is rich in phosphate, making it a valuable source of phosphorus for plant growth. In wastewater treatment processes, hydroxyapatite is separated from recovered sludge and used as a fertilizer, which could influence vegetation growth near concrete structures and potentially affect their interactions with the environment [22]. Therefore, various experiments are conducted in this study to examine how the phosphate and other components in FH contribute to plant growth. This section describes the preliminary experiment.

In this experiment, four types of soil specimens, Blank (horticultural soil only), FH-50 (horticultural soil + 50 g of FH), FH-100 (horticultural soil + 100 g of FH), and FH-200 (horticultural soil + 200 g of FH)—are prepared, with three specimens for each type, resulting in a total of 12 soil specimens. First, horticultural soil which is well mixed with FH is placed into a Wagner pot with dimensions ϕ15.9×19 cm. Subsequently, the viola seedlings are planted at the center of the Wagner pot, and water is provided until it begins to seep out from the bottom of the pot, allowing the roots of the viola seedlings to settle into the soil. The experiment is conducted in a location with ensuring adequate sunlight and ventilation. The implementation is conducted over a period of 43 days, from November 19, 2023, to December 31, 2023. As mentioned before, phosphorus promotes blooming and fruiting. Therefore, the viola which has a long blooming period and blooms even during cold seasons is selected as the plant for cultivation in this experiment. After the viola seedlings are planted, they are watered daily. In this experiment, measurements on the phosphorus content in the soil and the number of buds and flowers of the viola are conducted. First, to quantitatively measure the phosphate in the soil mixed with FH, the phosphate content in the soil after the experiment is measured using the method of water extraction proposed by the Japan Agricultural Research Organization (NARO) [23] as a reference. The method of measurement is as follows. First, 4 g of soil and 10 mL of distilled water are mixed in a cylindrical container and left to stand in a constant temperature chamber at 25°C for 18 hours. After standing, 0.5 mL of the filtrate obtained by filtration is put into a centrifuge tube and diluted 20 times with distilled water. Subsequently, 1.5 mL of the 20-fold diluted filtrate is transferred into a new centrifuge tube, and phosphate test kit reagent is added, followed by thorough mixing. After 5 minutes, the color of the liquid is compared with the phosphate ion color chart (Fig.8). If the concentration is 1 ppm or higher, the reaction is allowed to the proceed for at least 25 minutes before analysis using a portable spectrophotometer. If the concentration is less than 1 ppm, 0.5 mL of the undiluted filtrate is added, mixed, and then allowed to react for more than 25 minutes before analysis using a portable spectrophotometer. Finally, when the concentration is 1 ppm or higher based on comparison with the color chart, Eq. (1) is used to convert it to the phosphate content in the soil (mg/100 g). If the concentration is less than 1 ppm, Eq. (2) is used for the conversion.

$$\text{Phosphate content (mg/100 g)} = \text{Mesurement value} \times 13.4 \quad (1)$$

$$\text{Phosphate content (mg/100 g)} = \text{Mesurement value} \times 13.4 \quad (2)$$

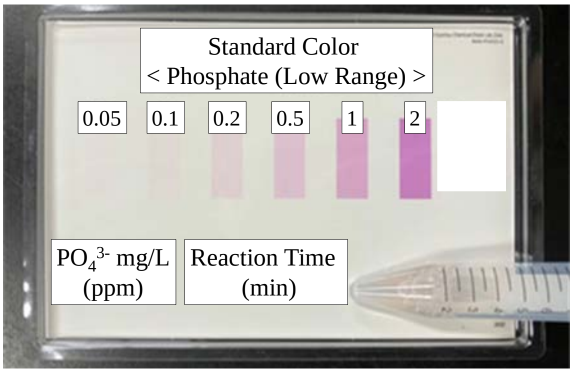

Fig.8 Color standard for phosphate ions

Next, the number of flowers and buds of viola is measured every 4 days, starting on the 7th day after planting the viola seedlings. It should be noted that all the buds and flowers of the viola seedlings are removed at the start of the experiment. Additionally, the violas flowers that began to close are removed to prevent energy from being concentrated on fruiting.

4.1.2 The result of preliminary experiment

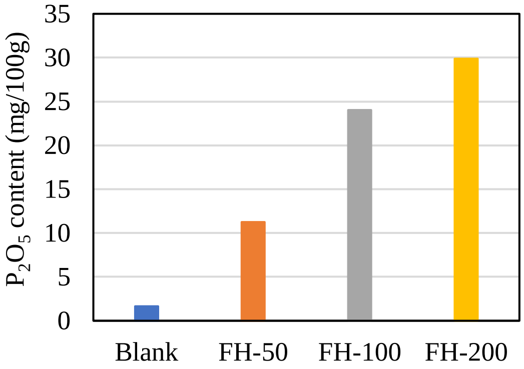

Fig.9 Phosphate content in each soil specimen

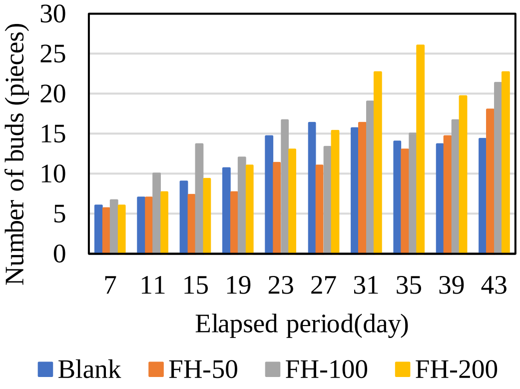

Fig.10 The trend in the number of buds of viola

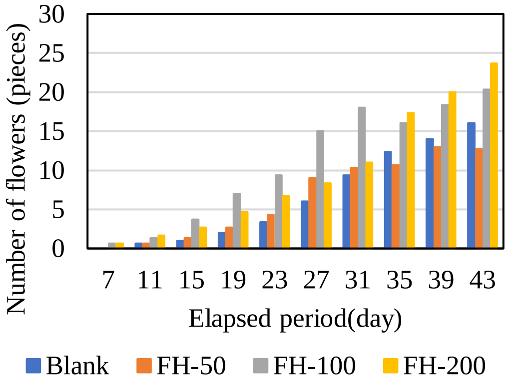

Fig.11 The trend in the number of flowers of viola

Fig.9 shows the phosphate content in each soil specimen, Fig.10 shows the trend in the number of buds of viola, and Fig.11 shows the trend in the number of flowers of viola. Fig.9 indicates that as the amount of FH mixed increases, the phosphate content in the soil also increases. On the other hand, Fig.10 shows that, until 27th day, there is little difference in the number of buds between cases where FH is mixed and where it is not. This is likely because the phosphate contained in FH, after being supplied to the soil, reacts with elements such as iron in the soil to form insoluble compounds, making it unavailable for plant absorption [24]. Fig.10 shows that, before the 31st day, the number of buds of the case with FH is equal or more than that of the case without FH. This is likely because the phosphate, which had become insoluble in the soil, is converted into a bioavailable form by organic acids released by the plants, making it accessible for plant uptake [25]. Fig.11 shows that, from the 19th day to the 31st day, the number of flowers in FH-100 is greater than that of the other soil specimens. This is likely because, as shown in Fig.10, the number of buds in FH-100 is higher from the 11th to the 23rd day, and these buds bloomed 7 to 10 days later. Additionally, Fig.11 shows that, after the 35th day, the number of flowers increases with the greater amount of FH mixed. This is likely because the phosphate, which had become insoluble in the soil, is converted into a bioavailable form by organic acids released by the plants, making it accessible for plant uptake, as mentioned above [25]. From the above, it is suggested that FH plays a role similar to that of a fertilizer, promoting flower bud formation and blooming.

4.2 Cultivation Experiment Using Grass

4.2.1 The method of cultivation experiment using grass

To verify the effect of FH mixed into PC on plant growth, a growth experiment is conducted by cultivating turf grass on the top of three types of PC specimens: Blank, FH-1%, and FH-5%. In this experiment, a 20mm soil covering is ensured on the top surface of the PC. The three types of specimens were cylindrical with φ100mm×180mm, and three specimens are prepared for each type, resulting in a total of nine specimens. After placing the PC, the specimens are cured in water for 28 days. Subsequently, slurry-like horticultural soil is filled into the voids of the PC as much as possible. Then, 0.2g of grass seed was sown on top of the 20mm soil covering. Here, Fig.12 shows the cross-sectional diagram of the experimental specimens. The duration of this experiment is 70 days, from November 9, 2023, to January 17, 2024. In the experiment, the test specimens are placed inside a cross-sectional diagram of the experimental specimens. The duration of this experiment is 70 days, from November 9, 2023, to January 17, 2024. In the experiment, the test specimens are placed inside a greenhouse. After sowing grass seeds on the top surface of the specimens, they are watered daily. In the experiment, leaf length and temperature measurements are taken. Leaf lengths are measured once a week starting from the 14th day after sowing. For each specimen, the five longest leaves are measured, and their average length is recorded. The average leaf length of the three specimens for each of Blank, FH-1%, and FH-5% is recorded as the leaf length measurement result for each type of specimen. In addition, in the temperature measurement, the temperature inside the greenhouse is recorded every 10 minutes using a data logger to investigate the growth of grass in response to temperature changes within the greenhouse.

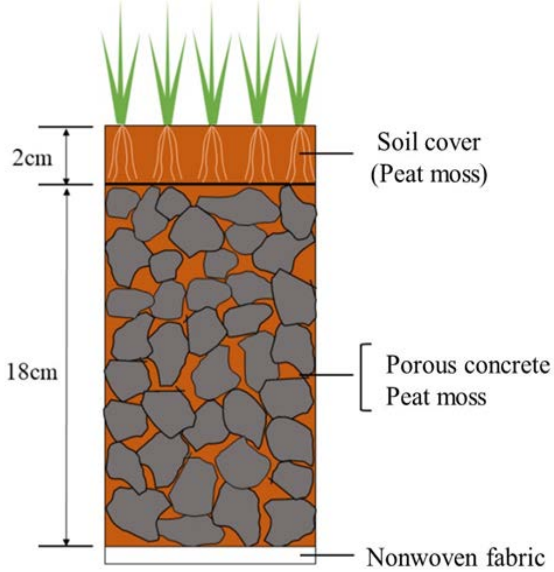

Fig.12 Cross-sectional diagram of specimens for grass cultivation experiment

4.2.2 The result of the cultivation experiment using grass

From Fig.13, it is confirmed that FH-5 % has the longest leaf length, followed by FH-1%, with Blank having the shortest leaf length. This suggests that the phosphate contained in the FH mixed into the PC contributes to plant growth. This suggests that the phosphate contained in the FH mixed into the PC contributes to plant growth. In other words, using PC mixed with phosphorus-rich FH as a vegetation base could lead to better plant growth. In the future, to determine the extent to which turf grass absorbs phosphate from the PC mixed with FH, elemental analysis to assess the phosphate concentration in the plant tissue quantitatively will be necessary to be conducted. Furthermore, Fig.14 shows the result of

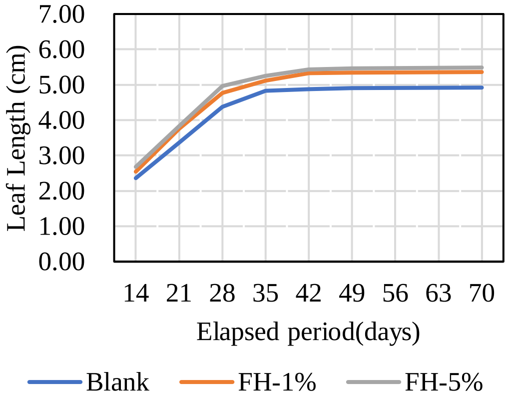

Fig.13 The results of leaf length growth

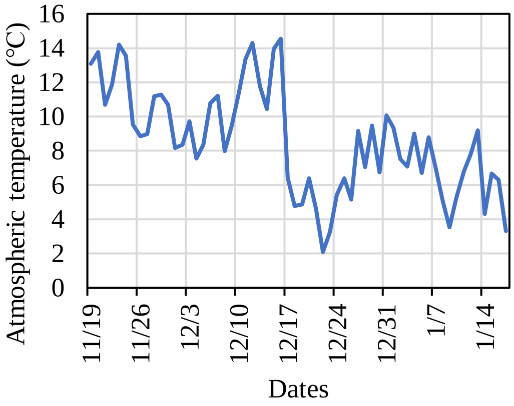

Fig.14 Temperature trends inside the greenhouse

the temperature measurement. Fig.13 shows that the growth rate of the leaf length decreases after the 35th day (December 13). This is likely because the average temperature inside the greenhouse on December 13 is approximately 12°C as shown in Fig.14, which is below the optimal growth temperature for grass of 15-20°C.

4.3 Cultivation Experiment Using Viola

4.3.1 The method of cultivation experiment using viola

Next, in this experiment, a cultivation experiment is conducted using three types of specimens of Blank, FH-1%, and FH-5% to verify whether the phosphate contained in the FH mixed into the PC affects the formation of flower buds in plants. In this experiment, three cylindrical specimens with a radius of 100 mm and a height of 200 mm are prepared for each type, making a total of nine specimens used for the test. Similar to the cultivation experiment using grass, slurry-like horticultural soil is filled into the voids of the PC cured in water for 28 days. Then, a viola seedling is planted on top of the PC, and water is supplied until it seeps out from the bottom of the PC. Similarly to the preliminary experiment, existing buds and flowers of the viola are removed at the start of the experiment to measure the number of buds and flowers. The duration of this experiment is 43 days, from November 19, 2023 to December 31, 2023, and daily watering of the specimens is conducted. Starting the 7th day after planting the viola seedling, the number of buds and flowers of the viola is counted every four days. Additionally, as in the preliminary experiment, newly blooming flowers are removed to prevent energy from concentrating on fruiting.

4.3.2 The result of the cultivation experiment using viola

Fig.15 and Fig.16 show the trend in the number of buds on viola and the trend in the number of flowers on viola, respectively. Fig.15 shows that the number of buds of the viola planted in PC mixed with FH is higher than that of the viola planted in PC without FH. This suggests that the phosphate contained in FH contributes to the flower bud formation. Furthermore, unlike Fig.10, Fig.15 shows that the number of buds of the case with FH is higher than that of the case without FH starting from the 7th day. This can be inferred as follows: in the preliminary experiment, FH is initially present in the soil, whereas in this experiment, the phosphate contained in FH is first leached from the PC and then supplied to the soil. Additionally, the presence of roots within the voids allowed them to absorb the phosphate directly. Consequently, phosphate from FH is supplied from multiple directions, increasing the opportunity for it to be absorbed by the roots before becoming insoluble [25]. Furthermore, Fig.16 shows that, after the 23rd day, the number of viola flowers in the case with FH is higher than that in the case without FH. Fig.16 also shows that, after the 23rd day, the number of flowers of the viola with FH-1% is equal to or greater than those with FH-5%. From these findings, it can be concluded that the phosphate contained in the FH mixed into the PC contributes to blooming and flower bud formation.

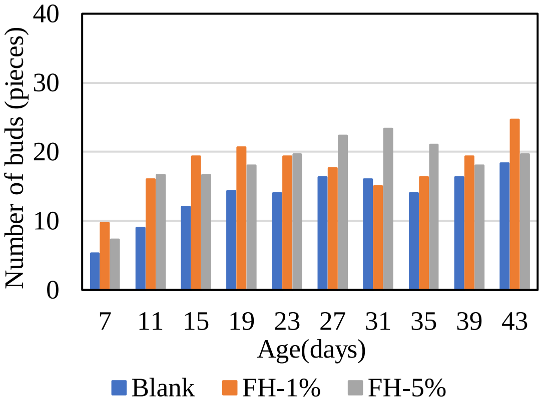

Fig.15 The trend in the number of buds of viola

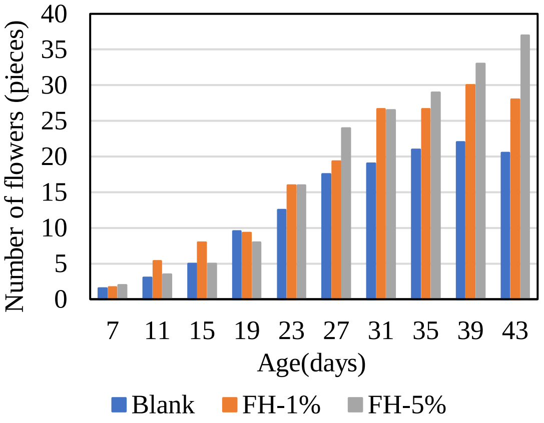

Fig.16 The trend in the number of flowers of the viola

5. CONCLUSION

Globally, achieving the Sustainable Development Goals (SDGs) is a major focus. This study specifically targets Goal 12: "By 2030, substantially reduce waste generation through prevention, reduction, recycling, and reuse.". The approach of the "circular economy," which emphasizes an overall economic model aimed at minimizing waste generation by maximizing the value of resources and products, has recently garnered significant attention. In Japan, a significant amount of fish residues are discarded annually due to the higher consumption of seafood compared to other countries. In Japan, the reuse rate of fish residues is low, and even when they are utilized, they are primarily repurposed into low-value products such as fish feed and livestock fodder. In light of these backgrounds, some authors of this article have developed fish bone-based hydroxyapatite powder (FH) by reutilizing fish residues. In this study, it is focused that the main component of the FH is calcium phosphate, and the FH is examined its application to PC, which is also suitable for vegetation. Specifically, in this study, we investigated the development of PC mixed with FH, expecting the calcium to maintain the strength of concrete and the phosphate to enhance plant growth capability. As a result, the following findings are obtained.

- PC mixed with FH has the necessary porosity and permeability for plant growth.
- Although the compressive strength of PC mixed with FH is lower than that without FH, the compressive strength of the PC mixed with FH at 28 days of curing meets the target value
- It has been found that after 31 days from the start of the experiment, the greater the amount of FH mixed into the concrete, the higher the number of viola buds in the soil test specimens. Furthermore, it has been found that after 35 days from the start of the experiment, the greater the amount of FH mixed into the concrete, the higher the number of viola flowers in the soil test specimens. These findings suggest that FH has a function of promoting flower bud formation and blooming.
- In the cultivation experiment using grass, the leaf length of grass cultivated on the test specimens (PC) is the longest with FH-5%, followed by FH-1%, and the shortest with Blank. Thus, it is inferred that the phosphate contained in the FH mixed into the PC contributes to plant growth.
- After 7 days from the start of the experiment, plant growth experiments using viola reveal that the number of buds on viola grown on the PC specimens mixed with FH is greater than that on specimens without FH. Furthermore, after 23 days from the start of the experiment, it is also found that the number of flowers on viola grown on the PC specimens mixed with FH is greater than on those without FH. Based on these findings, it is inferred that the phosphate contained in FH mixed into the PC contributes to flower bud formation and blooming in plants.

In summary, it is clarified that mixing the FH into PC secures the required strength, enhances plant growth capability, and promotes flower bud formation in plants, which suggests the possibility of developing a vegetation-focused type of PC. Furthermore, it can be applied in all locations where vegetation is required, since PC mixed with FH has a higher plant growth capacity than general PC. Here, the price of 1000 kg of cement is assumed to be 24,800 yen [26]. Furthermore, replacing 1% of the cement mass with FH can reduce the cement usage by 3.37 kg per cubic meter of PC. Here, 900 m^3 of PC was used in the Aizawa River embankment repair project in Yamagata Prefecture [27]. Furthermore, while the production cost of FH is certainly not free, it is currently not a commercial product, making it difficult to calculate the cost. Therefore, the production cost is considered to be zero. Under these assumptions, replacing 1% of the cement mass with FH results in a cost reduction of approximately 75,200 yen, and replacing 5% of the cement mass with FH results in a cost reduction of approximately 376,100 yen. Therefore, substituting cement with FH in PC can lead to cost savings.

6. FUTURE PROSPECTS

The physical property tests and plant growth experiments conducted in this study are short-term. Therefore, in the future, it is necessary to investigate the long-term strength, the leaching process, and the leaching duration of phosphate from the PC mixed with FH, with a focus on its long-term use. Additionally, in the future, it will be necessary to quantitatively analyze the phosphate concentration in the plants to clarify how phosphate from PC mixed with FH is transferred to the grass and viola. In addition, in the future, it will be necessary to investigate the compressive strength increase rate over an extended curing period, since the strength increase rate of FH-5% from 7 days to 28 days curing exceeds that of FH-1%. Furthermore, in this study, only the compressive strength test is conducted to evaluate the durability of the PC. Therefore, it will be necessary to conduct other durability tests, such as wet-dry cycle tests in the future. And, it will be necessary to evaluate the environmental impact, such as the reduction in carbon dioxide emission, resulting from the substitution of cement with FH. Here, FH is very cost-effective compared to other industrial hydroxyapatites since its production cost only involves electricity expenses [28]. Moreover, unlike hydroxyapatite derived from livestock, which carries risks such as BSE and avian influenza, FH is derived from fish bones, making it much less risky and highly biocompatible. On the other hand, the applications of FH have not been widely explored at this point. Therefore, this study initially aimed to verify the usefulness of FH as a concrete material. In the future, researches will likely to expand the applications of FH, such as its use in medical fields.

7. ACKNOWLEDGMENTS

This work is supported by the Iwatani Naoji Foundation, the Kajima Foundation, Takahashi Industrial and Economic Research Foundation, the Nankai Scholarship Association, the Nikko Memorial Foundation JST Japan Grant Number JPMJPF2306. We would like to express our gratitude here.

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