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Fundamental Properties of Porous Concrete by Aggregate Size

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Abstract: Porous concrete has been used recently for the purpose of decreasing the load on the earth environment. It consists solely of cement, water and coarse aggregate of uni form size. Its fundamental properties are considerably affected by the physical properties of aggregate because the aggregate is the main material for the most part in its mix proportion. Because of this reason, this study carried out an investigation of the influence of the size and type of aggregate on the fundamental properties of porous concrete. It is shown that the fundamental properties of porous concrete was seldom affected by the size of aggregate except for the case of using 2.5~5 mm aggregate but varied significantly by the type of aggregate. In particular, the compressive strength of porous concrete using 2.5~5 mm aggregate was much higher than that using other aggregate, and its void ratio and coefficient of permeability was lower. Moreover, the capacity to maintain the permeability of porous concrete was found to vary by the size and type of aggregate. Of particular notice was that it decreased greatly when 2.5~5 mm aggregate was used. Unlike ordinary concrete, porous concrete exhibited very high dynamic modulus of elasticity at early age and continued to increase but slowly afterwards.

Keywords: porous concrete, size and type of aggregate, compressive strength, coefficient of permeability.

1. Introduction

The preservation of earth environment has become a serious issue around the world, and the preconception on concrete as the main construction material has been changing accordingly. In other words, there have been efforts to expand the use of environment-friendly materials by decreasing the load on the environment during concrete production and use (prolongation of concrete life and use of porous concrete).[1,2]

Among these construction materials, porous concrete injects many continuous voids inside the concrete artificially to make it permeable, ventilative, and sound-absorbing. This functionally-facilitated concrete is used as permeable road pavement material, foundation material for afforestation, water purifying material, sound absorbing material, etc. It has also become noticed as a construction material, which reduces the load on the earth environment.[1,2] Fig. 1 shows the comparison of mix proportion between porous concrete (a.k.a. concrete without fine aggregate) and ordinary concrete. The former does not contain fine aggregate and has a greater proportion of coarse aggregate compared to the latter (ordinary concrete). Thus, it is presumed that the fundamental property of porous concrete will be greatly affected by coarse aggregate.

Accordingly, this study intends to suggest fundamental data (such as compressive strength and permeability) on porous concrete in relation to the experimental variable of the type and size of aggregate. Additionally, it is expected that the permeability of porous concrete will decrease with years of time due to the accumulation of impurities such as earth soil and sand when it is used as permeable pavement material. Thus, this study aims to suggest fundamental data on improving the capacity to maintain permeability of porous concrete by examining the influence of the type and size of aggregate on its permeability as it is being infiltrated by muddy liquid.

2. Overview of experiment

2.1 Experimental plan and mixing design

The experimental plan of this study is shown in Table 1. The series I is composed of four groups of aggregate sizes of 2.5~5 mm, 2.5~8 mm, 5~8 mm, 5~13 mm and unit cement contents of 330 kg/m^3 and 400 kg/m^3. The series II varied aggregate types in two groups under the same mixing condition. This experimental setup is to investigate the influence of the type and size of the aggregate on the fundamental properties of porous concrete.

The fundamental properties of porous aggregate being investigated are compressive strength, continuous void ratio, all void ratio and coefficient of permeability. Additionally, unit weight, ultra-sonic pulse velocity and dynamic modulus of elasticity are measured to examine their relationship to the fundamental properties. Moreover, the porous concrete is infiltrated by muddy liquid to examine the influence of the size

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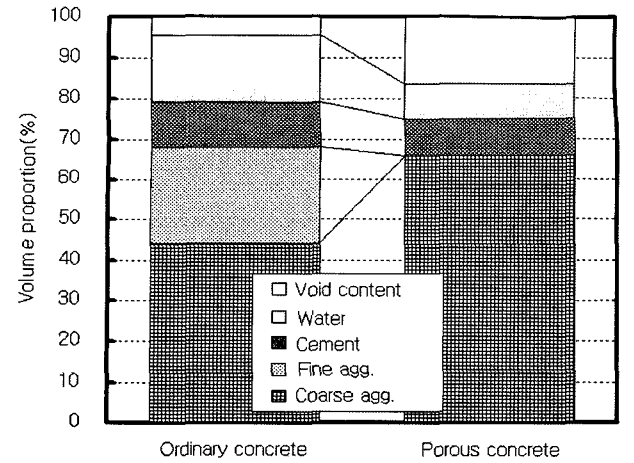


Fig. 1 Comparison of mix proportion between porous concrete and ordinary concrete.[1)]

and type of aggregate on the capacity of the porous concrete to maintain its permeability in simulation of the effect of time passage on the proportional reduction in coefficient of permeability.

The mix proportion for the porous concrete used in this study is shown in Table 2.

2.2 Materials

The aggregate was prepared by crushing rocks of maximum size of 13 mm with a jaw crusher and then classified by the size of the crushed aggregate. There were two types of aggregate used in this study to investigate the influence of different aggregate type on the fundamental properties of porous aggregate. Their physical properties are summarized in Table 3. In addition, Portland cement of first class and the superplasticizer of polycarboxylic ether composition were used as the cement and chemical admixture. Their physical properties are summarized in Tables 4 and 5, respectively.

2.3 Preparation of test specimen and curing method

A forced pan-type mixer of 100 liter capacity was used for mixing. Aggregate and cement was put in the mixer for mixing at dry air for 30 seconds. Then, water and superplasticizer were added for additional mixing for 150 seconds.

After mixing, the porous concrete material filled a mold

Table 1 Experiment plan.

Series	Sizes of agg. (mm)	Kinds of agg.	Unit cement content (kg/m^3)	W/C (%)	Items of measurement
I	2.5~5	A	330 400	25	·Compressive strength (kgf/cm^2) ·All void ratio (A.V.R) (%) ·Continuous void ratio (C.V.R) (%) ·Unit weight (t/m^3) ·D.M of elasticity ($\times 10^5$kgf/cm^2) ·Coefficient of permeability (cm/s) ·Ultra-sonic pulse velocity (km/s) ·Reduction ratio of coefficient of permeability (%) ·Measurement age : 28 days
	2.5~8				
	5~8				
	5~13				
II	5~8	A	400		
		B			

Table 2 Mix proportion of porous concrete.

Series	Sizes of agg. (mm)	Kinds of agg.	W/C (%)	Unit water content (kg/m^3)	Unit volume (l/m^3)		Unit weight (kg/m^3)	
					Cement	Agg.	Cement	Agg.
I	2.5~5	A	25	83	105	613	330	1581
	2.5~8					613		1582
	5~8					612		1579
	5~13					609		1571
	2.5~5			100	127	613	400	1581
	2.5~8					613		1582
	5~8					612		1579
	5~13					609		1571
II	5~8	A	25	100	127	612	400	1579
		B				610		1665

Table 3 Physical properties of aggregate.

Sizes of agg. (mm)	Kinds of agg.	Specific gravity	Absorption ratio (%)	Unit weight (kg/m^3)	Void ratio (%)	Note
2.5~5	A	2.58	1.65	1,581	38.74	Crushed stone
2.5~8				1,582	38.68	
5~8				1,579	38.79	
5~13				1,571	39.10	
5~8	B	2.73	1.54	1,665	39.00	

Table 4 Physical properties of cement.

Type of cement	Specific gravity	Blaine (cm^2/g)	Setting time (hr.:min.)		Compressive strength (kgf/cm^2)		
			Ini.	Fin.	3 days	7 days	28 days
Ordinary portland cement	3.15	3,265	3:35	5:35	227	298	388

Table 5 Physical properties of chemical admixture.

Type	Appearance	Main composition	pH	Specific gravity (20°C)
Superplasticizer	Dark brown, liquid	Polycarboxylic ether	8	1.20 ± 0.05

(ϕ100 × 200 mm) half full and was subjected to rod compaction of 50 times and jigging of 25 times. This compaction and jigging process was repeated to prepare the test specimen. The test specimen was taken out of the mold after 24 hours and was cured routinely under water (20 ± 3°C) until the measurement time.

2.4 Experimental method

2.4.1 Compressive strength, unit weight, ultra-sonic pulse velocity and dynamic modulus of elasticity

The compressive strength, ultra-sonic pulse velocity and dynamic modulus of elasticity were measured pursuant to the specifications of KS < Korean (Industrial) Standards > F 2405, KS F 2418, and KS F 2437, respectively. The unit weight measured the weight (kg) of the specimens undergoing compressive strength test per unit volume (m^3).

2.4.2 All void ratio and continuous void ratio

All void ratio and continuous void ratio were measured in accordance with 『Guideline(s) for Measuring Void Ratio of Porous Concrete』 as specified by Echo Concrete Research Commission of Japan Concrete Institute. They are computed by the following eq. (1).

$$A = [1 - (W_2 - W_1) V_1] \times 100 \quad (1)$$

A : all void ratio or continuous void ratio (%)
W_1 : wet-weight of the test specimen (g)
W_2 : dry weight (all void ratio) or constant weight (continuous void ratio) after 24 hours of curing under the condition of 20 ± 2°C and RH of 60% (g)
V_1 : volume of the specimen (cm^3)

2.4.3 Coefficient of permeability

The coefficient of permeability was measured pursuant to 『Guideline(s) for Measuring the Coefficient of Permeability for Porous Concrete』 as specified by Echo Concrete Research Commission of Japan Concrete Institute. It is computed by the following eq. (2).

$$K = (H/h) \times Q/[A \times (t_2 - t_1)] \quad (2)$$

K : coefficient of permeability (cm/s)
H : height of the specimen (cm)
Q : quantity of water permeating from time t_1 to time t_2 (cm^3)
h : difference in water level (cm)
$t_2 - t_1$: measuring time (sec)
A : cross sectional area of the test specimen (cm^2)

2.4.4 Proportional reduction in coefficient of permeability by infiltration of muddy liquid

The investigation of proportional reduction in coefficient of permeability by infiltration of muddy liquid was carried out by infiltrating muddy liquid of constant quantity (1 liter), which was prepared by mixing a powder material (fly ash of 2.13 specific gravity and fineness of 3,158 cm^2/g) in water at the volumetric ratio of 2%, into the specimen (ϕ150×150 mm) for permeability test. Then, after hardening the remnants in the test specimen, the coefficient of permeability was measured in accordance with the aforementioned 『Guideline(s) for Measuring the Coefficient of Permeability for Porous Concrete』. This process was repeated for the simulation of time passage. The proportional reduction in the coefficient of permeability was computed by eq. (3).

$$R_n = (K_n / K_0) \times 100 \quad (3)$$

K_o : initial coefficient of permeability (cm/s)
R_n : reduction ratio of coefficient of permeability after n cycle (%)
K_n : coefficient of permeability after n cycle (cm/s)

3. Experimental result and discussion

Table 6 shows the results of measuring various properties of the porous concrete specimen.

3.1 Analysis of experimental results on compressive strength

Fig. 2 shows variation of compressive strength by the type and size of aggregate. The compressive strength remained

Table 6 The results of porous concrete.

Unit cement content (kg/m^3)	330				400				400	
Kinds of aggregate	A				A				A	B
Sizes of aggregate (mm)	2.5~5	2.5~8	5~8	5~13	2.5~5	2.5~8	5~8	5~13	5~8	5~8
Compressive strength (kgf/cm^2)	215	140	151	157	244	204	203	201	203	274
All void ratio (%)	20.6	26.7	28.1	27.6	18.1	22.3	22.5	23.6	22.5	18.0
Continuous void ratio (%)	17.1	22.3	24.6	23.8	14.0	18.3	18.9	20.5	18.3	14.4
Coefficient of permeability (cm/s)	0.57	0.87	0.95	0.94	0.36	0.61	0.61	0.67	0.61	0.38

about the same regardless of the size of the aggregate given the same unit cement content except that it showed a significantly higher value when the size of the aggregate was 2.5~5 mm. This trend was noted similarly for both cases of unit cement contents of 330 kg/m^3 and 400 kg/m^3. It can be reasoned as the following. The void ratio of A type aggregate used in thus study is similar at 38.68~39.90 % regardless of the aggregate size. However, when the same amount of cement paste fills the void between the aggregate, the void size formed between 2.5~5 mm aggregate becomes relatively smaller, and the number of contact points between the aggregate increases during the densely-packed preparation of the test preparation. Thus, it is construed that the compressive strength of porous concrete increases due to these reasons.

Additionally, the compressive strength of porous concrete differs depending on the type of the aggregate even if the size of the aggregate and unit cement content remain the same. Although the void ratio of A and B type aggregate used in this study were similar to each other at 38.79% and 39.00%, respectively, the grain shape of B type aggregate was smoother compared to that of A type aggregate as shown in Photo 1. This resulted in denser packing of the specimen with B type aggregate and smaller void ratio. Moreover, the contact area between aggregate also increased for the specimen with B type aggregate. All these facts worked together to increase the compressive strength of the specimen with B type aggregate. Additionally, the examination of failure of the specimen under compressive strength test revealed that most of the failure occurred at the aggregate rather than the interface between the aggregate and cement paste. This points to the analysis that the compressive strength of porous concrete is influenced by the strength of the aggregate itself more than other materials.[3)] Thus, it is found that it is more effective to use aggregate of smoother grain shape and harder mother-rock (from which the aggregate is obtained by crushing it) to improve on the strength of porous concrete.

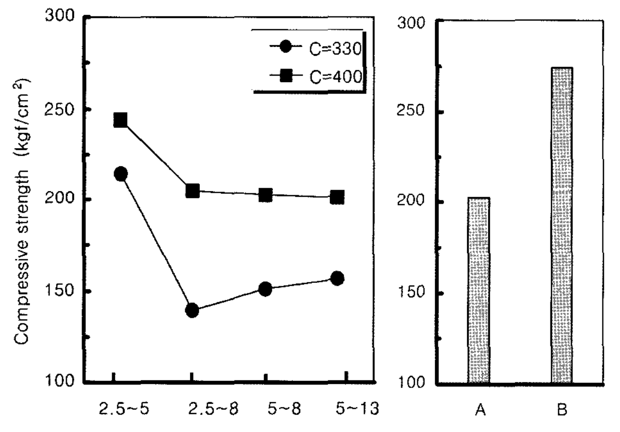
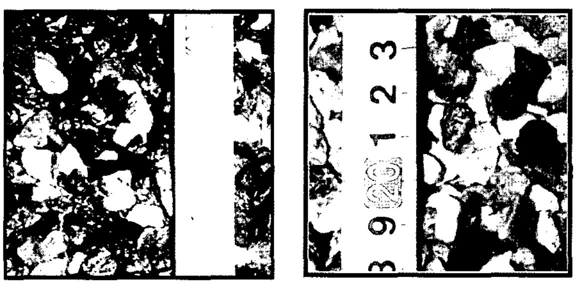


Fig. 2 Variation of compressive strength according to the sizes and kinds of aggregate.



(a) (b)

Photo 1 External appearance of aggregate.

3.2 Analysis of experimental results on void ratio

Fig. 3 illustrates variation of all void ratio (A. V. R.) and continuous void ratio (C. V. R.) depending on the type and size of aggregate. A. V. R. and C. V. R. remained almost the same given the same unit cement content regardless of the size of the aggregate except for the case of using aggregate of 2.5~5 mm size, which showed significantly less void ratios. This trend was observed for both cases of using unit cement contents of 330 kg/m^3 and 400 kg/m^3. This observation is explained by the following reasoning. The specimens using aggregate of 2.5~5 mm size have voids of inherently smaller size between the aggregate, and the voids between the aggregate is easily closed by the cement paste filling in the void between the aggregate given the same unit cement content, resulting in the significantly reduced void ratios.

Additionally, given the same unit cement content and the same aggregate size, A. V. R. and C. V. R. differed depending on the type of the aggregate. The void ratios of the specimens with A-type aggregate showed slightly higher void ratios than those of B-type aggregate. This is because although the void ratios of the specimens with both types of aggregate are almost the same at 38.79% and 39.00%, respectively, the grain shape of the specimen with B-type aggregate is smoother as it has been shown in Photo 1. This results in compact filling of the specimen by the cement paste during the specimen preparation to create this difference in void ratio. Thus, it is found that the grain shape of aggregate also influences the formation of void ratio.

Fig. 4 shows the C. V. R. to A. V. R. ratio by the size of aggregate. In general, the C. V. R. increased with larger aggregate size, and this trend was observed more noticeably as the unit cement content increased.

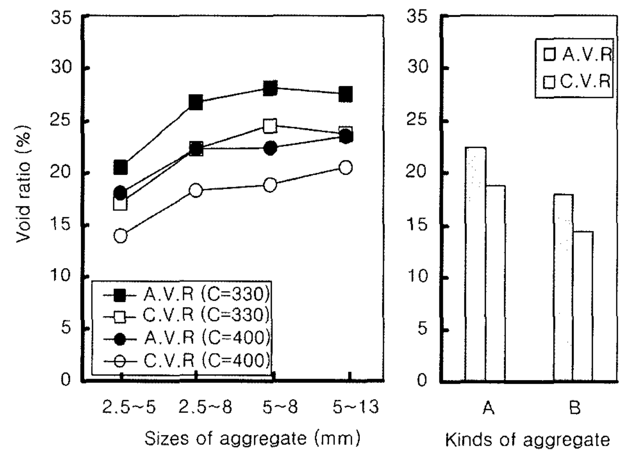


Fig. 3 Variation of void ratio according to the sizes and kinds of aggregate.

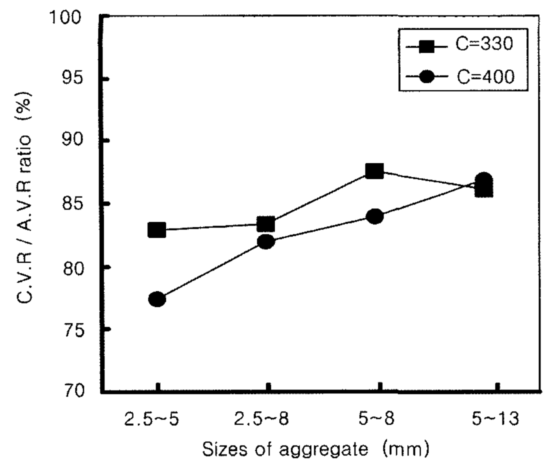


Fig. 4 C.V.R / A.V.R ratio according to the sizes of aggregate.

3.3 Analysis of coefficient of permeability

Fig. 5 represents variation of coefficient of permeability by the size and type of aggregate. The coefficient of permeability stayed almost the same regardless of the aggregate size given the same unit cement content except for the case of test specimen with 2.5~5 mm aggregate, which exhibited significantly lower coefficient of permeability. This is the same trend as manifested for the case of variation of void ratios discussed in the previous section. This finding concurs with previous research,[4] which reported that the coefficient of permeability of porous concrete depended on void ratio, especially C. V. R.

In addition, the coefficient of permeability differed depending on the type of the aggregate given the same unit cement content and the same aggregate size. The coefficient of permeability of the specimens with B-type aggregate exhibited lower coefficient of permeability than that of A-type aggregate. This is because the void ratio differs by the grain shape of the aggregate given the same aggregate size, resulting in the difference in coefficient of permeability. Thus, it is also found that the grain shape of aggregate influences the coefficient of permeability of porous concrete as well.

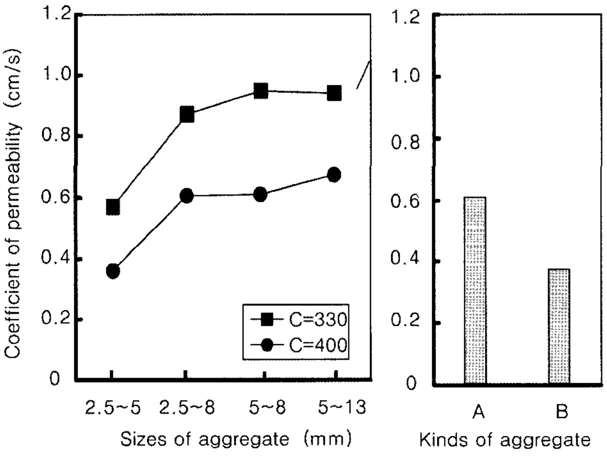


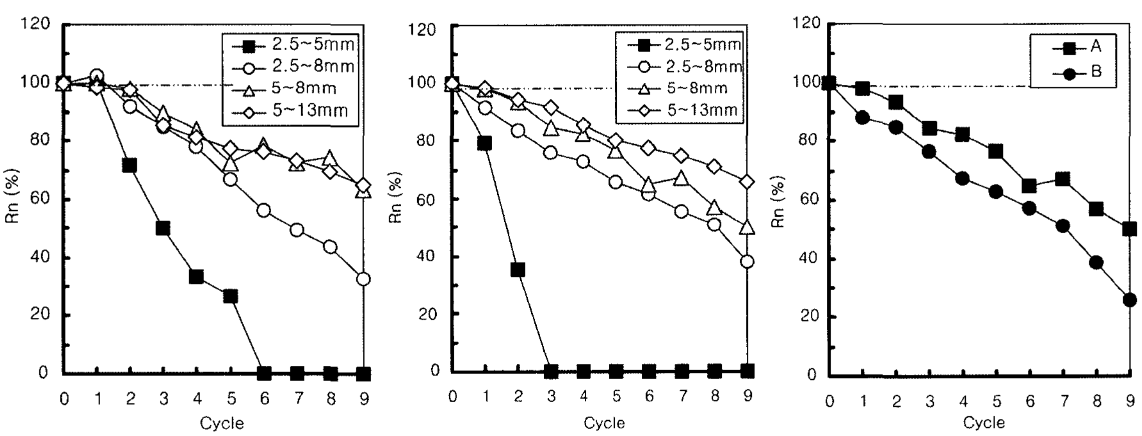
Fig. 5 Variation of coefficient of permeability according to the sizes and kinds of aggregate.

3.4 Analysis of proportional reduction in coefficient of permeability

When porous concrete is used as permeable pavement material, it is expected that the coefficient of permeability will decrease gradually with years of time passage due to the accumulation of impurities such as earth soil, sand, etc. Nevertheless, an investigation on this point has hardly been reported. Thus, this study compared and analyzed the proportional reduction in the coefficient of permeability of the test specimens by infiltration of muddy liquid. Fig. 6 demonstrates the proportional reduction in the coefficient of permeability of the test specimens by infiltration of muddy liquid depending on the size and type of aggregate.

The result of changing the aggregate size shows that the reduction in coefficient of permeability is significantly increased as the aggregate size is smaller. This trend was observed for both cases of unit cement contents of 330 kg/m^3 and 400 kg/m^3.

It is then determined that the void ratio of porous concrete is about the same regardless of the aggregate size. However, the coefficient of permeability is greatly reduced with the impurities remaining at the upper part of the specimens for permeability test and accumulating inside the void as the void diameter decreases with smaller aggregate size given the same void ratio (Fig. 7). Especially, using aggregate of 2.5~5 mm size makes less void ratio. Moreover, since its void size is relatively lower than other aggregate, the accumulation of impurities increases rapidly with the infiltration of muddy liquid, resulting in the



(a) Unit cement content = 330 kg/m^3 (b) Unit cement content = 400 kg/m^3 (c) Kinds of aggregate

Fig. 6 Proportional reduction in the coefficient of permeability of the test specimens by infiltration of muddy liquid.

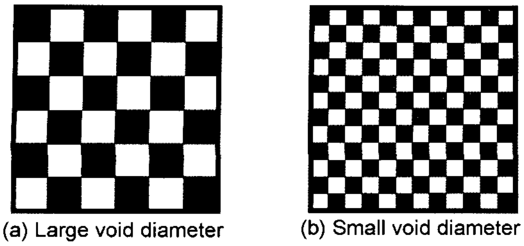


Fig. 7 Example of different texture of aggregate (void ratio is kept constant).

rapid reduction of the coefficient of permeability.

In addition, the proportional reduction in the coefficient of permeability differed by the aggregate type given the same unit cement content and the same aggregate size. This can be explained by the following reasoning. The difference in grain shape of the test specimens by the aggregate type results in the difference of the void ratio and void diameter size of porous concrete to bring about the different reduction ratio for the coefficient of permeability with the infiltration of muddy liquid.

Considering all these experimental results, the performance capacity to maintain the satisfactory coefficient of permeability even in the event of muddy liquid infiltration depends on the size and grain shape of the aggregate. Thus, it follows that the size and grain shape of the aggregate must be fully considered for porous concrete to maintain a satisfactory permeability performance in the long run when selecting the aggregate material.

3.5 Analysis of the change in dynamic modulus of coefficient

This study investigated the process of the increase in dynamic modulus of elasticity up to the age of 28 days. Fig. 8 shows variation of dynamic modulus of elasticity (D. M. E.) by the age and aggregate size. The figure shows that the dynamic modulus of elasticity at 7 days was about 90% of the value of dynamic modulus of elasticity at 28 days in all cases. Additionally, the slope of increase in D. M. E. of porous concrete after 7 days was significantly smoother unlike ordinary concrete. This is, because the porous concrete contains many continuous voids, the area of contact between water and cement paste increases to have the hydration completed at early age.[6] In addition, although the D. M. E. of porous concrete remained about the same except for the case of test specimens using aggregate of 2.5~5 mm size, which exhibited higher D. M. E. than the case of specimens using other aggregate size.

3.6 Analysis of relationships between experimental variables

Generally speaking, ordinary concrete has often been applied to non-destructive tests, having its high correlation among compressive strength, D. M. E., and ultra-sonic pulse velocity established. Thus, this study aimed to investigate the appropriateness of porous concrete being applied to such non-destructive tests by examining the correlation among compressive strength, D. M. E., and ultra-sonic pulse velocity.

Fig. 9 illustrates the relationship between compressive strength and D. M. E. of porous concrete. Porous concrete also exhibits high correlation between two variables as evidenced by its D. M. E. increasing along with its compressive strength.

Additionally, Fig. 10 represents the relationship between ultra-sonic pulse velocity and compressive strength of porous concrete. It shows that the ultra-sonic pulse velocity increases along with the increase in compressive strength. This is construed by the fact that both ultra-sonic pulse velocity and compressive strength depend on the void ratio inside, resulting in the high correlation between them.[6]

Furthermore, it has been reported that the unit weight of porous concrete depends greatly on the void ratio, especially all void ratio, given the same materials.[1] Fig. 11 shows the relationship between unit weight and all void ratio of porous concrete as measured in this study. As the void ratio increases, the unit weight decreases in inverse proportion. This trend was observed regardless of the aggregate size. Additionally, since this inverse relationship is significant, it is expected that void ratio (especially, all void ratio) of porous concrete can be reasonably predicted by its unit weight.

Fig. 12 demonstrates the relationship between all void ratio and compressive strength of porous concrete. As all void ratio

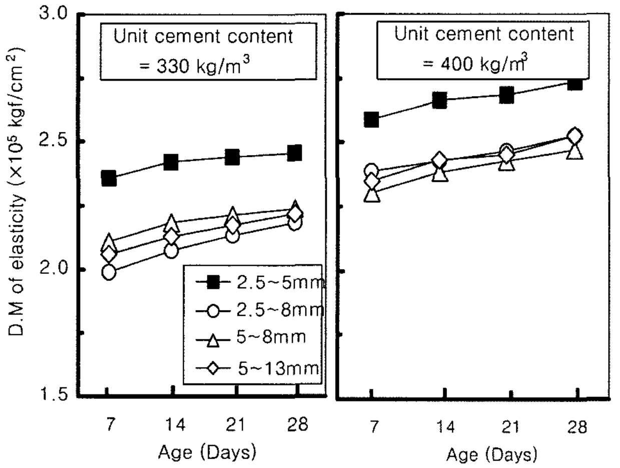


Fig. 8 Variation of D.M of elasticity according to the age.

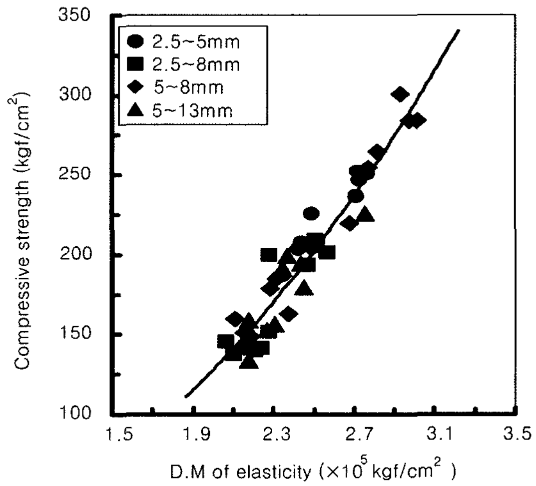


Fig. 9 Relationship of D.M of elasticity and compressive strength.

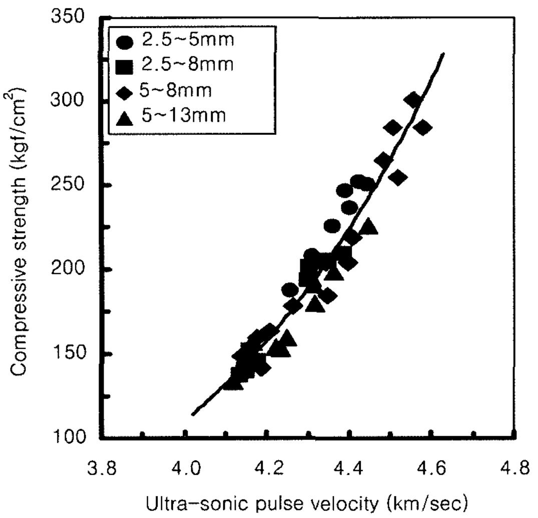


Fig. 10 Relationship of ultra-sonic pulse velocity and compressive strength.

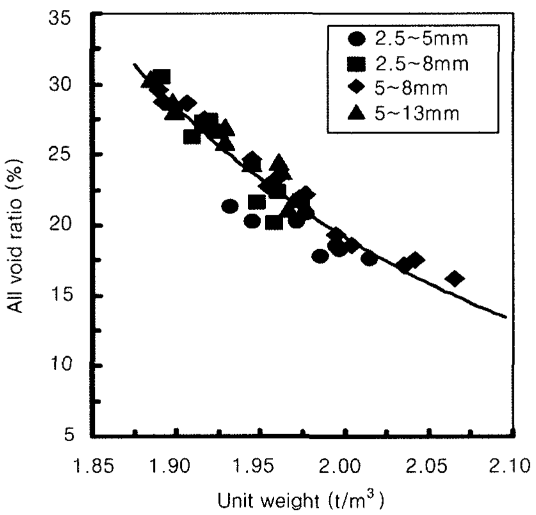


Fig. 11 Relationship of unit weight and all void ratio.

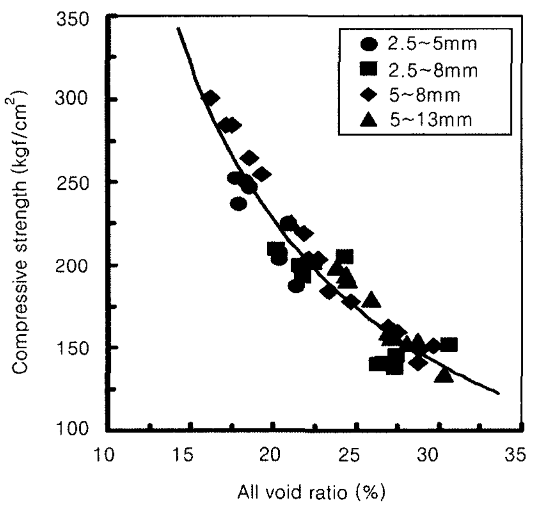


Fig. 12 Relationship of all void ratio and compressive strength.

decreases, the compressive strength of porous concrete increases significantly regardless of aggregate size. This observation concurs with previous research, which reports the compressive strength of porous concrete largely depends on void ratio, especially all void ratio.[1)]

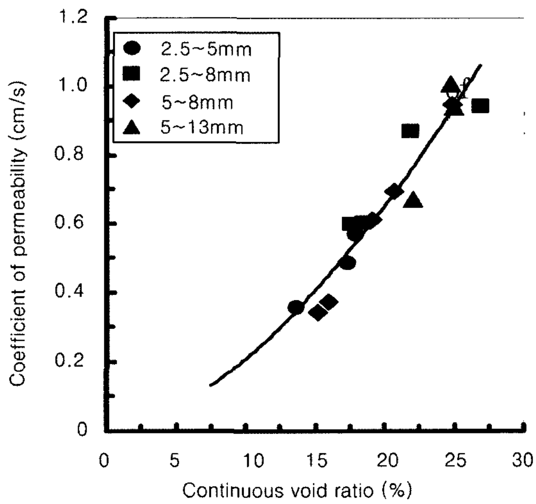


Fig. 13 Relationship of continuous void ratio and coefficient of permeability.

Fig. 13 exhibits the relationship between continuous void ratio and coefficient of permeability of porous concrete as measured in this study. It shows that the coefficient of permeability increases significantly as the continuous void ratio increases regardless of the aggregate size. Thus, this observation also confirms the previous research, which reports the coefficient of permeability of porous concrete depends on continuous void ratio. Moreover, it is found in this study that the coefficient of permeability of porous concrete with continuous void ratio of 15~20% will be within the range between 0.65~0.40 cm/sec.

4. Conclusions

The following conclusions are derived from the results of experiment, which delineated the influence of the size and type of aggregate on the fundamental properties of porous concrete.

1) The compressive strength of porous concrete remained about the same regardless of the aggregate size except that it was significantly higher when the aggregate size was 2.5~5 mm. In addition, the compressive strength of porous concrete differed by the aggregate type. Moreover, the examination of failure of the specimen under compressive strength test revealed that most of the failure occurred in the aggregate itself rather than the interface between the aggregate and cement paste. This points to the fact that the strength of the aggregate itself influences the compressive strength of porous concrete.

2) The void ratios and coefficient of permeability of porous concrete maintained about the same value regardless of the aggregate size except for the case of using aggregate of 2.5~5 mm in size, which showed lower values. Additionally, they also differed depending on the aggregate type. This observation can be explained by the fact that compaction of the concrete differs by the grain shape of the aggregate.

3) The proportional reduction in the coefficient of

permeability of the test specimens with the infiltration of muddy liquid was more conspicuous when the aggregate size was smaller. Especially, it decreased rapidly for the case of test specimens using 2.5~5 mm aggregate. In addition, it also differed by the aggregate type. Thus, it follows that the size and type (grain shape) of the aggregate must be fully considered for porous concrete to maintain a satisfactory permeability performance in the long run when selecting the aggregate material.

4) Porous concrete exhibited high correlation among compressive strength, dynamic modulus of elasticity, and ultrasonic pulse velocity like regular concrete. In particular, the void ratio and unit weight of porous concrete exhibited significant inverse relationship. Thus, it is expected that void ratio of porous concrete can be reasonably predicted by its unit weight.

5) The dynamic modulus of elasticity of porous concrete was manifested much earlier than ordinary concrete. Additionally, the slope of the increase in dynamic modulus of elasticity after 7 days was significantly smoother unlike ordinary concrete. This is construed due to the fact that the area of contact between water and cement paste increased markedly by many continuous voids in the porous concrete to have the hydration completed at early age.

The experimental results of this study revealed that the fundamental properties of porous concrete are similar to ordinary concrete except for the case of using aggregate of 2.5~5 mm in size. Thus, it is recommended to use aggregate of large size to maintain its permeability performance effectively in the long run.

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