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Experimental Study on Mechanical and Hydrological Properties of Pervious Concrete with Different Water Cement Ratio

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Abstract: The aim of this research was to study the effect of various water-to-cement ratio on the properties of pervious concrete. Tests were carried out to find the optimum water-to-cement ratio that gives a high compressive strength with acceptable permeability. The tests of fresh density, compressive strength at 7days, porosity and water permeability for four mixes of pervious concrete with various water-to-cement ratio are investigated. A small single sized natural river aggregate ranged from (9.5 to 12.5mm) with aggregate cement ratio equal to (3.7) were used in the mixtures. The properties of pervious concrete such as compressive strength, fresh density, permeability and porosity are significantly affected by using different amount of water-to-cement ratio. The results indicates that the higher strength at 7 days is (17 Mpa) and acceptable water permeability can be achieved with optimum water cement ratio at (0.32). The results also showed that the water permeability of pervious concrete is primarily effected by porosity.

Keywords: Pervious Concrete, Porosity, Water Permeability, Compressive Strength.

1. Introduction

Pervious concrete typically describes a near zero-slump, gap-graded system, generally comprising of cement, coarse aggregate, little or no fine aggregate, admixtures and water. These materials will produce a hardened concrete that allows water to pass through easily. The water permeability of pervious concrete typically ranges from 0.14cm/s to 1.22cm/s and the compressive strengths generally fall under the range of 2.8 MPa to 28 MPa [1].

Pervious concrete is a comparatively novel special type of concrete that is gaining fast popularity in many parts of the world. A porosity of 15% to 30% is typical for this material [1,2,3, 4,5,6].

Although the pervious concrete has high water permeability and low strength compared to conventional concrete, but it has enough strength for use in many applications [7]. Pervious concrete has been used in a wide range of applications including: pervious pavement for parking lots, rigid drainage layers under exterior mall areas, greenhouse floors to keep the floor free of standing water, driveways, bridge embankments, swimming pool decks, beach structures, seawalls and sewage treatment plant sludge beds [8]. The major drawback of pervious concrete is its lower compressive, low durability and flexural strength compared to conventional concrete [1].

A small and single-sized aggregate gradation is commonly used to produce pervious concrete[7,9], which can easily achieve the required void content (≥ 15%)[2], w/c ratio between 0.27 and 0.30 are used normally and those as high as 0.34 to 0.40 have been used effectively. A mix design with little water can produce a weak binder. A mix design with excessive water can collapse the void space, making an almost impervious concrete surface [10].

2. Experimental Investigation

2.1. Materials and properties

Ordinary Portland Cement (PC CEM, I 42.5R) was used in this study. The chemical composition and physical characteristics of the cement is provided in (Table 1), one single sized coarse aggregate ranging from (9.5-12.5)mm was used in all pervious concrete mixes. The specific gravity and absorption were 2.72 and 1.47% for natural aggregate, respectively.

Table 1: Chemical analysis and physical properties of Portland cement

Chemical properties & analysis (%)		Physical properties	
Calcium oxide (CaO)	62.12	**Specific gravity**	3.15
Silica (SiO_2)	19.69	**Fineness (m^2/kg)**	326*
Alumina (Al_2O_3)	5.16	**Initial Setting Time (min)**	215
Iron oxide (Fe_2O_3)	2.88	**Final Setting Time (min)**	250
Magnesium oxide (MgO)	1.17	**Volume Expansion (mm)**	1
Sulfur trioxide (SO_3)	2.63	**Compressive Strength (MPa)**	
Potassium oxide (K_2O)	0.88	**1 day**	18.2
Sodium oxide (Na_2O)	0.17	**2 days**	29.5
Free CaO	1.91	**7 days**	42.0
Loss on ignition	2.99	**28 days**	50.2
Insoluble residue	0.16	-	-

* Blaine specific surface area

2.2. Specimen Preparation and Mix Proportions

To get well bond between aggregate and cement paste, the following mixing procedure was used:

1) A small amount of cement (5-10% by mass) was mixed with aggregate for about 1 minute.
2) The remaining cement and water was added the mixer.
3) Then, the mixture was mixed for three minutes, rested for two minutes and then mixed for another two minutes before casting.

The mixing procedures proposed by Wang et al., All specimens were placed by rodding 25 times in three layers along with applying a vibration for 5-7 seconds after cast last layer. The samples were remolded after 24 hours and cured by water 7days before test. A total of 24 specimens were made from this research project, 12 Cylinders (100mm diameter and 200mm in height) and 12 cubes 150mm. Cylinders were used for water permeability test and fresh density. Cubes were used for compressive strength test. The mix proportion is presented in (Table 2).

Table 2: Mix Proportions for Pervious Concrete

Mix number	Cement (kg/m³)	w/c	Aggregate - Cement ratio	Natural Aggregate (kg/m³)	Water (kg/m³)
1	420	0.27	3.7	1554	114
2	420	0.3	3.7	1554	126
3	420	0.32	3.7	1554	135
4	420	0.36	3.7	1554	152

3. Test Methods

3.1. Fresh Density and Void Content Tests

The fresh density and void content for each cylinder specimen was calculated according to the new ASTM standard C1688 C1688M- 13 [11].

The total porosity (A_t) determined by volume method is presented by Equation (1):

$$A_t = \frac{T - W}{T} \times 10 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where :
T = Mass of unit volume in the assumption of no air.
W = Mass of unit volume in the container, kg.

Mass of unit volume in the assumption of no air (T) is given by Equation (2):

$$T = \frac{W_4}{V_2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:
W_4 = Total mass of all materials on the concrete of $1m^3$.
V_2= Sum of absolute volume of all materials on the concrete of $1m^3$.

Absolute volume in this equation means each mass of every material divided by each density.

Mass of unit volume in the container (W) is calculated by Equation (3):

$$W = \frac{W_3}{V_1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:
W_3= Mass in the air after 24 hours, kg.
V_1= Total volume of specimen, m^3.

3.2. Water Permeability Test

The water permeability was determined under a falling head system, using a specially made permeability device. (ACI 522R.2006) recommended that the falling head method developed by Some researchers, could be used to find the water permeability of pervious concrete[8]. The falling head permeability test adopted from soil mechanics [4,12] as shown in the (Figure 1). The test specimen (100mm diameter by 200mm high) was firstly wrapped with a latex membrane tightly to stop the water leak along the sides and to allow the water to flow through the cross-section of the specimen. The top of the specimen were fitted to glass tubes. For each concrete mix, three identical specimens were tested and the average of five readings are reported for each specimen. The average coefficient of permeability (k) is determined using equation (4):

$$k = \left(\frac{a \times L}{A \times T}\right) \ln\left(\frac{h_0}{h_1}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \ldots (4)$$

Where:
k: Coefficient of permeability, cm/sec
a: Cross-Sectional area of the pipe (cm^2)
L: Length of the specimen (cm)
A: Cross-sectional area of the specimen (cm^2)
T: Time taken for the head to fall from (h_0) to (h_1), by (sec)
h_0: Initial water head (cm)
h_1: Final water head (cm)

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Figure 1. Falling Head Permeability Test for Pervious Concrete.

3.3. Compressive strength tests

Compressive tests were conducted on the concrete mixtures at the end of 7days curing periods. These tests were made on three 150mm cubes with respect to ASTM C39-2010[13]. Three cubs of size (150×150×150 mm) were used to calculate the compressive strength and the average of the three results was reported for each mix.

4. Experimental Results and Discussion

Results obtained from the laboratory testing are reported and analyzed in this section to evaluate the effects of various w/c ratio on the properties of pervious concrete. Summarized results of all testing can be found in (Table 3) The information result values in the table explain the average of three test specimens for each mix group.

Table 3: Properties of Pervious Concrete

Mix ID	w/c	Porosity (%)	Fresh Density (kg/m³)	Compressive Strength (7days) (MPa)	Water Permeability Coefficient (cm/sec)
1	0.27	22	2000	14	1.1
2	0.30	21	2010	15	0.76
3	0.32	20	2040	17	0.5
4	0.36	12	1998	12	0.2

The water content is one of the important paramount factors on the properties of pervious concrete. The control of water proportion is essential to produce the fresh cement paste with a good workability and not clogging up all of the voids.

The water content was adjusted gently to explore the optimum mix design of pervious concrete. The (w/c) ratio ranging from 0.27 to 0.36 was used while other compositions were kept identical. It can be clearly seen from Figure (2) that the mix 3 with (w/c) of 0.32 yielded the highest compressive strength after 7days curing. It reached 17 Mpa. The presence of the turning point at 0.32 divided the whole trend line into two different stages. When the w/c ratio was less than 0.32, the compressive strength was slightly augmented along with the increase of w/c ratio; when it was more than 0.32, the compressive strength steeply declined. The mix 4 with water to cement ratio of 0.36 produced the lowest compressive strength and water permeability. The low w/c ratios can cause insufficient cohesion and constancy, thus reducing bonds between the particles, which cause the low workability of pervious concrete. On the contrast, w/c ratio more than the optimum values leads to paste draw down, leads to accumulation of paste at the bottom of the sample. This may leads to weaker cement aggregate joints and lesser compressive strength as shown at Figure (3).

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Decreasing the aggregate cement ratio and increasing the thickness of cement paste layer is an effective way of improving compressive strength of pervious concretes. The other way for improving the compressive strength of pervious concrete may be utilization of the smaller single sized aggregate and good compaction. Because, the smaller single sized aggregate has higher surface area than the coarser single sized aggregate, This has been applied in this study. The pervious concrete with compressive strength values ranged from 3.5 to 28 MPa suitable for a wide range of applications [1,7]. Namely, the results obtained in this article are acceptable for pervious concrete.

Fresh density values for pervious concrete ranging between 1998 and 2040 kg/m^3,was obtained in this study. Systematically increasing of density was observed with rising the water cement ratio until 0.32. This can be explained by the cement content. Utilization of high cement content in pervious concretes produced at w/c ratio of 0.32 filled the voids between aggregate particles. For this reason, denser pervious concretes were obtained with higher compressive strength, Figure (4).

The total porosity of 20-22% were in the range recommended by ACI 522 for first three mixes. As expected, if the density of pervious concretes increases, the porosity and water permeability decrease. Meanwhile, the change of permeability based on different porosity was given in Figure (5) It can be found that the trend of permeability agreeing to that of porosity for pervious concrete with increasing and decreasing. The minimum point was also taken place at w/c ratio of 0.36, where the permeability is down to 0.2 cm/s. Taking the value of w/c 0.32 as a threshold, once the amount of water overran this thresh, it can be concluded that the void space fill by cement paste at the bottom of cylinder sample.

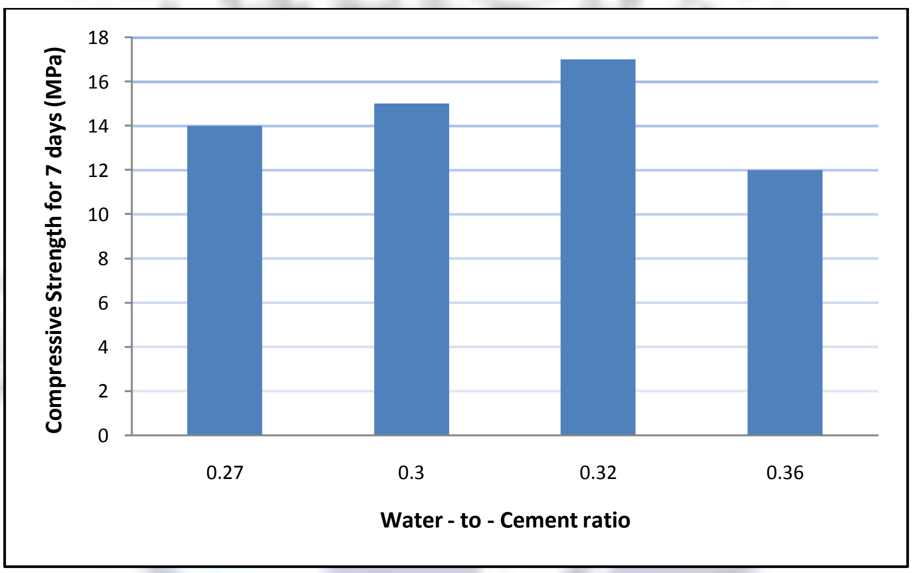

Figure 2. Relationship between water cement ratio and compressive strength for 7days

Figure 3. (Mix.4) Clogging Bottom of Sample Pervious Concrete because of use High too much Water

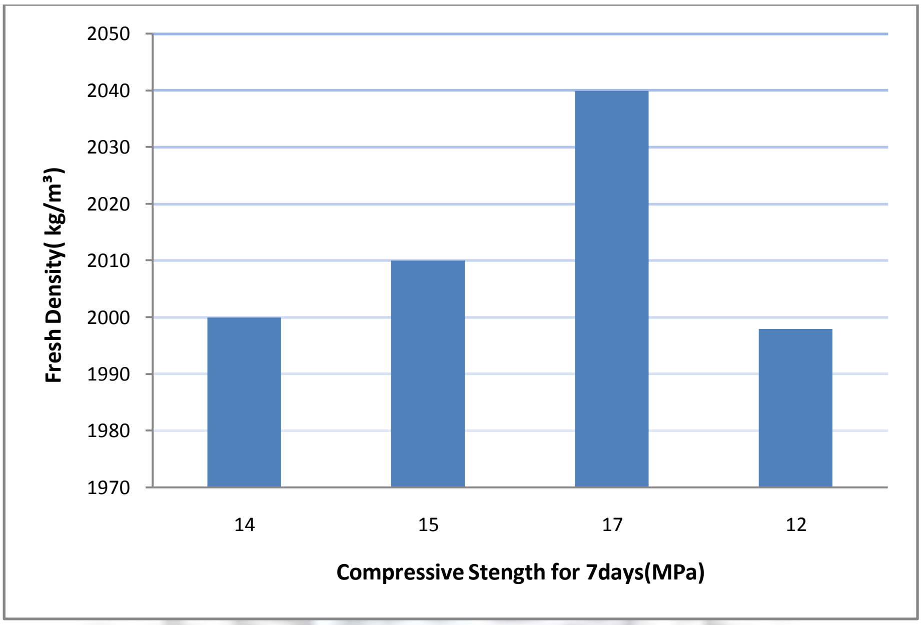

Figure 4. The relationship between Compressive Strength and Fresh Density

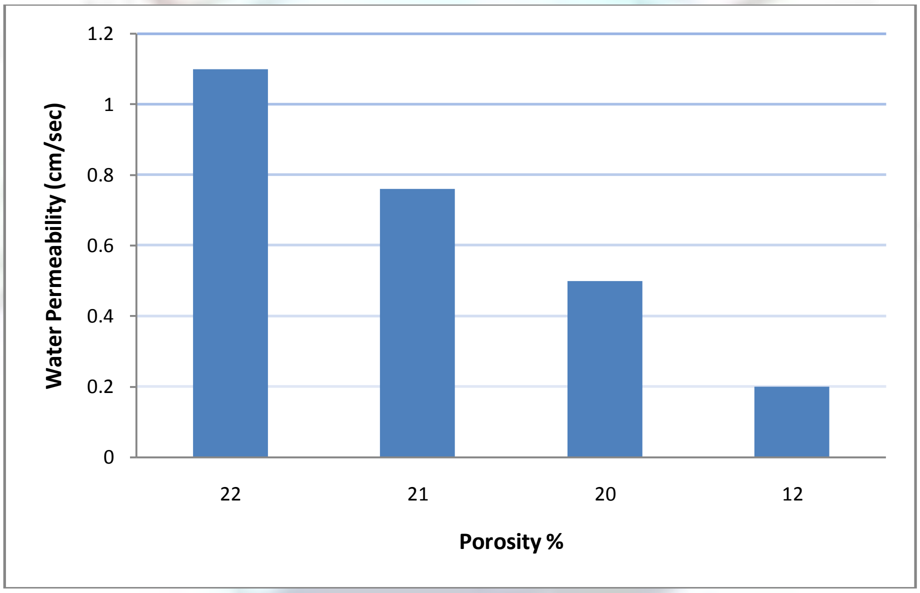

Figure 5. Relationship between porosity and water permeability

5. Conclusion

The following conclusions and summary are derived from the present study:

1- The water content is one of the paramount factors for the compressive strength. Lowering the w/c ratio would lead to higher compressive strengths in the normal concrete. However in the case of pervious concrete, the control of water proportion is essential to produce the fresh cement paste with a good workability and not clogging up all of the pores. The low w/c ratios can cause reducing bonds between the aggregate and cement paste. On the contrast, w/c ratio more than the optimum values leads to accumulation of paste at the bottom of the sample. The optimum w/c ratio turns out to be 0.32. This could produce the compressive strength of 17 MPa after 7 days with acceptable water permeability above 0.5 cm/s.
2- Water permeability of pervious concrete is influenced by the void content and the use of high water cement ratio led to clog the voids at the bottom of samples hence significant decreasing in water permeability or make impervious concrete.
3- Using the cement content of 420 kg/m^3 and low aggregate cement ratio of 3.7, results a high average compressive strength .
4- Compacting degree directly affects on the porosity, it is essential to attain pervious concrete with improved strengths.

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