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Research Article

Mechanical Characteristic of Pervious Concrete Considering the Gradation and Size of Coarse Aggregates

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Abstract: Pervious concrete is a kind of sustainable pavement with high permeability which is becoming more common as a storm water management. The purpose of this study was to investigate the effects of coarse aggregate on physical and mechanical properties of the pervious concrete such as density, strength, porosity and permeability at 7, 28, 56 days. This experimental investigation conducted by comparing nine different mixtures. Taguchi design of experiments used to optimize the performance of these characteristics. To test the influence of aggregate systematically, water to cement ratio (w/c), paste content and coarse aggregate size were kept constant at 3 levels. 9.5, 12.5 and 19.0 mm were used for maximum aggregate sizes. The relationship between strength and porosity for pervious concrete are found to be dependent on coarse aggregate size. The test results demonstrated when the maximum size of the coarse aggregate increased, the strength decreases and the permeability and porosity grows up. An increased aggregate amount resulted in a significant decrease in compressive strength due to the subsequent decrease in paste amount. Age and coarse aggregate size had effect on the pervious concrete characteristic. To meet the specification requirements in the mix design of pervious concrete, considering both compressive strength and permeability is necessary. Finally, a parametric study is conducted to investigate the influence of design factors on the properties of porous concrete. The general equations for pervious concrete are related to compressive strength and void ratio for different aggregate sizes.

Keywords: Coarse aggregate, mix design, permeability, pervious concrete, porosity, strength

INTRODUCTION

Nowadays, many places around the world have experienced raining, with ponding consequence. It caused by combination of increased rainfall and reduced permeability in urban regions. To solve this problem, it is necessary to reduce various environmental problems occurring around residential regions. Different approaches can be used to aid in achieving the new EPA standards. Therefore, to overcome this difficulties, pervious concrete is considered a Best Management Practice (BMP) because of its capability to reduce excessive storm-water runoff (Bury *et al*., 2006).

Pervious concrete consists of portl and cement, water, coarse aggregate and, in some cases, chemical admixtures and supplementary cementing materials. Its structure with interconnected voids allows both water and air to percolate through and reduces runoff. Therefore it prevents interrupting in transportation and waste water treatment. The gradation and size of the coarse aggregate, water to cement ratio (W/C) and the level of compaction influence on size of these pores, which are typically 2-8 mm. The water that percolate in the pavement and could not drain out is the one of the major reasons that cause damages on the pavement material and structure. Pervious road with course aggregate has 30-50% longer service life than normal pavement (Ghofoori and Duta, 1995). With a combination of structural and hydrological design with the use of pervious concrete for pavement construction provided the best solution to stormwater management (Stormwater Management Handbook, 2009). It can be used in numerous applications. As a stormwater management tool, pervious concrete is used to construct low volume pavement infrastructure such as sidewalks, driveways, parking lots and residential roads (Tennis *et al*., 2004). It is an accepted fact that pervious concrete is lower in strength compared with conventional concrete mixtures, hence the reason for its application in low-traffic roads, parking lots, driveways and sidewalks (Tennis *et al*., 2004).

Although, the pervious concrete has different aspects, considering the purpose of this study to investigate the effects of coarse aggregate on physical and mechanical properties of the pervious concrete, it

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may be necessary to use single-sized aggregate only to get optimized design with respect to both hydrologic and strength properties, which it is possible to reach maximum permeability with the use of uniform aggregate, but the strength of the pavement fell into decline. As a result, single-sized and no fine aggregate were used. The volume of voids between coarse aggregate is greatest when the particles are of uniform size.

The main objective of this study was to investigate the effects of aggregate on the performance of pervious concrete mixtures. In this study the influence of the gradation factors of the aggregate such as maximum size and the content of the 6.5-19.0 mm aggregate on the properties of the concrete are examined. The typical porosity of pervious concrete ranged from 15 to 30% and the presence of interconnected large pores system allows the water to flow easily through the pervious concrete (ACI Committee 522, 2006). Therefore, the selection of orthogonal arrays for Taguchi is based on the percentage of void and it effects on levels of variation for paste content, that will be described below. The paste consistency is such that it coats each aggregate particle and creates a workable mixture. By choosing proper levels for each parameters, the design mixes meet the specification requirements for permeable concrete. Taguchi method was used for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic. Instead of having to test all possible combinations, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources. In this research, number of variables are 3 and only few interactions between variables. Considering these variables, the pervious concrete in this study was prepared by using 9 different mix design with three nominal maximum aggregate sizes. Pervious concrete mix consists of 210-421 kg/m^3 of binder material, 1565-1672 kg/m^3 of coarse aggregate and water to cement ratio ranged from 0.25 to 0.35 in this. The typical 56-day compressive strength ranges from 6.2 to 10.4 Mpa, with void ratios ranging from 15 to 30%. Previous investigations discussed the effective void content affects the compressive strength and water permeability of the hardened concrete-at higher effective void contents, water permeability is increased, but the compressive strength is decreased (Meininger, 1988).

The results showed that the strength of pervious concrete is affected by the density of aggregate. The desired void content may be achieved either by adjusting the level of compaction or modifying the aggregate proportions. It is more beneficial to modify the aggregate proportions and properties, such as gradation, size and amount to reach desired void contents. Also the results of an experimental examination into the properties of pervious concrete with different aggregate size discussed. As the aggregate size decreases, the number of particles per unit of volume increases. As the amount of particles increases, the binding area increases, resulting in improved strengths (Yang and Jiang, 2003). Finally, the influence of coarse aggregate on the mechanical characteristics of pervious concrete should be investigated to determine the optimal formula for different application.

MATERIALS AND METHODS

The cement used in this project was Portland cement type I supplied by Tehran Cement Company, containing 21.61% of SiO2, 4.50% of Al2O3, 3.00% Fe2O3 and 63.03% of CaO, meeting the requirements of ASTM C150/C150M-09 (2009).

Pervious concrete mixtures require a careful analysis of aggregate properties for a structure which have adequate strength and allowing water to drain through its matrix. The crushed coarse aggregate supplied by Metosak Plant, was used in this study. The particle size distribution of the crushed stone was unified. Fine aggregate was deliberately omitted in the mix designs. Pervious concretes investigated in this study incorporated three size of aggregate including 4.75 to 9.5 mm or 9.5 to 12.5 mm or 12.5 to 19 mm which means sieve No #4, 3/8″ and 1/2″. The details of the aggregates are listed in Table 1. The aggregates were batched in the saturated surface dry condition and no chemical admixture was used in the concrete mixes.

The mixture design for each pervious concrete batch had a target void content of 15-30% as recommended by ACI Committee 522 (2006). This design resulted in mixture proportions of 210-421 kg/m^3 of binder material, 1565-1672 kg/m^3 of coarse aggregate and water to cement ratio ranged from 0.25 to 0.35 for a 1 m^3 batch of concrete. Taguchi design of experiments used to optimize the performance of

Table 1: Summary of aggregate properties

Test description	#4	3/8″	1/2″	ASTM Code No.
Absorption, %	1.707	1.657	1.505	C 127
Specific gravity, bulk	2.55	2.61	2.68	C 127
Specific gravity, saturated surface dry	2.57	2.62	2.69	C 127
Specific gravity, apparent	2.59	2.64	2.71	C 127
Bulk density, Kg/m^3	1689.1	1606.3	1580.9	C 29

Table 2: Parameters and interrelated levels

Level	Aggregate size	W/C	Paste content percentage
1	# 4	0.25	14
2	3/8″	0.3	21
3	1/2″	0.35	28

characteristics of pervious concrete. For this research, 3 parameters were selected: coarse aggregate size, water to cement ratio and percentage of cement paste that all can be easily controlled. Then, the number of levels that the parameters should be varied at must be specified. By reviewing literature, aggregate size ranging of 6.5-19.0 mm which means sieve No #4, 3/8″ and 1/2″, water to cement ratio might be varied to 0.25 and 0.35 and finally percentage of cement paste ranging from 14 to 21%, as shown in Table 2.

Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. Therefore, this study consists of three parameters and three levels.

Each mix proportion is designated by a specific code. The first labels, ‘C’, represent the types of cementitious material used, which is cement type I in this research. The first number, ‘1, 2 and 3’ refer to size of aggregates used, are ‘No #4, 3/8″ and 1/2″’, respectively. The second number, ‘25, 30 and 35’, determine water to cement ratio used. The third labels, ‘14, 21 and 28’, denote the percentage of paste content in mixtures. The mixture proportions used in this study is listed in Table 3, which shows the conditions and variables of the experiment to examine the physical, mechanical characteristics of pervious concrete.

The standard compressive, split-tensile and flexural strength tests were performed on the cylinders and cubes.

For permeability test, it was common practice to use a falling-head apparatus to measure permeability (Yang and Jiang 2003; Kevern *et al*., 2005). Specimens were prepared for the permeability test by sawing off 10.0 mm from each side. Around of the permeability samples were confined and sealed with bitumen Insulation to prevent water from throwing out sidelong. The sealed specimen was placed at the bottom of the standpipe which sealed with glass glue in joints. The standpipe had an inside diameter of 45.4 mm. Test were initiated by allowing to saturate the pervious concrete sample to release the entrapped air in the specimens. At an initial head of above the sample, the time was started till the water level reached a final head. This process was repeated three times for each specimen under falling head for water permeability to improve the accuracy of the results. The coefficient of water permeability k of the specimens was calculated using Eq. (1) (Das, 2001):

$$K = \frac{a.L}{A.t}.\ \mathrm{Ln}\ (h_0/h_1) \quad (1)$$

where,

k = The permeability coefficient

a = The cross-sectional area of the standpipe ($1618.01\ mm^2$)

L = The vertical distance of the measuring points of the specimen (200 mm)

Table 3: Mixture proportions

Specimen	Agg size (mm)	W/C	Unit Weight (kg/m^3) Cement	Water	Agg
C1-1.25.14	4.75-9.5	0.25	247.78	61.94	1672.28
C2-1.30.21	4.75-9.5	0.30	341.46	102.42	1672.28
C3-1.35.28	4.75-9.5	0.35	421.05	147.35	1672.28
C4-2.25.21	9.5-12.5	0.25	371.68	92.92	1590.30
C5-2.30.28	9.5-12.5	0.30	455.28	136.50	1590.30
C6-2.35.14	9.5-12.5	0.35	210.52	73.67	1590.30
C7-3.25.28	12.5-19	0.25	495.57	123.89	1565.08
C8-3.30.14	12.5-19	0.30	227.64	68.29	1565.08
C9-3.35.21	12.5-19	0.35	341.46	119.51	1565.08

A = The cross area of the pervious concrete specimen ($7850\ mm^2$)

t = The time taken for the head to fall from ho to h1, h0 is the initial water head

h1 = The final water head

Void and porosity: The pervious concrete porosity was calculated by taking the difference in weight of oven dry and saturated, submerged under water (Montes *et al*., 2005). Two types of void ratio are measured based on Porous concrete void ratio experiment method (Eco-concrete Research Committee, 1995). Opened and closed void ratio. Cylindrical specimens 100 mm in diameter and 200 mm in length are used. The void ratio was calculated using Eq. (2) and (3), respectively (Seo, 2006):

$$A_{open} = \left(1 - \frac{W_2 - W_1}{V_1 \rho_w}\right) \times 100 \quad (2)$$

$$A_{close} = \left(1 - \frac{W_3 - W_1}{V_1 \rho_w}\right) \times 100 - A_{open} \quad (3)$$

where, A_{open} and A_{close} are the opened and closed total void ratio of concrete (%), respectively, W_1 is the weight of the specimen under water, W_2 weight of the specimen following 24 h exposure to the air and W_3 is the weight of the specimen was totally dried in an oven, V_1 is the volume of the specimen and ρ_w is the density of water (Seo, 2006).

RESULTS AND DISCUSSION

Test results including the void ratio, density, compressive and tensile and flexural strength. These results are analyzed in the following subsections.

Strength analysis: The pervious concrete strength tests studied in this research included compression, split-tensile and flexural strength tests. By examining strength of specimens, it was observed that the most of the failures occurred because of the aggregate fracture and cement paste had less effects on this issue. The concrete strength testing results are shown in Table 4, sorted by aggregate size. The influence of maximum

Table 4: Pervious concrete strength results at 7, 28 and 56 days

	Parameters			Strength Compressive (Mpa)			Strength Tensile (Mpa)			Strength Flexural (Mpa)		
Mix design	Aggregate	W/c	Paste	7	28	56	7	28	56	7	28	56
C1-1.25.14	4.75-9.5	25	14	5.4	6.6	7.2	1.2	1.6	1.7	1.3	1.8	2.2
C2-1.30.21	4.75-9.5	30	21	6.1	7.2	8.0	1.1	1.3	1.5	1.5	2.1	2.6
C3-1.35.28	4.75-9.5	35	28	7.8	9.4	10.4	1.8	2.2	2.4	3.1	3.7	4.7
C4-2.25.21	9.5-12.5	25	21	5.1	6.3	7.4	1.0	1.2	1.3	1.5	1.8	1.9
C5-2.30.28	9.5-12.5	30	28	7.0	8.2	9.6	1.3	1.5	1.7	1.7	2.0	2.8
C6-2.35.14	9.5-12.5	35	14	5.34	6.2	7.0	1.0	1.2	1.3	1.5	1.7	2.0
C7-3.25.28	12.5-19.0	25	28	5.2	7.2	6.8	0.9	1.1	1.2	1.4	1.7	1.9
C8-3.30.14	12.5-19.0	30	14	4.9	5.5	6.2	0.9	1.1	1.2	1.4	1.6	1.8
C9-3.35.21	12.5-19.0	35	21	6.6	7.2	8.0	1.1	1.3	1.5	1.6	1.9	2.1

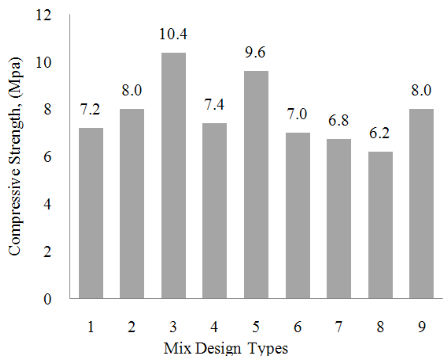

Fig. 1: Compressive strength grouped according to aggregate size

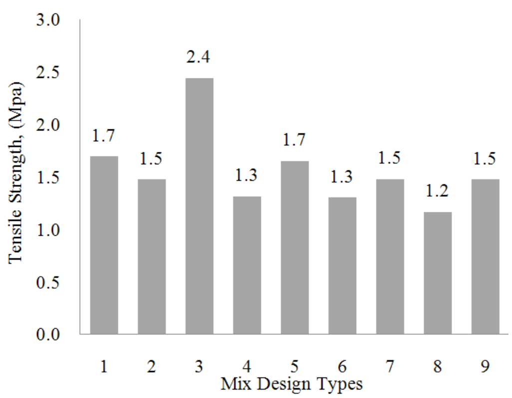

Fig. 2: Splitting-tensile Strength grouped according to aggregate size

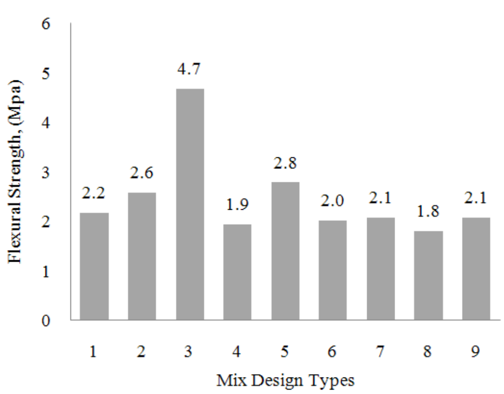

Fig. 3: Flexural strength grouped versus aggregate size

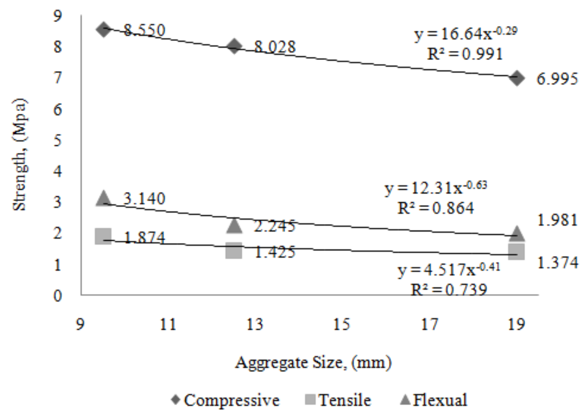

Fig. 4: Correlation between the compressive and tensile and flexural strengths

aggregate size on the strength of pervious concrete investigated in this study.

Figure 1 through 3show the results of the compressive, split-tensile and flexural strengths of pervious concrete specimens, respectively. Based on the results, it is evident that the size of the aggregate had a critical effect on all strength properties. The 4.75-9.5 mm (Mixture No. 3) had the maximum compressive strength of 10.41 MPa corresponding to the lowest porosity. The 12.5-19 mm (Mixture No. 8) had the lowest compressive strength of 6.21 MPa.

When comparing the effect of aggregate size on the strengths, strength within each aggregate size grouping were quite similar. If compressive strength of 7.0 MPa consider as a limitation for compressive strength, however, then there were two mixtures (Mixtures No. 7 and 8) with range of 12.5-19 below the borderline (Fig. 2 and 3).

As shown in Fig. 4 It is obvious that with the increase in the aggregate size, the strength of the pervious concrete decreases, the bulk density of aggregate is decreased and the connecting between the aggregate decreases, therefore it leads to reduction of strength of the Pervious concrete.

The results indicated a correlation between the compressive and tensile and flexural strengths of the pervious concrete mixtures in this study. This correlation, as shown in Fig. 4, is significant in the estimation of the flexural strength of a concrete mixture. The trend of flexural strength as same as compressive strength.

Table 5: Density and types of void ratio of the pervious concrete mixtures

Mix design	Density	Target Void Ratio (%)	Open Void Ratio (%)	Close Void Ratio (%)	Total Void Ratio (%)	Permeability (mm/s)
C1-1.25.14	1794	30	25.228	6.126	31.354	13.6
C2-1.30.21	1863	22	30.147	7.018	37.165	9.5
C3-1.35.28	1901	15	13.517	5.254	18.683	8.8
C4-2.25.21	1824	22	22.963	7.232	30.195	14.1
C5-2.30.28	1869	15	16.367	6.234	22.601	12.4
C6-2.35.14	1723	30	33.124	7.234	40.358	16.3
C7-3.25.28	1835	15	14.738	4.958	19.696	12.8
C8-3.30.14	1719	30	29.366	8.223	37.589	16.2
C9-3.35.21	1769	22	22.472	7.346	29.818	15.7

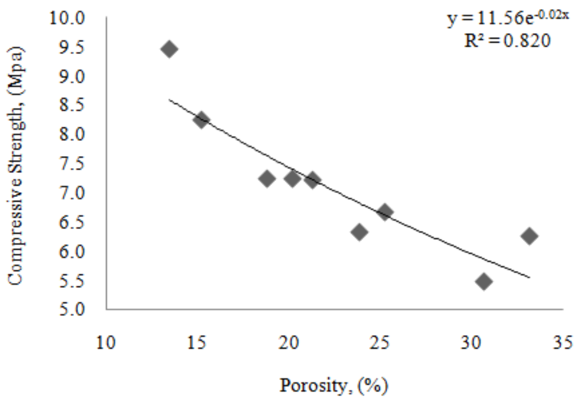

Fig. 5: Correlation between 28-days compressive strength and porosity of pervious concrete

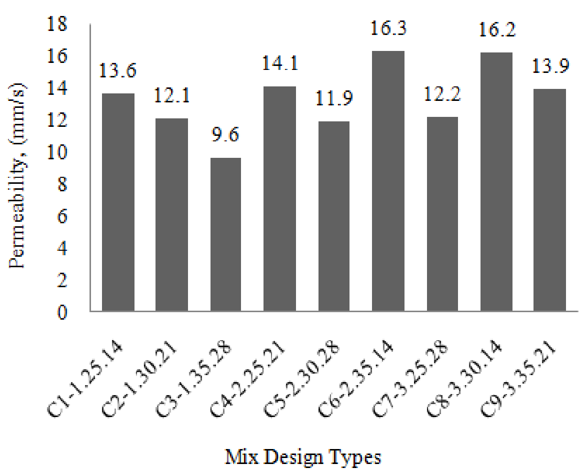

Fig. 6: Permeability of pervious concrete mix designs grouped according to coarse aggregate size

Void ratio and density: While the uniform gradation has a smaller range of aggregate sizes, it results in a higher void content and decrease the paste amount. The density and types of void ratio of the pervious concrete mixtures is shown in Table 5. The mixture design for this study revealed open void content of 13.5-33.1% for the pervious concrete mixtures.

With the increase in the porosity, the strength of pervious concrete is reduced. Figure 5 shows the correlation between compressive strength and porosity of pervious concrete. In this graph aggregates are

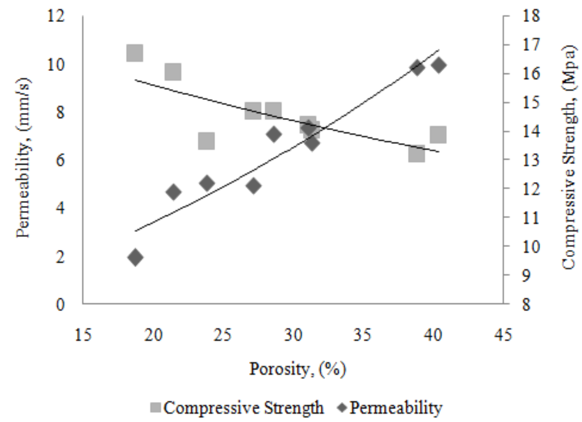

Fig. 7: Relationships among porosity, strength and permeability for pervious concrete

clearly different. It displays the tendency of compressive strength to decrease when the void ratio increase. The following empirical equations for 28-day compressive strength are obtained for pervious concrete.

The results confirm that the compressive strength of pervious concrete reduces with an increase in void ratio. The equation relating strength and void ratio is applicable.

$$C = 11.568e\text{-}0.022P \text{ (Mpa)}, R^2 = 0.8205 \quad (4)$$

where,

C = The 28-day compressive strength for pervious concrete

P = The porosity of the pervious concrete mix

Permeability: The pervious concrete mixtures that were expected to have highest permeability rates were those constructed from single-sized aggregates. The permeability of the pervious concrete mixtures is shown in Table 5 and illustrated in Fig. 6. As with the effective porosity, the trends were opposite those of the concrete strength.

Figure 7 shows the relationships among porosity, strength and permeability for pervious concrete. It used to estimate the void content needed for mixtures to satisfy the specification requirement for permeability and strength of concrete. By determining the void ratio, it could possible to obtain proper permeability and compressive strength.

CONCLUSION

A scientific research is conducted to check the influence of aggregate size on the mechanical characteristics of pervious concrete. Based on the results from this experimental research, the following conclusions have been drawn:

With the increase of the maximum size of the aggregate in the porous concrete, the compressive, split-tensile and flexural strengths of the single-sized aggregate gradations decreases while the void ratio increases. Strength of pervious concrete specimens depends primarily on total void ratio. The compressive, split-tensile and flexural strengths are inversely related to permeability. As the permeability increased, the strength properties of pervious concrete mixtures decreased.

In pervious concrete, content of paste and age had marginal influence on the strength of pervious concrete in a certain porosity, However there was no significant difference between the voids, strength and permeability when using uniform gradation.

The void ratio of specimens are little higher when larger size aggregates are used, but the difference is negligible. These results are related with the surface area of the aggregates.

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