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Performance Evaluation of Permeable Block using Hydroball

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Abstract. Carbon dioxide and fine dust have recently been a concern not just in Korea, but also around the world. As a result, a way to eliminate dangerous elements in the air, such as carbon dioxide and fine dust, is necessary. The goal of this study is to evaluate the performance of the permeable block by analyzing the flexural strength, compressive strength, permeability coefficient, carbon dioxide, and fine dust adsorption rate of the permeable block produced according to the hydroball replacement rate. The flexural strength and permeability coefficient of the permeable block are evaluated based on 'KS F 4419', the standard for permeable blocks, and the performance evaluation of adsorption of harmful substances such as carbon dioxide and fine dust is based on the small chamber method proposed by Hanbat University. The following are the findings of this study: As the hydroball replacement rate increased, the flexural and compressive strengths decreased over time. Due to the porous properties of the hydroball, this is thought to have reduced the strength as a consequence of insufficient moisture necessary for hydration. In the case of flexural strength, it is judged that the hydroball replacement rate is appropriate up to 20% based on 'KS F 4419', which is the water-permeable block standard. In the case of carbon dioxide and fine dust concentrations, the concentration decreased as the hydroball replacement rate increased. When the hydroball replacement rate is 30%, carbon dioxide is adsorbed 79%, and fine dust was adsorbed 82%. The concentration of carbon dioxide and fine dust was lowered as a result of physical adsorption generated by generating voids inside the cured body and the influence of hydroball photocatalysts. Based on the results of this study, replacing the permeable block using hydroball with the existing permeable block is expected to contribute to health

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improvement as a solution to air pollutants, and it can be used as basic data to secure engineering properties and adsorption of harmful substances.

Keywords: Permeable block, Hydroball, Fine dust, CO_2, Adsorption

1. Introduction

Humanity has progressed to its current state as a result of growing urbanization and the industrial revolution. However, as a side effect of this, the impermeable surface has risen and lives in a polluted atmospheric environment. Recently, the risk of fine dust has emerged in Korea. According to a report by HEI (Health Impact Research Institute) in 2015, the concentration of ultrafine dust in Korea was the second- highest among OECD member countries (Ministry of Environment, 2016). In addition, fine dust was designated as a carcinogen by the WHO (World Health Organization) as the cause of respiratory diseases, and it was reported that the risk to the human body increases as the concentration of fine dust increases. As a response to this, the most active method at present is the reduction of ventilation and purification facilities, but economic losses occur due to the increase in facilities and continuous management, so a solution is needed(Choi, 2020; Choi, 2020). Accordingly, research using Tio_2, which is a photocatalyst, and a porous material as an adsorbent, is underway as a fundamental solution to alleviate air pollution(Kim, Pyeon, and Lee, 2018; Pyeon, Nam, and Lee, 2019). Furthermore, as urban areas have developed due to rapid industrial development during the 1960s, green space has reduced and impermeable surface has increased as the area of high-rise structures has grown(Yu, Lee, Pyeon, Kim, and Lee, 2018; Kim, & Jeong, 2019). Due to this problem, the circulation structure of rainwater was changed, and in the past, rainwater flowed into or evaporated into groundwater, but as the green area decreased and the impermeable surface rose, the circulation structure of rainwater was disrupted. As a solution to this problem, the front permeable block is paved on the road so that rainwater flows into groundwater(Lee, Kim, Yoo, and Lee, 2021). Accordingly, this study aims to produce a multifunctional permeable block capable of adsorbing carbon dioxide and fine dust using hydroball, an eco-friendly material, and to evaluate the permeable block`s performance through experiments analyzing flexural strength, compression strength, water permeability coefficient, carbon dioxide, and fine dust adsorption. In addition, since research on building materials using hydroball is insufficient, it is intended to be presented as basic research data based on the findings of this study.

2. Experimental plan

This is a cement-based experiment, and the performance of the water-permeable block will be evaluated in relation to the hydroball replacement rate. The water-cement ratio was fixed at 20%, the hydroball replacement rate was 0, 10, 20, and 30(%), and the experiment was conducted at four levels. The ratio of coarse aggregate to cement mass is 1:5. The experimental items were flexural strength, compressive strength, water permeability coefficient, carbon dioxide, and fine dust adsorption, and 40x40x160(mm^3) was used as a test specimen to measure adsorption. The experiment on adsorption was conducted with a small chamber method. Flexural and compressive strength were measured on 3, 7, and 28 days, and the experimental factors and levels accordingly are as follows.

Table 1: Experimental factors and levels

Experimental factors	Experimental levels	
Binder	OPC[1)]	1
Adsorbents	Hydroball	1
W/C	20 (%)	1
Binder : Aggregate	1 : 5	1
Replacement rate of adsorbents	0, 10, 20, 30 (wt %)	4
Curing condition	Temp. 20±2℃, Hum. 60±5%	1
Experimental item	Flexural strength, Compressive strength, Permeability coefficient, CO_2 concentration, Fine dust concentration	5

1) OPC : Ordinary Portland Cement

2.1 Materials

2.1.1 Hydroball

Hydroball is an artificial culture soil sterilized with a high heat of about 1200°C or higher using loess as a raw material. It is a natural material with a density of about 2.3 and excellent air permeability, absorption, repairability, and porosity. In particular, since it has excellent ventilation, it has the advantage of preventing decay by adsorbing pollutants or dust in the atmosphere. Hydroball has a large porosity, Ph is neutral, and is made of a porous material with many small holes, so it is light and has good absorption and discharge capacity of moisture. In addition, there is a lot of space for water to escape, so it is excellent in preventing mold from forming in the hydroball, and the material itself is not damaged because it is red clay with chemical properties, not soil.

Figure 1. Hydroball

Table 2. Physical properties of hydroball

Physical properties of hydroball				
Density	Grading	Specific powder surfaces	Specific gravity	Percentage of water content
2.3	10~20mm	$148m^2/cm^3$	$0.4\sim0.7g/m^3$	40~50%

Table 3. Chemical properties of hydroball

Component	Ratio(%)	Component	Ratio(%)
SiO_2	60	Al_2O_3	12
Fe_2O_3	4	FeO	1.1
TiO_2	0.5	MnO	0.5
CaO	16	MgO	6

2.1.2. Ordinary Portland cement

The cement to be utilized in this study is Portland cement, which is made by combining raw materials such as silica, aluminum, iron oxide, and lime in the proper proportions and then adding the right amount of gypsum to the clinker generated by firing them. Table 4 shows the physical properties of Portland Cement.

Table 4. Physical properties of ordinary portland cement

Density (g/cm^3)	Fineness (g/cm^2)	Loss ignition (%)	Compressive strength (MPa)		
			3days	7days	28days
3.15	3,413	0.97	22.7	29.8	38.8

Table 5. Chemical properties of ordinary portland cement

Chemical properties (%)							
OPC	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	TiO_2
	63.8	22.1	5.0	3.0	1.6	2.0	0.3

2.1.3 Coarse aggregate

According to ‘KS F 2527,’ the aggregate utilized in this study should have an absolute density of 2.5 or greater and an absorption rate of 3% or less, as stated in Table 6. As a result, the aggregate utilized in this study is thick, with a particle diameter of 5-10mm, a 2.74 percent absorption rate, and an absolute density of 2.65 g/cm^3.

Table 6. Physical properties of aggregate

Sortation	Particle size(mm)	Absorption rate(%)	Drying density (g/cm^3)
Coarse aggregate	10	2.74	2.65
‘KS F 2527’ aggregate	-	less than 3	2.5 and above

2.2 Experimental methods

2.2.1. Hazardous substance concentration

Since there is no standard for measuring the concentration of hazardous substances, the experiment was conducted using the small chamber method proposed by Hanbat University. Hazardous substances filled while continuously operating the pan in the closed empty chamber are convectively moved by the wind of the pan and move throughout the interior to finally reach the surface of the hardened body. At this time, the concentration of hazardous substances is kept constant, and after inserting the test specimen, it is measured in the same manner as in Figure 2 using a hazardous substance concentration meter. The measurement time was 2 hours, and the concentration of hazardous substances was checked every 10 minutes(Pyeon, Lim, and Lee, 2018; Pyeon, & Lee, 2018; Lee, 2021; Kyoung, 2021; Lim, 2020; Kim, 2022; Kim, Lee, and Lee, 2022).

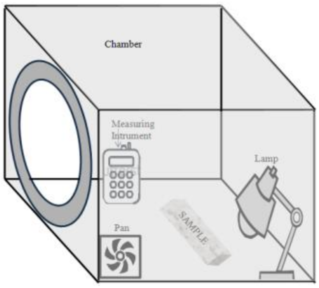

Figure 2. Adsorption measurement

2.2.2. Flexural and Compressive strength

The flexural strength test is conducted in accordance with 'KS F 4419'. After immersing the sample in water for 24 hours, test it immediately after taking it out. Take the point-to-point distance as 140mm and apply the load to the center between points. The dimensions of the sample are 40x40x160 (mm^3). The formula associated with the calculation of flexural strength is given in [Equation 1].

$$R_f = \frac{3Pl}{2bd^2} \qquad (1)$$

R_f : Load applied to the center of the footnote in case of destruction(N)
P : Maximum breaking load indicated by the testing machine
l : Distance between supports(mm)
b : The side of the incision that forms a right angle to the leg(mm)
d : Average thickness of the block

The compressive strength test method was used by specimen 50×50×50(mm^3) in accordance with KS L 5105, and the formula for calculating compression strength is as follows in [Equation 2].

$$R_c = \frac{F_c}{A} \tag{2}$$

F_c : Maximum destructive Load (N)
A : Area of the pressurized or auxiliary plate (mm^2)

2.2.3. Permeability coefficient

The water permeability test method was based on 'KS F 4419,' and a specimen 40×40×160(mm^3) was used. Fix the block in the formwork after measuring its thickness and cross-sectional area with a vernier caliper. Ensure that no water leaks out of the block at this time, with the exception of the paraffin or sealing material-coated block. Fill the test equipment with water and maintain a steady water level. Wait for the discharge amount to stabilize, then measure the outflow quantity using a measuring cylinder for 30 seconds. The permeability coefficient is calculated as the average of each value obtained after testing three samples at 1 minute or longer intervals. The formula for calculating the permeability coefficient is as follows in Equation 3.

$$K = \frac{d}{h} \times \frac{Q}{A \times 30s} \tag{3}$$

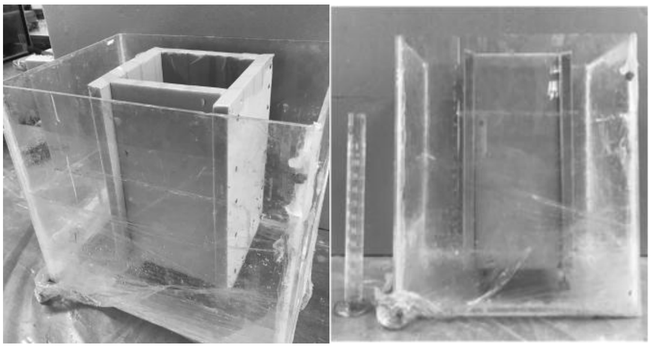

Figure 3. Permeability coefficient experimental testing

3. Experimental result and analysis

3.1 Flexural and compressive strength

Figure 4 and Figure 5 are graphs showing flexural strength and compressive strength according to the hydroball replacement rate. As a result of the experiment, as the hydroball replacement rate increased, the flexural strength and compressive strength tended to decrease. This is judged to have decreased the strength due to the lack of moisture required for curing by the hydroball absorbing a large amount of moisture during the blending process(Lee, Kim, Yoo, and Lee, 2021).

3.2 Permeability coefficient

Figure 6 is a graph showing the water permeability coefficient according to the hydroball replacement rate. As a result of the experiment, as the hydroball replacement rate increased, the permeability coefficient tended to increase, and the results were satisfied according to 'KS F 4419'. It is judged that the amount of water permeated increases as the voids in the permeable block increase according to the hydroball replacement rate.

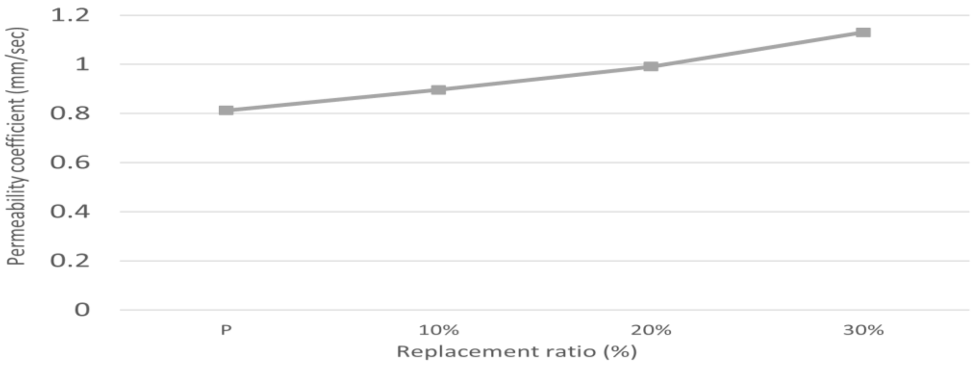

Figure 4. Flexural strength

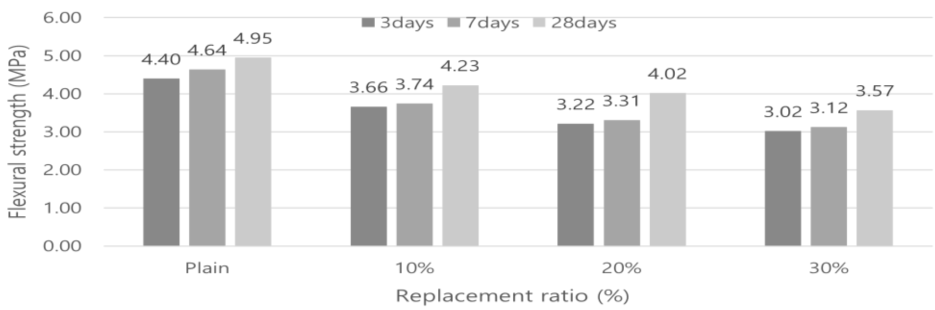

Figure 5. Compressive strength

Figure 6. Permeability coefficient

3.3 CO_2 concentration

Figure 7 is a graph showing the carbon dioxide concentration according to the hydroball replacement rate. As a result of the experiment, it can be seen that the carbon dioxide concentration tends to decrease as the hydroball replacement rate increases. It is determined that the concentration of carbon dioxide present in the chamber decreases due to physical adsorption generated by porous characteristics and chemical adsorption of the photocatalyst of the hydroball when carbon dioxide circulates in the chamber through an airflow and contacts the permeable block(Kim, 2022; Kim, Lee, and Lee, 2022).

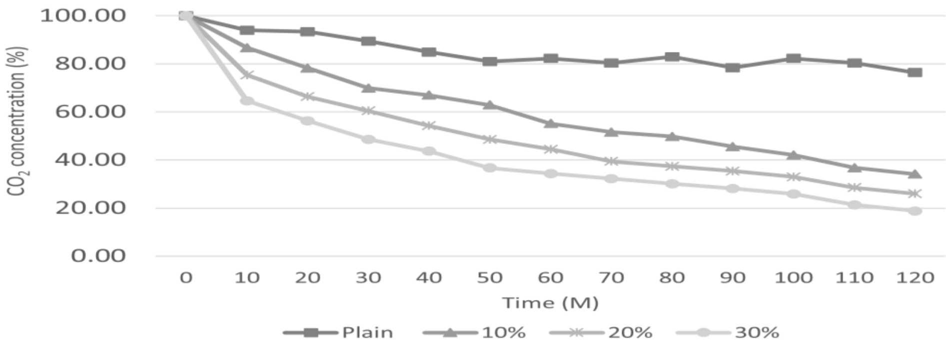

Figure 7. CO_2 concentration

3.4 Fine dust concentration (PM2.5, PM10)

Figure 8 and Figure 9 is a graphs showing the concentrations of fine dust (PM2.5 and PM10) according to the hydroball replacement rate. As a result of the experiment, it can be seen that the concentration of fine dust tends to decrease as the hydroball replacement rate increases. It is judged that the concentration of fine dust has decreased due to physical adsorption caused by generating voids inside the cured body and the influence of photocatalysts of the hydroball by utilizing the hydroball(Kim, 2022; Kim, Lee, and Lee, 2022).

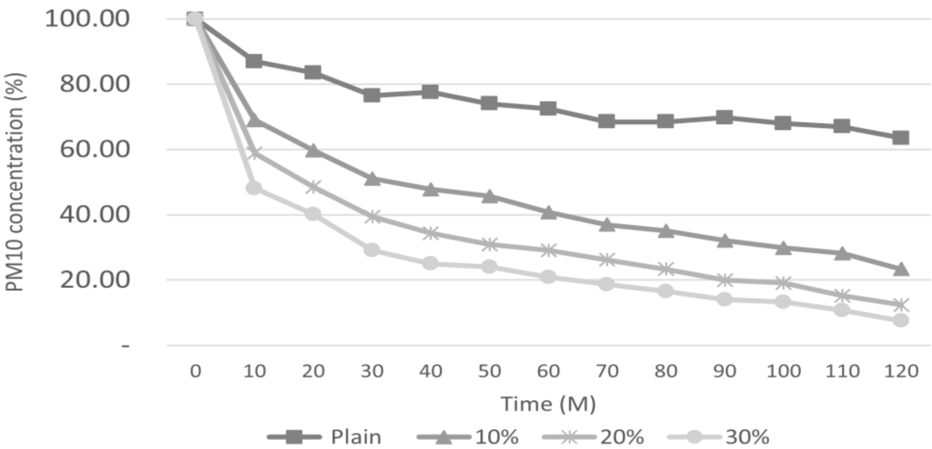

Figure 8. Fine dust concentration (PM 2.5)

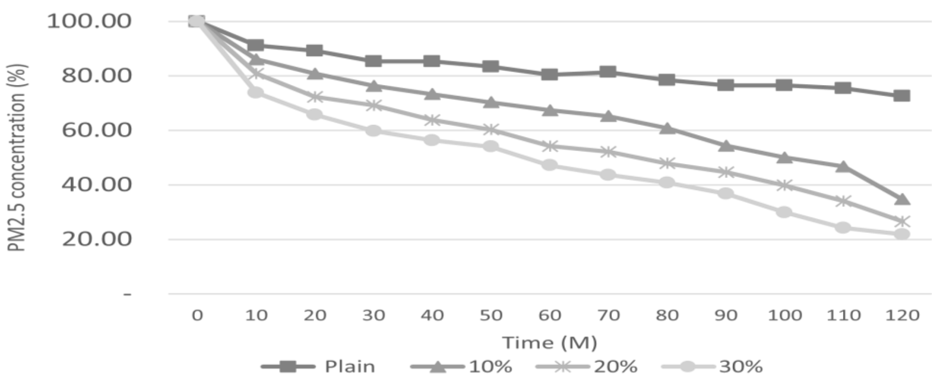

Figure 9. Fine dust concentration (PM 10)

4. Conclusion

This study analyzes the flexural strength, compressive strength, water permeability coefficient, carbon dioxide, and fine dust concentration of the permeable block produced according to the hydroball replacement rate, and the results are as follows. As a result of the review, the flexural and compressive strength of the hydroballs decreased as the replacement rate increased. This is judged to have decreased the strength due to the lack of moisture required for hydration due to the absorption of a large amount of moisture by hydroball during the blending process. In the case of flexural strength, it is determined that the hydroball replacement rate up to 20% is appropriate based on ʹKS F 4419ʹ. The permeability coefficient showed a result of satisfying 0.1 (mm/sec) stipulated in ʹKS F 4419ʹ. As the hydroball replacement rate increased, the amount of water permeated tended to increase as the voids generated in the permeable block increased. In the case of carbon dioxide and fine dust concentrations, the concentration tended to decrease as the hydroball replacement rate increased. When the hydroball replacement rate was 30%, carbon dioxide showed 79% adsorption, and fine dust showed 82% adsorption. The physical adsorption of the hydroball in the pores, as well as influence of the hydroball`s photocatalyst, are reported to decrease carbon dioxide and fine dust concentrations. Therefore, it is judged that the permeable block using the hydroball is superior to the general permeable block. However, it is believed that additional experiments such as freeze melting are needed to evaluate the utilization performance of the permeable block using hydroball, and as a result of this paper, it can be used as basic data to secure engineering properties and adsorption of harmful substances.

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