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Performance Assessment of Pervious Concrete by Using Silica Fume

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Abstract—*Pervious concrete became more popular due to having some exceptional characteristics viz. water infiltration, reducing runoff and many more. The intended of the previous concrete is in parking areas, roadways, pedestrian and residential walkways. Porosity and permeability are the attractiveness of the previous concrete beside its low compressive strength. However, it can be improve by using various cementitious and durable materials. The aim of the research is to assess the effect of permeability, compressive strength, porosity, and abrasion resistance of Pervious Concrete (PC) by using silica fume. Permeability test was conducted by Falling head method and Abrasion resistance was as per Cantabro Loss test. The study was conducted at constant w/c ratio 0.33 and fixed porosity of 20% to achieve higher compressive strength and better permeability by 5- 10 percentage replacement of silica fume as cement and sand as coarse aggregate. The test results exhibited that, 8% of sand replacement offered desired porosity PC. While; partial replacement of silica fume did not have detrimental effect on permeability but increase the compressive strength and abrasion resistance.*

1. INTRODUCTION

Pervious concrete is a newer kind of concrete that having rapid performance in stainable construction. Pervious concrete is special type of high porosity concrete which allows water from precipitation and other sources to pass through it for reducing the water flow on ground and increases the ground water level. It used for pavement as it provides a good performance against skidding for vehicles in rainy days and a better sound absorption property. In many ways, pervious concrete is an environmentally friendly material. Main concept of pervious concrete design is to pack coarse aggregates (usually a narrow grade) and wrap the cement paste on it and leave voids unfilled. These remaining voids allow water permeation. Because of the voids it is expected that pervious concrete may have a lower compressive strength than normal concrete. Therefore, most pervious concretes have 28-day compressive strength lower than 21 MPa, which is the minimum required compressive strength for structural use. Most applications for pervious concrete are parking lot pavement, pedestrian walkway, bike route and places where concrete compressive strength is not important. It is quite controversial for requiring the high permeability and high compressive strength at the same time.

The use of Portland cement pervious concrete (PCPC) pavements among the best management practices for the management of storm water runoff. PCPC pavement decreases the necessity of water detention ponds, permits groundwater recharge, decreases or eliminates pollutants from runoff, and improves water quality [1]. PCPC pavement is usually designed to have a void ratio of 15–35% and a permeability of 1.4–20.3 mm/s. It has a typical compressive strength ranging from 2.8 to 21 MPa, which limits its usage in structural applications. Gesogˇlu et al. [2] studied the effect of adding three types of rubber to replace aggregates for pervious concrete. They found that the use of rubber significantly aggravated the pervious concrete mechanical properties and its permeability but in different degrees according to the rate and type of rubber used. However, replacement of natural aggregate with rubber particles resulted in a significant increase of toughness and ductility of concrete as well as better damping capacity. Gesogˇlu et al. [3] further investigated the effects of particle size and volume content of waste tire rubber on the flexural strength, abrasion and freezing thawing resistances of pervious concretes. They reported that use of rubber significantly enhanced the abrasion and freezing–thawing resistance while it decreased the flexural strength of the pervious concrete. Tennis et al. [4] used a narrow gradation size aggregate, sized between 3.75 mm and 19.0 mm, 2.36 mm and 9.5 mm, or sized from 0.5 mm to 1.18 mm. Results shows that flaky aggregate has more permeability than the angular and irregular. The average sizes of coarse aggregate used are 4.75-10 mm and 10-20 mm. Omkar Deo et al.(2010) [5] investigates several pervious concrete mixtures proportioned using different size aggregates and their blends on their propensity to clogging so as to bring out the influence of pore structure features on particle retention and the consequent permeability reduction. Significant permeability reductions were observed with incremental finer sand addition for pervious concrete mixtures made with 3/8” aggregates and their blends whereas the specimens made with 3/8” aggregates experienced negligible loss in permeability. Weichung Yeih et al (2015) [6] used Electric Arc Furnace Slag (EAFS) aggregates in pervious concrete. Test results showed that under the same condition, pervious concrete made with EAFS aggregates had a better mechanical strength and a greater permeability coefficient than that made with natural river gravels.

According to [1], the strength of pervious concrete can be improved using the following strategies:

(1) Enhancing the characteristics of cement paste by decreasing the water–cement (w/c) ratio and adding pozzolanic materials such as silica fume.

(2) Adopting different cementitious materials such as epoxy.

(3) Applying slight pressure and increasing the temperature during the curing stage.

In this study, pervious concrete was designed according to NRMCA (National Ready Mixed Concrete Association) guidelines and SF used as SCM to improve compressive strength and abrasion resistance. There are multiple goal for doing so: (1) increasing the compressive strength of pervious concrete; (2) increasing the interlocking force due to small particles of Silica Fume: (3) increasing the Abrasion resistance of pervious concrete.

2. EXPERIMENT PROGRAM

2.1 Materials and properties

Two sizes of coarse aggregate (CA) were used in this study in order to maintain the interlocking between the aggregates. The two sizes are 4.75-10 mm size A (60%) and 10-16 mm size B (40%). For betterment of pervious concrete ZONE II sand is used as partial replacement of aggregates. Properties of CA & sand were as shown in Table-1.

Table 1: Physical properties of Aggregates

property	unit	Aggregates	Sand
unit wt.	(kg/m3)	1650	1920
absorption	%	1	1.2
bulk specific gravity (ssd)	-	2.65	2.7
bulk specific gravity (od)	-	2.63	2.66

Type I Ordinary Portland cement 53 grade is used as primary binder. SCMs, such as SF is used as a cement replacement to modify the binder properties. Chemical composition of Cement & SF were as shown in Table-2 No admixtures were used for this study

Table 2 Chemical composition of Cement & SF

Component	Cement	Silica Fume
CaO	62.34	0.87
SiO2	20.14	90.12
Al2O3	4.65	0.94
Fe2O3	3.29	1.62
SO3	2.42	0.29
MgO	2.23	-
K2O	0.72	1.21
LOI	1.96	2.87

2.2 Mixture proportions

There is no perfect mix design for Pervious Concrete so mix design is prepared from NRMCA guidelines [7]. 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. For better performance little amount of sand is replaced with aggregate, with a predefined void ratio (20%) and W/C ratio (0.33). Two sets of pervious concrete mixes, (1) ordinary pervious concrete (OPC) and (2) SCM-modified pervious concrete (SPC) are designed, and their mix proportions are presented in Table-3. The SF dosages are 5%, 8% and10%. Mixtures were prepared using a rotating drum mixer.

Table 3 Mix design per 1m^3 of PC

Mix Type	Aggregates	Cementitious material		Sand (%)	water-to binder ratio
	(kg)	Cement(kg)	SF(kg)		w/b
OPC1	1536	393	-	5	0.33
OPC2	1492	383	-	8	0.33
OPC3	1457	376	-	10	0.33
SPC1	1490	363	19.15 (5%)	8	0.33
SPC2	1490	352	30.65 (8%)	8	0.33
SPC3	1490	345	38.3 (10%)	8	0.33

2.3 Test procedures

2.3.1 Porosity

Main properties of pervious concrete like permeability and compressive strength, have been directly related to the porosity of the PC. Therefore, it was very important to obtain the porosity. Porosity was measured on concrete casted cylinder specimens, using the method developed by Montes et al. [8] which was the basis for ASTM C1754[9]. The porosity calculated using the following equation.

$$P = \left[1 - \frac{w_2 - w_1}{\rho_w * V}\right] * 100, \%$$

Where

P = porosity, %.

W1 = Weight under water, kg.

W2 = Air-dried weight, kg.

V = Volume of sample, m3.

ρ_w = Density of water, kg/m^3.

2.3.2 Permeability test

After the total void ratio test, the specimen was placed in the water permeability test set-up as shown in Fig. 1. It was determined as per falling head permeability method according to IS 2720-17 (1986) [10]. For the measurement of the permeability 300 mm water head is used for measuring permeability. For permeability test cylinder having 150 dia. and 300 mm height is used. Fig. shows the Falling head permeability test setup. The Permeability is measured according to Darcy's Law given by the following equation.

$$k = \left[\frac{(A1*L)}{(A2*t)}\right] * \left[log\frac{h2}{h1}\right]$$

Fig. 1: Test setup of permeability test

Where,

k = water permeability coefficient, (mm/s)
t = time, (seconds)
A1 = cross-sectional area of the specimen, (mm²)
A2 = cross-sectional area of the specimen tube, (mm²)
h1 = the initial water head, (mm)

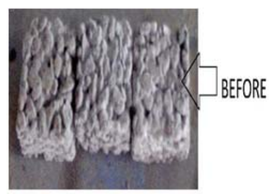
h2 = the final water head, (mm)
L = length of the specimen, (mm)

2.3.3. Cantabro test

As pervious concrete mostly used in road pavements so Abrasion resistance need to be checked. The Cantabro test was conducted by using Los Angeles (LA) abrasion machine without the steel ball. In accordance with this testing procedure, each testing set consists of three cores of 70x70x70 mm is casted, which are placed together inside the abrasion machine. Therefore, the six cores that were extracted per mixture generated two testing sets consisting of three specimens each. The testing procedure began by measuring the initial mass (W1) of a set of three specimens. The next step consisted of placing three specimens inside the drum of the Los Angeles Abrasion machine Fig. 2 (a).Then, the machine was rotated up to 500 times at a constant rate of 30 rpm. No steel balls were used during this test. After the loose debris passing the 25 mm sieve (1 in) was removed and discarded, the final mass (W2) of the specimens was recorded Fig. 1(c) [11] Finally, the percentage of mass loss was calculated using the following formula:

$$\text{Cantabro mass loss, \%} = \frac{(W1-W2)}{W1} * 100, \%$$

(a)



(b) **(c)**

Fig. 2: Los Angeles Abrasion machine & specimen before &after test

Compressive strength

The compressive strength of pervious concrete was carried out on a 2000 kN capacity compressive testing machine according to IS: 516-1959 [12]. For finding out compressive strength 150x150x150 mm size cubes are casted and tested. Load was applied gradually with the rate of travel of machine equivalent to 5.2 kN/s.

3. RESULTS AND DISCUSSION

3.1 Porosity

Porosity was measured on all cores according to [12].. Porosity of all pervious concrete mixes can be found in Table 1. The analysis of sand content in OPC indicated that porosity were closed to 20% target. The value of porosity of mixture OPC3 was fond below 20% so it was not used in further analysis. In SPC 8% sand was used and the test results were in table. Test results indicating that in mixture SPC3 the target porosity 20% not achieved because of pore holes filled up with the SF particles.

Table 4: Porosity & Permeability of PC

Mix type	POROSITY (%)	Permeability (mm/sec)
OPC1	27.24	16.23
OPC2	23.06	14.81

OPC3	17.03	12.04
SPC1	21	16.04
SPC2	20.2	15.5
SPC3	18.5	14.8

3.2 Water permeability

It is a major property for evaluating the performance of pervious concrete. According to the Japan Road Association the water permeability coefficient being greater than 0.01 cm/s. [13]. The test results of water permeability are tabulated in **Error! Reference source not found.**. Permeability of OPC is in between 12 to 17 mm/sec. Permeability decreased from 16 to 12, when sand content increased from 5 to 10%.

3.3 Compressive strength and Density

The results of density and compressive strength of OPC & SPC were as shown in table. The densities of OPC were between 1810 to 0720 kg/m3, which were lower than the conventional concrete due to the voids in the pervious concrete. Similarly densities of SPC were between 1970 to 2040 kg/m3. The compressive strength of OPC containing sand were between 4.8 to 9.5 N/mm2 and SPC containing SF were between 13.1 to 20 N/mm2. From Fig. 3 it is observed that increase in the sand percentage increases the compressive strength. As it can be seen, the compressive strength increased with increasing the amount of SF, but using more of them reduces the Porosity. Therefore, 8% use of SF can be considered as the optimal value and shows significant improvement in strength.

Table 5 Comp. strength at 28 days

Mix Type	Density (kg/m3)	Comp. strength (N/mm2)
OPC1	1819	4.8
OPC2	1910	6.8
OPC3	2072	9.5
SPC1	1975	13.1
SPC2	1995	15.2
SPC3	2038	20.0

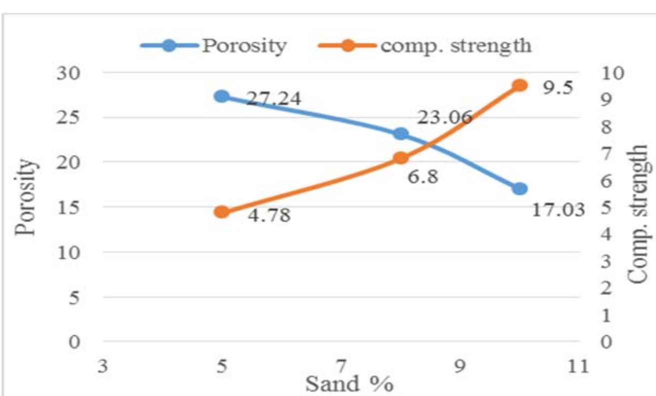


Fig. 3 Optimum dosage of sand

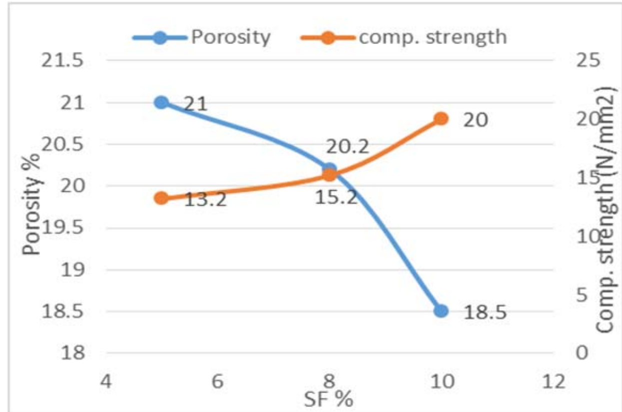


Fig. 4 Optimum dosage of SF

4. CANTABRO ABRASION RESISTANCE TEST

The cantabro mass loss was measured for two sets of cores per mixtures. Each set consisted of three specimens according to [11]. Mass loss of OPC and SPC were as per Table 6. Fig. 5 cantabro mass loss of OPC shows the average mass loss after 500 revolutions at 25 rpm for each concrete mixture produced. The mass loss of OPC were between 40 to 67%. Reason for reducing mass loss was interlocking aggregates voids by sand particles. Experimental results indicated positive effect of SF utilization on pervious concrete against abrasion so that SPC had superior abrasion resistance. Moreover, increasing the SF content from 5% to 10% resulted enhancement in abrasion resistance.

Table 6 cantabro mass loss

Mix type	Mass loss (%)
OPC1	66.2
OPC2	51.0
OPC3	40.4
SPC1	28.1
SPC2	25.2
SPC3	20.4

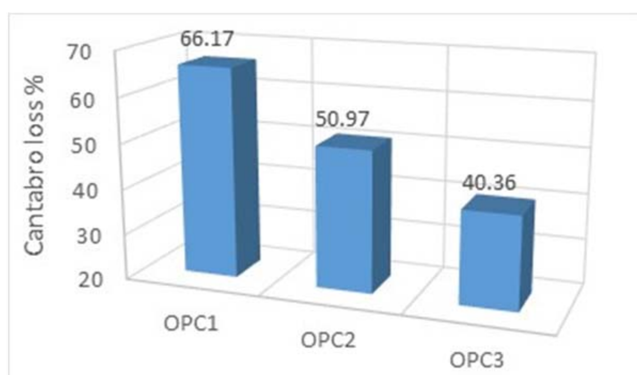


Fig. 5 cantabro mass loss of OPC

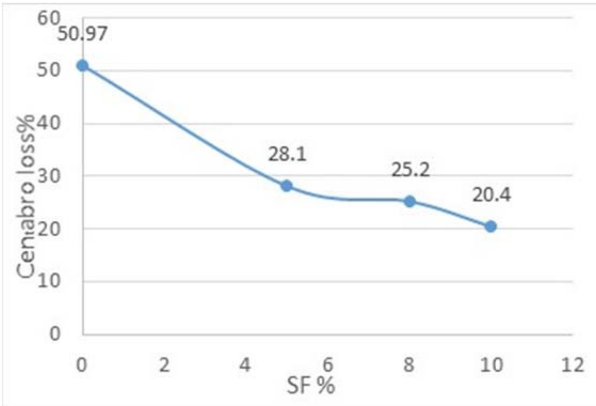


Fig. 6 cantabro mass loss of SPC

5. CONCLUSION

Compressive strength, Permeability, Porosity and Abrasion resistance were carried out on OPC and SPC for constant W/C ratio (0.33). Based on the test results and discussions, following conclusions are drawn

1. The Compressive strength of pervious concrete increased by increasing sand content but desired porosity was not achieved when sand content is more than 8%.
2. When sand content increases from 5 % to 10%, Abrasion resistance was increased around 20%.
3. Permeability decreased from 16 to 12 mm/sec, when sand content increased from 5 % to 10%.
4. Compressive strength of 10% SF replaced pervious concrete increased around 30%. But desired porosity was not achieved so optimum percentage of silica fume for 20% porosity was 8%.
5. 8% use of silica fume increased Abrasion resistance around 40%.

Further studies can be carried out for 8% sand and 8% silica fume in pervious concrete using various admixtures. Studies can also be carried out in future using the any other SCM materials.

REFERENCES

[1] Norbert Delatte, P. E., F. ACI, and Stuart S. Schwartz. "*Sustainability Benefits of Pervious Concrete Pavement.*"
[2] Gesog˘lu M, Guneyisi E, Khoshnaw G, _Ipek S. *Investigating properties of pervious concrete containing waste tire rubbers*. Construction and Building Materials 2014;63:206–13.
[3] Gesoğlu, Mehmet, Erhan Güneyisi, Ganjeena Khoshnaw, and Süleyman İpek. "*Abrasion and freezing–thawing resistance of pervious concretes containing waste rubbers.*" Construction and Building Materials 73 (2014): 19-24.
[4] Paul D. Tennis, Michael L. Leming, and David J. Akers, "*Pervious Concrete Pavements*", Portland Cement Association, ISBN 0-89312-242-4, PCA Serial No. 2828,2004.
[5] Deo, Omkar, Milani Sumanasooriya, and Narayanan Neithalath. "*Permeability reduction in pervious concretes due to clogging: experiments and modeling*." Journal of Materials in Civil Engineering (2010).
[6] Yeih, Weichung, Tun Chi Fu, Jiang Jhy Chang, and Ran Huang. "*Properties of pervious concrete made with air-cooling electric arc furnace slag as aggregates." Construction and Building Materials (2015).*
[7] *www.nrmca.com (NRMCA guidelines)*
[8] Montes F, Valavala S, Haselbach LM. "*A new test method for porosity measurements of portland cement pervious concrete*" J ASTM Int 2005;2(1) [ASTM International, West Conshohocken, PA].
[9] ASTM C1754/C1754M.12, "*Standard Test Method for Density and Void Content of Hardened Pervious Concrete"*; 2012. 3p.
[10] IS 2720-17 (1986): "*Falling head permeability test for infiltration rate"*
[11] Gaedicke, Cristián, Armando Marines, and Farel Miankodila. "*Assessing the abrasion resistance of cores in virgin and recycled aggregate pervious concrete*." Construction and Building Materials 68 (2014): 701-708.
[12] IS : 516-1959 Method of Tests for Strength of Concrete.