Experimental Studies on Pervious Concrete by Varying the Size of Aggregate and Sand Content

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***Abstract*— Pervious concrete is a mixture of cement, water, coarse aggregate and little to no sand. It is also called as porous concrete and no fines concrete. This paper deals with the experimental results of pervious concrete based on three different sizes of aggregates with three sand contents. A mix design of Grade M25 was developed. The sizes of aggregate taken are 10, 12.5 and 16mm and the sand content is reduced to 5%, 10% and 15%. Three cubes and three cylinders were casted for each size and sand content respectively. A total of 27 cubes and 27 cylinders are casted which are tested for compressive strength and infiltration rate. Based on the analysis of the results obtained, applications of pervious concrete will be recommended.**

Keywords—Pervious Concrete, Mix Design, Fine Aggregate Reduction, Compressive strength, Infiltration Rate.

I. INTRODUCTION

Pervious concrete is a mixture of cement, water, coarse aggregate and little to no sand. It is a special type of concrete with a high level of porosity that allows water from precipitation and other sources to pass directly through the sub grade. It helps to reduce the run off thereby allowing ground water discharge. It is used for concrete flatwork applications. It is an open graded structure with interconnected voids which gives this concrete its high level of porosity. Generally, Pervious concrete has water to cement ratio of 0.3 to 0.45 and the void ratio ranges from 0.2 to 0.38.

Pervious concrete is sensitive to changes in water content which makes the field modifications vital for a proper concrete mixture. Excess water may result in segregation and bleeding while less water may affect the curing of the solid. The high porosity achieved also results in the reduction of strength as compared to conventional concrete mixtures but sufficient strength for many different applications is readily achieved.

It represents a near zero-slump. Permeability to water depicted by pervious concrete generally ranges from 1.2 mm/s to 13.2 mm/s. While it's compressive strength generally ranges from 2.5 MPa to 30 MPa. Pervious concrete is rapidly becoming popular in many countries due to its use in sustainable construction.

II. NEED FOR PERVIOUS CONCRETE

A. *Environmental effects of conventional concrete*

Cement production is one the top ranking producers of anthropogenic carbon dioxide in the world after transport and energy generation. Around 5% of the worldwide total of carbon dioxide emissions is caused by cement production. Concrete causes damage to the topsoil which is the most fertile layer of the earth. The hard surfaces created by concrete result in surface runoff causing soil erosion, flooding and water pollution.

B. *Environmental benefits of pervious concrete*

Pervious concrete helps to solve the problems of conventional concrete by reducing the surface run off volume, rate and pollutants. It helps to collect and fill the retention ponds which is collected beneath the pavement itself, allowing filtration thereby reducing the need for retention ponds themselves. Pervious concrete reduces the heat island effect, as it stores less heat allowing the growth of trees for shade.

C. *Applications of pervious concrete*

Pervious concrete can be used in parking areas with light traffic, residential streets, greenhouse and pedestrian walkways. It is application of environment friendly construction. It is a type of low impact development technique used to protect the quality of water. Other applications are drainage media for hydraulic structures and tennis courts. It can also be used for thermal insulation and as sound barrier in walls.

III. RESEARCH OBJECTIVES

The pervious concrete is generally used for the construction of low volume and low speed traffic areas pedestrian walkways and residential streets. Many jurisdictions are now considering the other uses of pervious concrete. The design mix and physical characteristics of pervious concrete should be investigated. As a result, the objectives of this research were:

- To develop a mix design for pervious concrete.
- To carry out tests for compressive strength and infiltration rate.
- To analyze suitability of pervious concrete for various applications.

IV. LITERATURE REVIEW

In Dec. 2014, a study was conducted to obtain the most appropriate design mix of pervious concrete for the District of Columbia wherein five different design mixes were developed by varying the method of compaction as self-consolidating, half rodding and Standard Proctor Hammer. These samples were investigated for optimum compressive strength and permeability rate. After testing, the sample with maximum coefficient of permeability of 57.8 inches/hour and compressive strength of 3,500 pounds/square inch (psi) was identified to be the ideal mix of pervious concrete. This optimum mix was also tested for infiltration rate at three different locations in Washington D.C obtained between 86 to 208.8 inches/hour and lastly the modulus of rupture was determined to be 565 pounds/square inch. Finally, the study concluded that the most appropriate method of compaction was Standard Proctor Hammer and based on the results certain recommendations were made. [1]

A sample of pervious concrete of grade M20 was developed by ACI522R-10 design code with the flexural strength of 3.14 MPa in which the effect on compressive strength was taken into account by varying the water-cement ratio between 0.34 to 0.43 routinely and aggregate sizes. In this study, cement was replaced by fly ash in certain amounts and comparative analysis on certain properties with and without fly ash was done and presented by graphical means. The tests revealed that there was an increase in the compressive strength of pervious concrete with the corresponding decrease in water-cement ratio until the optimum value of 0.38 is reached and also with an increase in the volume of paste. Also, the optimum replacement of fly ash was concluded to be 20% which additionally reduces the effective cost of casting pervious concrete. [2]

At Cecos Engineering University, Peshawar, an experimental study was conducted to investigate the compressive strength and infiltration rate of pervious concrete by reducing the content of fine aggregates from 0 to 100%. The curing period was set for 7 and 28 days. These results concluded that the compressive strength of pervious concrete decreases simultaneously with the decrease in fines whereas there was an increase in the infiltration rate of the sample. Thus, it was found that with 100% sand reduction, compressive strength was reduced by almost 50% with 49% for 7 days and 46% for 28 days and the infiltration rate to be maximum with 273 inches/hour. For 0 to 40% sand reduction, the compressive strength was within the optimum range however with zero infiltration rates. Thereby, the study concluded that 90% reduction of sand with compressive strength of 2150 psi and infiltration rate as 165.79 inches/hour showed optimum results and applications were recommended. [3]

In Indonesia, a study was conducted on pervious concrete wherein the design mix was obtained by reducing the amount of fines in conventional concrete. Thus, only 30% fines of the proportion of coarse aggregate were used in the mix. Thereafter, the voids in the pervious concrete were filled with soil, natural sand and volcanic sand routinely and the samples were tested for compressive strength, speed of absorption and permeability. This study revealed that optimum results were obtained for permeability in case of natural sand being 0.38 cm/sec as vertical permeability and 0.364 cm/sec as horizontal permeability. Values for compressive strength assessed were 5.62 MPa, 5.28 MPa and 5.71 Mpa for soil, natural sand and volcanic sand respectively. Based on these results the recommendations were made for its application in low volume roads only. [4]

A case study was conducted in British Columbia, Canada in a parking lot wherein a 1000 sq.ft area constructed by asphalt was replaced by pervious concrete. The details about the various prevailing conditions of the same were investigated. Here the runoff absorbed by the pavement was monitored by a network of embedded perforated pipes and this study revealed that the capacity of its detaining runoff reduced over a period of time due to clogging also with a slightly lower value of compressive strength which was most likely due to the lack of an appropriate technique for its measure. However, conclusively the overall capacity and infiltration of the pavement remained high. [5]

The property of high porosity of pervious concrete was enhanced during a research conducted in the year 2015 in Indonesia by using volcanic pumice as an aggregate replacement. In this study, the effect of varying proportions of volcanic pumice per normal aggregate and proportion of aggregate to cement with a constant water-cement ratio was evaluated on the mechanical properties of volcanic pumice porous cement and on porous cement with normal aggregates. The tests were conducted for void content, compressive strength and flexural strength. Thus based on the test results it was concluded that volcanic pumice could be effectively used to improve the porosity of pervious concrete without much reduction in its strength. [6]

In 2014, a study was conducted in The States on three different types of permeable shoulders with stone reservoirs; Porous Asphalt, Pervious Concrete Pavement and Permeable Interlocking Concrete Pavements with full, partial and no infiltration. Full infiltration system allowed the entire water to pass to the sub grade. Partial infiltration system allowed only the excess water above infiltration capacity to be removed via an outlet pipe. No infiltration system, did not allow any water to pass through the sub grade. It was concluded that pervious concrete pavement with partial infiltration system was most suitable for the construction of highway shoulders for effective storm water management. [7]

A study was conducted to evaluate the suitability of pervious concrete for sidewalks. Eleven different pervious design mixes (including commercial and laboratory design mixes) were evaluated for different mechanical and hydrological properties. Slabs were casted using both conventional and pervious concrete respectively which were then tested for thermal and radial performance. The values of compressive strength ranged from 1100 to 3400 psi at 28 days and modulus of rupture ranged from 1000 to 2800 ksi. The hydraulic conductivity and elastic modulus were 0.04 to 0.06 cm/sec and 1000 to 2800 ksi respectively. Freeze and thaw tests showed about 6% loss of mass for 100 cycles. It was concluded that porous asphalt can be used most economically for sidewalks considering all the different properties. [8]

A study was conducted which suggested that pervious concrete could be used as a solution for sustainable development for pavements. A comparison was made between the mechanical, physical and hydrological properties of conventional and pervious concrete. It was found that pervious concrete cannot be used for pavements having high bearing capacity but can be successfully used for sidewalks and footpaths which do not bear much load. The environmental problems encountered by conventional concrete can be minimized by the use of pervious concrete. It was concluded that pervious concrete can be used for the construction of certain pavements successfully if it is designed and maintained properly. [9]

A study was conducted were pervious concrete was designed by replacing cement by waste materials- rice husk, glass powder, ceramic waste and hypo sludge. No significant changes were observed in compressive strength when cement was replaced with 20% and 30% of rice husk. The properties of pervious concrete were evaluated by replacing cement partially from pervious concrete with 10%, 20%, 30%, 40%, 50% and 60% of hypo sludge. It showed an increase in the compressive strength when the replacement was increased up to 40% When ceramic waste powder was replaced from 0 to 50% by weight for M25 grade concrete, the strength increased when replacement was 30% whereas further replacement showed decrease in strength. The best results were obtained for M25 grade concrete with replacement by 0 to 30% by weight of ceramic waste powder. It was concluded that when cement from pervious concrete was replaced partially by different waste materials, the overall cost can be reduced, but the increase in strength depends on the type of waste material used. [10]

V. RESEARCH METHODOLOGY AND DATA COLLECTION

The first part of this study focused on developing a mix design for pervious concrete of grade M25. The sand content is reduced to 5%, 10% and 15%. The material properties required for developing the mix design were obtained based on different test results and some information observed in literature reviews and industrial standards. Details of materials, mix proportion, sample preparation and test methods used are as follows:

A. Materials

Cement:

Ordinary Portland cement (C 53 grade) confirming to requirements of IS 12269-2013 obtained from local suppliers was used in the experiments. After conducting all the tests on this procured cement, its specific gravity was found to be in the range of 2.8-3.2. Various properties of cement are given in table 1.

TABLE 1. PROPERTIES OF CEMENT

Aggregates:

The sizes of aggregates to be used in the preparation of pervious concrete mix were chosen based on findings and reports of various researchers. Irregular type of coarse aggregates of sizes 10mm, 12.5mm and 16mm were selected confirming to IS 383:2016. The aggregate test samples were separated into single size fractions according to IS standard sieves. Crushed sand is used confirming to IS 383:2016 Details of the properties of aggregates are given in table 2.

PARTICULARS TEST	RESULT VALUES	REQUIREMENTS OF IS 12269-2013	
Standard consistency (%)	29-30	-	
Setting time			
a. Initial	160-170	30	Minimum
b. Final	225-240	600	Maximum
Compressive Strength (N/mm²)			
a. 168 +/- 2hr (7 days)	42.0	37	Minimum
b. 672 +/- 4hr (28 days)	61.0-62.0	53	Minimum

TABLE 2. PROPERTIES OF AGGREGATE SAMPLES USED IN THE EXPERIMENT

	PROPERTIES	MATERIALS	VALUE
1.	Flakiness Index	Coarse Aggregates	18.54%
2.	Elongation Index	Coarse Aggregates	15.47%
3.	Abrasion Value	Coarse Aggregates	21.44%
4.	Dry Loose Bulk Density	Fine aggregates	1.53
		Coarse Aggregates	1.67
5.	Water Absorption	Fine aggregates	2%
		Coarse Aggregates	1.4%
6.	Specific gravity	Fine aggregates	2.75

Water:

Potable water was used during the entire process of the experiment from preparation of mix to curing of sample. Chemical admixtures were not used in the study as the main aim of the study is to find the effect of size of aggregates in pervious concrete.

B. Mix design

A mix design of grade M25 was developed according to IS 456:2000 and IS 10262-2009. The sand content was reduced to 5%, 10% and 15%. The water- cement ratio used for the mix is 0.43. The final mix design obtained is:

1:0.0685:2.21 (for 5% sand)
1:0.137:2.21 (for 10% sand)
1:0.205:2.21 (for 15% sand)

C. Test Methods

Various physical and engineering properties of the aggregate sample used are flakiness index, elongation index, specific gravity, water absorption, dry loose bulk density and

Los Angeles Abrasion Value were determined using IS 2386 (Part I)-1963 and IS 2386 (Part III)-1963 and in IS 2386 (Part IV)-1963.

Three cubes of size 150mm and three cylinders of diameter 106mm and height 150mm were casted for each size and sand content. Hence a total of 27 cubes and 27 cylinders were casted. The cubes were tested for compressive strength and the cylinders were tested for infiltration rate at the age of 28 days. The test for compressive strength was carried out as per IS516-1959. The test for infiltration rate was carried out by placing the cylinder in a closed container open at top and bottom. A known volume of water is passed through it by maintaining a constant head of 50mm. The time required for the water to infiltrate the cylinder is measured. The ratio of volume of water to the time taken for that volume to infiltrate gives the infiltration rate.

TABLE3 : NUMBER OF SAMPLES CASTED

SR. NO.	SAND CONTENT	SIZE OF AGGREGATES (mm)	NO. OF CUBES	NO. OF CYLINDERS
1.	5%	10	3	3
		12.5	3	3
		16	3	3
2.	10%	10	3	3
		12.5	3	3
		16	3	3
3.	15%	10	3	3
		12.5	3	3
		16	3	3
			27	27
TOTAL			54	

On the basis of results obtained, the effect of size of aggregate and reduction of sand content on pervious concrete mixes will be analyzed and suitable applications of pervious concrete will be recommended accordingly.

VI. Results And Discussion

The results for compressive strength were obtained by performing tests on cubes and infilteration rate was evaluated by testing cylinders

TABLE:4 TEST RESULTS FOR COMPRESSIVE STRENGTH

SAND CONTENT → / SIZE OF AGGREGATE	COMPRESSIVE STRENGTH (N/mm^2)		
	5%	10%	15%
10mm	41.68	42.73	44.39
12.5mm	40.97	41.05	41.64
16mm	26.5	28.18	30.53

TABLE5 TEST RESULTS OF INFILTERATION RATE

SAND CONTENT → / SIZE OF AGGREGATE	INFILTERATION RATE mm/hr		
	5%	10%	15%
10mm	57	44	31
12.5mm	92	76	49
16mm	113	98	85

The graphicl representation of the results of compressive strength and infilteration rate are shown below;

Fig.1: Graph for Compressive strength

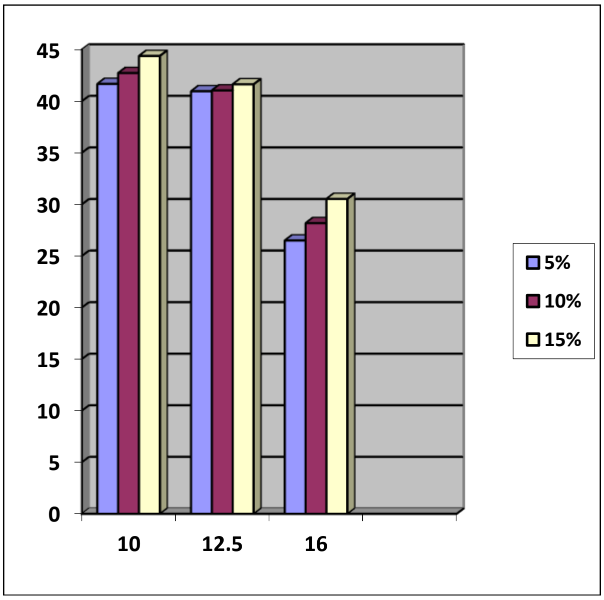
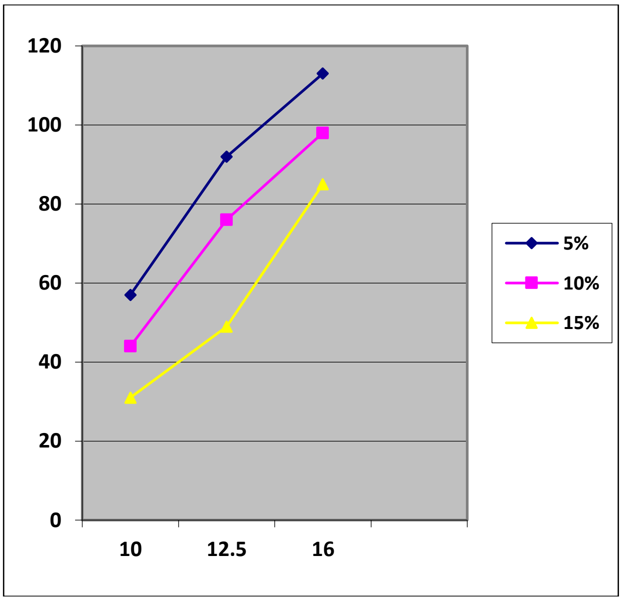


Fig.2 : Graph for infilteration rate



From the graphs obtained we conclude that optimum results for compressive strength and infiteration rates were obtained in samples having 10% sand content having 12.5mm sized aggregate.

VII. CONCLUSION

1. Mix design of pervious concrete of grade M25 developed using IS 456:2000.
2. Compressive strength of concrete increases with the increase in the sand content.
3. Infiltration rate of concrete increases with the increase in size of aggregate.

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