EVALUATION OF COMPRESSIVE STRENGTH AND PERMEABILITY OF PERVIOUS CONCRETE USING MICRO SILICA

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Abstract
The term pervious concrete typically describes a near zero slump open graded material consisting of portland cement, coarse aggregate, little or no fine aggregate, admixtures and water. The high flow rate of water through a pervious concrete pavement allows rainfall to be captured and to percolate into the ground, reducing stormwater runoff, recharging groundwater, providing a solution for construction that is sensitive to environmental concerns. The intended applications of the pervious concrete is in parking areas, roadways, pedestrian and residential walkways with comparatively light traffic loads. In this regard, a study was carried out to assess the effect of permeability and compressive strength of pervious concrete by partial replacement of cement with micro silica and find the optimum mix. The study was conducted at constant water cement ratio 0.34 and fixed porosity of 20% to achieve higher compressive strength and better permeability by 5- 15 % replacement of cement with micro silica and 7.5% of coarse aggregate with sand. Freshened concrete test for each mix were carried out and the data were collected.

Index Terms: compressive strength, micro silica, pervious concrete, permeability, pavements, porosity

I. INTRODUCTION

Pervious concrete which is also known as no fines, porous, gap graded, and permeable concrete and enhance porosity concrete has been found to be a reliable storm water management tool. Pervious concrete has the same basic constituents as conventional concrete and is composed of Portland cement, coarse aggregate, water, admixtures, and little or no fine aggregates. Unlike conventional concrete, which has a void ratio anywhere from 3-5%, pervious concrete can have void ratios from 15-30% depending on its application and flow rates for water through pervious concrete are typically around 480 in./hr (0.34 cm/s, which is 5 gal/ft²/ min or 200 L/m²/min), although they can be much higher. In pervious concrete, carefully controlled amounts of water and cementitious materials are used to create a paste that forms a thick coating around aggregate particles. The aggregate usually consists of a single size and is bonded together at its points of contact by a paste formed by the cement and water. Using sufficient paste to coat and bind the aggregate particles together, creates a system of highly permeable, interconnected voids that drains quickly. Both the low mortar content and high porosity also reduce strength compared to conventional concrete mixtures, but sufficient strength for many applications is readily achieved.

While pervious concrete can be used for a surprising number of applications, its primary use is in pavement. When pervious concrete is used for paving, the open cell structures allow storm water to filter through the pavement and into the underlying soils. In other words, pervious concrete helps in protecting the surface of the pavement and its environment. The use of pervious concrete to date has been limited to low volume and low speed traffic areas such as parking lots and sidewalks. These facilities are not typically subjected to high volume and standard wheel loads. Many jurisdictions are now considering the use of pervious concrete on low volume roads such as residential streets and alleys. Since the strength of pervious concrete is as important as its permeability characteristics, for an effective utilization of pervious concrete in various pavements, it should have comparable strength to that of conventional concrete pavements.

The presence of silicon dioxide increases the compressive strength in concrete. Among supplementary cementitious materials (SCM) micro silica contains about 85-97% of silicon dioxide. The objective of our research is to study the change in compressive strength and permeability of pervious concrete by adding varying amount of micro silica and finding out the most optimum mix. As with any research, the experiments performed are subjected to limitations. These limitations are in regards to the type and size of aggregate used and the curing process

II. MATERIAL CHARACTERISATION

A narrow grading is the important characteristic in pervious concrete mixtures. Crushed stone coarse aggregate (CA) of size 12.5 mm were used in this study. For betterment of pervious concrete,7.5 % of coarse aggregates were replaced with fine aggregates. The specific gravity of sand was obtained as 2.56 .Properties of CA obtained is as shown in Table 1.

Table 1 : Physical properties of coarse aggregates

Property	CA	Unit
Specific gravity	2.738	-
k density	1.588	kg/ m3
Void ratio	0.724	-
Impact strength	25.18	%
Crushing strength	26.39	5

Ordinary Portland cement 53 grade was used as primary binder. Micro silica was used as SCM, replacing 5-10% of cement to modify the binder properties. Specific gravity of micro silica obtained was 2.2. Properties of cement & Micro silica obtained is shown in Table-2. No admixtures were used for this study.

Table 2 : Properties of cement and micro silica

Material	Specific gravity
Cement	3.125
Microsillica	2.2

III. MIX DESIGN

There is no perfect mix design for Pervious Concrete so mix design was prepared based on ACI 522R 10 and NRMCA guidelines. It is porosity based design. Pervious concrete porosity depends on the volume of the voids between the aggregate particles and the volume of paste/mortar that fills the voids. Pervious concrete is typically designed for a void content in the range of 15% to 30%. Generally as the void content decreases, the strength increases and permeability decreases. For better performance, little amount of sand can be used to replace coarse aggregates. The study was conducted at constant w/c ratio 0.34 and fixed void content (or porosity) of 20% to achieve higher compressive strength and better permeability by 5-15 percentage replacement of cement with silica fume and 7.5 % of coarse aggregates was replaced with sand. Two sets of pervious concrete mixes, (1) ordinary pervious concrete (OPC) and (2) SCM-modified pervious concrete (SPC) were designed. The designation of each pervious concrete mixes and their mix proportions are presented in Table 3 and Table 4 respectively. The Micro silica dosages were 5%, 10% and 15%.

Mix	Percentage of fines	Percentage of micro silica
CPC 1	0%	0%
CPC 2	7.5%	0%
SPC 1	7.5%	5%
SPC 2	7.5%	10%
SPC 3	7.5%	15%

Table 3: Designation of pervious concrete mixes

Mix	% of fines	% of micro-silica	Cement (kg)	Coarse aggregates (kg)	Fine aggregates (kg)	Water (kg)	Micro-silica (kg)
CPC 1	0	0	393.7	1478.5	0	134	0
CPC 2	7.5	0	364.7	1367.6	110.9	123.99	0
SPC 1	7.5	5	346.5	1367.6	110.9	123.99	18.24
SPC 2	7.5	10	330.1	1367.6	110.9	123.99	34.65
SPC 3	7.5	15	312.8	1367.6	110.9	123.99	51.96

Table 4: Pervious concrete mix proportion for 1 m3

IV. TEST PROCEDURES

A. Void content and density

The density of fresh pervious concrete can be determined by ASTM C1688 and is directly related to the void content of a given mixture. Void content is highly dependent on several factors such as aggregate gradation, cementitious material content, water cement ratio and compactive effort. The measured fresh density maybe used as verification of mixture proportions. The fresh density and void content calculated from this test may differ from the in place density and void content, and this test shall not be used to determine in place yield.

Balance or scale accurate to 50g , standard Proctor hammer and a cylindrical measure. According to ASTM C1688, cylindrical container with a capacity of 7.0+0.6 L and a diameter equal to 0.75 to 1.25 times the height is required and the cylindrical measure conforming to the above requirements had been prepared as shown in Fig.1.1.

Fig.1 Cylindrical measure and standard proctor hammer as per ASTMC 1688

The pervious concrete sample was consolidated using a standard Proctor hammer by dropping the hammer 20 times per layer at full 305 mm drop height and the mass of the concrete was determined.

The theoretical density is a laboratory determination and is assumed to remain constant for all batches made using identical component ingredients and proportions. It is calculated from the following equation:

$$T = Ms/Vs \qquad [1]$$

Where,

T is the theoretical density of the concrete computed on air free basis (kg/m3).

Ms is the total mass of all materials batched (kg).

Vs is the sum of absolute volumes of the component ingredients in the batch (m3).

The net mass of the concrete is calculated by subtracting the mass of the measure Mm, from the mass of the measure filled with concrete, Mc. Density, D is obtained by dividing the net mass of concrete by the volume of the measure, Vm as follows:

$$D = (Mc - Mm)/Vm \qquad [2]$$

Percentage of voids, U is calculated as follows.

$$U = (T - D)/T \times 100\ \% \qquad [3]$$

Table 5 Percentage of voids in pervious concrete mixes with varying percentage of microsilica

Sl. No.	Pervious concrete mix	Theoretical Density, T (kg/m3)	Experimental Density, D (kg/m3)	Percentage of voids
1.	CPC 1	2509.41	1978.31	21.16%
2.	CPC 2	2513.46	2005.42	20.41%
3.	SPC 1	2509.44	2025.75	19.2%
4.	SPC 2	2510.83	2029.81	19.15%
5.	SPC 3	2495.44	2032.52	18.55%

B.Compressive strength

As per ACI 522 R10, compressive strength of pervious concrete is affected by the mix proportion and compaction effort during placement. Relatively, high compressive strength of pervious concrete is achieved only when there is reduction in the air void content. This results in a loss in percolating efficiency of pervious concrete.

Compressive strength is a very important parameter for deciding on the concrete quality and performance. The compressive strength test was conducted according to ASTM C 39. Cube specimens measuring 150 mm x 150 mm x 150 mm were prepared for each mix and tested after curing in water. Fig.2 shows the cube specimen used for compression test.

Fig.2 Cube specimen for conducting compression test

The compressive strength of three cube specimens of each pervious concrete mix were tested after 14th day and 28th days of water curing. The specimen was placed on the compression testing machine such that the upper plate of the machine just touches the specimen. The measured compressive strength of the specimen was calculated by dividing the maximum load applied to the specimen during the test by the cross sectional area, calculated from the mean dimensions of the section and shall be expressed to the nearest N/mm2. Average of three values shall be taken as the compressive strength of the corresponding mix.

Table 6: Compressive strength of pervious concrete after14th and 28th day of curing

Pervious concrete mix	14th day average compressive Strength(MPa)	28th day average compressive Strength(MPa)
CPC 1	5.06	6.48
CPC 2	5.94	8.09
SPC 1	7.96	11.43
SPC 2	9.70	13.30
SPC 3	8.56	12.48

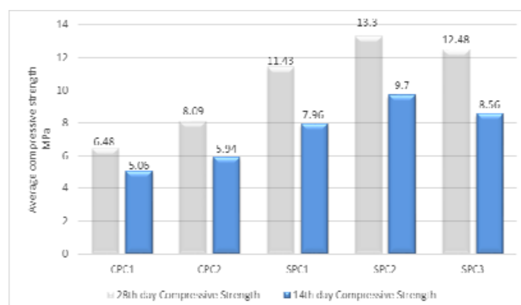

Fig.3 14th day and 28th day compressive strength of pervious concrete mixes with varying percentage of microsilica

C.Permeability

One of the most important features of pervious concrete is its ability to percolate water through the matrix. As per ACI 522 R 10, the percolation rate of pervious concrete is directly related to the porosity and the pores sizes. The challenge in pervious concrete mixture proportioning, is achieving a balance between an acceptable permeability and an acceptable compressive strength. The permeability of pervious concrete can be measured using falling head permeability method by a simple falling head permeameter.

The experimental setup for finding permeability consists of a specimen cell of 150mm diameter and 300mm height for placing the cylindrical specimen of pervious concrete. The Polyvinyl chloride (PVC) pipe was used as specimen cell. A 50 mm diameter valve connects the bottom part of the specimen cell to a vertical pipe through which water can drain out. The water flow rate can be controlled by means of this valve. The top of this pipe is positioned 10 mm above the top of the specimen so that no unsaturated flow occurs during the test. A graduated transparent cylinder of 300 mm length was attached to the top of the specimen assembly and clamped tightly using a rubber sleeve. This was used to monitor the water level during the test. Fig.1.3 shows the experimental setup of falling head permeability.

Fig.4 Cylindrical specimens for conducting falling head permeability test

Fig.5 Apparatus for measuring permeability of pervious concrete by falling head permeability

The Permeability is measured according to Darcy's Law given by the following equation:

$$k = \frac{2.303 \times a \times L \times \log\left(\frac{h1}{h2}\right)}{A \times t} \qquad [4]$$

Where,

k = permeability coefficient, (cm/s)

t = time, (seconds)

a = cross-sectional area of the specimen, (cm^2)

A = cross-sectional area of the calibrated cylinder, (cm^2)

h1 = the initial water head, (cm)

h2 = the final water head, (cm)

L = length of the specimen, (cm)

Table 7: Permeability values obtained for pervious concrete mixes with varying percentage of microsilica

Pervious concrete mix	Average Permeability(cm/s)
CPC 1	4.02
CPC 2	3.64
SPC 1	3.48
SPC 2	3.39
SPC 3	3.20

Fig.6 shows the relation between percentage of voids and permeability of different pervious concrete mixes. It is the graphical representation of the relation of percentage of voids which was found during the test on fresh concrete with the permeability of pervious concrete. The permeability value is decreasing as the microsilica content increases in the pervious concrete. The permeability value thus obtained ranges between 3.20 to 4.02 cm/s. Even though the permeability value is decreasing, it is in the permissible range of permeability of pervious concrete pavements. The pervious concrete mix SPC2 having maximum compressive strength had been found to possess the required permeability

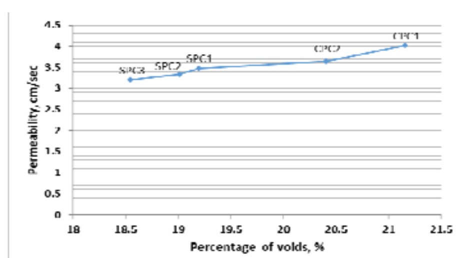

Fig.6 Relation between percentage of voids and permeability of pervious concrete mixes with varying percentage of microsilica

IV. CONCLUSION

The experimental investigations to find the properties of pervious concrete was carried out to check the practicability of pervious concrete which can be used in pavements. From the prepared five mixes of pervious concrete, the optimum mix was found to be the pervious mix with 10% microsilica, which have the comparable compressive strength and permeability which suits for pavement constructions. The tests for compressive strength, permeability, were carried out on all the five pervious concrete mixes for constant w/c ratio (0.34). Based on the test results and discussions, the conclusions drawn are discussed in this chapter.

Maximum compressive strength is obtained for pervious mix with 10% microsilica for both 14th day and 28th day after curing. Compressive strength of pervious concrete mix with 10% microsilica is more than double the value of compressive strength of the mix having 0% microsilica content.28th day compressive strength is gradually increasing upto the mix with 10% microsillica and reaches the maximum value of 13.3 MPa.

The permeability value is decreasing as the microsilica content increases in the pervious concrete. Permeability gets decreased from 4.02cm/s to3.20cm/s when percentage of microsilica is increased from 0% to 15%. Even though the permeability value is decreasing, it is in the permissible range of permeability, suitable for pervious concrete pavements. Typical flow rates for water through pervious concrete are 0.54cm/s, with rates of up to 1.2 cm/s. Higher rates have been measured in the laboratory[1]. So the effect of microsilica increases the compressive strength,while permeability is slightly decreased which is in the permissible range and the optimum mix is obtained at 10% replacement of cement with microsilica for pervious concrete. . Thus, further studies on pervious concrete can be done for the optimum mix.

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