International Journal on Recent and Innovation Trends in Computing and Communication
ISSN: 2321-8169 Volume: 12 Issue: 2
***Article Received:** 25 December 2023 **Revised:** 12 January 2024 **Accepted:** 20 February 2024*

Effect of Aggregate Gradation on Hydraulic Properties of Pervious Concrete and Fly Ash as SCM

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Abstract: This paper deals with the hydraulic properties of pervious concrete with the effect of coarse aggregate gradation and fly ash as SCM. Initially, mixes were categorized into three (i.e., PV1, PV2, and PV3) with 16.5-12mm, 12-10mm and 10-4.75mm, respectively. In each group, cement was replaced from 0 to 30%, which was about twenty-one mixes, including conventional mixes prepared with a constant w/c ratio as 0.35 and superplasticizer at 1%. Samples were tested for compressive strength and hydraulic properties like porosity and permeability. Permeability was tested against the constant head method and variable head method. The results show that the hydraulic properties of pervious concrete enhanced with the usage of larger-sized aggregates. Fly ash effects adversely on the percolation capacity of pervious concrete.

Keywords*: Pervious concrete, hydraulic properties, porosity, permeability, fly ash*

1.0 Introduction:

Long-term research has been carried out on pervious concrete, also referred to as porous or permeable concrete. Stormwater can no longer stand still on rigid pavement thanks to pervious concrete. In order to improve the penetration of water through pervious mixtures, the sand fraction is intentionally excluded from their composition, either entirely or partially. Therefore, cement, water, and coarse particles make up the majority of pervious concrete's ingredients. In addition to having a high permeability rating, pervious concrete also has low density, drying shrinkage, and thermal conductivity. ACI 522R-2010 states that pervious concrete is designed with porosity of 15% to 35% to achieve permeability value of 0.20 to

3.00 cm/s along with bulk density of 1600 kg per cu.m with cement content of 270-415 kg per cu.m, fine aggregate content of 0 to 10%, water to cementitious material ratio of 0.26 to

0.45. Single-sized coarse aggregate content of 1190-1480 kg per cu.m, aggregate to cementitious material ratio of 4.0 to 4.5.

The type of aggregate, aggregate size, additional cementitious ingredients, or fibres are just a few examples of the many variables that might affect the quality of pervious concrete. According to studies, an optimum range of aggregate size is between 10 and 20 mm, and combining different aggregate sizes is useful. It was discovered that different kinds of aggregates had an impact on the compressive strength of pervious concrete. In addition to enhancing concrete strength, supplementary cementitious elements like silica fume, pulverised granulated blast furnace slag, fly ash, or metakaolin significantly increased abrasion resistance. S.S.Hwang.et.al[] studied the utilization of coal fly ash and glass powder, and the results concluded that the mineral admixtures increase the strength properties and decrement in the permeability of the pervious concrete. J.Huang.et.al[] conducted study on the effect of pervious concrete properties with the single size aggregate and size combination aggregates. It was observed that the single aggregate size shows the higher porosity values than the mixed aggregate samples. F.B. Pereira da Costa.et. al[] In order to achieve the necessary porosity by regulating density and compaction efforts, a straightforward design method is proposed. To achieve the necessary porosity and assess their impact on the permeability and mechanical performance of pervious concrete, the w/c ratio and chemical additive were changed. The addition of a rheology-modifying admixture improved the mixture's flowability and densification, which can boost its mechanical strength. The drop in w/c ratio was proven to boost flexural tensile strength while having no effect on compressive strength for mixtures with the same porosity. P Shen.et.al[] This work proposes a unique design technique to improve compressive strength and permeability in high strength pervious concrete. Ultra-high-performance paste binds high-strength pervious concrete. Paste aggregate characteristics and membrane-forming capacities were examined. Using ultra-high- performance paste, enhancing homogeneity and compatibility, and eliminating coarse particles increased mechanical properties. Due to enhanced homogeneity and interlocking, two-size aggregates increase compressive strength. Increasing membrane-forming abilitycould improve aggregate bonding and cement paste thickness. The proposed design concepts yielded a high strength pervious concrete with a compressive strength of 60.93 MPa and a water permeability of 0.37 mm/s.

Based on previous studies, it was observed that the studied pervious concrete islimited in the usage of mineral admixtures. Very low studies were observed on the impact of aggregate gradation on fresh, mechanical and hydraulic properties of pervious concrete. This study mainly focused on the hydraulic properties named as porosity and permeability of concrete and the compressive strength of pervious concrete with using graded coarse aggregate and fly ash as a secondary cementitious material.

2.0 Methodology:

Initially three mixes were prepared with three variations of coarse aggregate grades. First mix PV1 has 16-12.5mm, second mix PV2 has 12.5-10mm and third mix PV3 has 10-4.75mm sized aggregates. Later in each mix cement was replaced with fly ash from 0 to 30%.Total twenty one mixes were designed and executed to determine the compressive strength and hydraulic properties of pervious concrete to know the effect of coarse aggregate size.

3.0 Materials:

53 Grade Ordinary Portland Cement confirming to IS , having relative density of

3.12. fly ash used as secondary cementitious material in pervious concrete, which wascollected from the ash pond of themal power plant having relative density of 2.34. To improve the workability of pervious concrete a polycorboxylic ether based superplasticizer was used. Coarse aggregate was procured and later segregated according to the methodology developed with the help of sieves. The physical properties of the materials used in the study was tabulated in table.2, and chemical properties were tabulated in table.1 .

Table.1: Chemical analysis of cement and fly ash

Chemical Oxides	Cement	Fly Ash
CaO	60.54	0.35
SiO_2	20.13	69.04
Al_2O_3	2.49	11.77
MgO	0.6	0.33
SO_3	1.54	-
K_2O	0.71	0.86
Fe_2O_3	4.86	1.74
Loss of Ignition	2.29	1.98

Table 2: Physical parameters

S.No	Properties	Cement	Fly Ash
1	Specific Gravity	3.12	2.34
2	Normal Consistency	32	-
3	Initial Setting Time	45 min	-
4	Final Setting Time	235 min	-

5	Fineness (retained)	5%	15%

Table.3: Mix details

S.N o	Mix Name	C (kg /m3)	F (kg /m3)	CA (kg /m3)	Water/Powder ratio	Water (l/m3)	SP (l/ m3)
1	**PV1**	335	-	1622	0.35	117.85	3
2	**PV1F5**	318.25	16.75	1622	0.35	117.85	3
3	**PV1F10**	301.5	33.5	1622	0.35	117.85	3
4	**PV1F15**	284.75	50.25	1622	0.35	117.85	3
5	**PV1F20**	268	67	1622	0.35	117.85	3
6	**PV1F25**	251.25	83.75	1622	0.35	117.85	3
7	**PV1F30**	234.5	1005	1622	0.35	117.85	3
8	**PV2**	335	-	1660	0.35	117.85	3
9	**PV2F5**	318.25	16.75	1660	0.35	117.85	3
10	**PV2F10**	301.5	33.5	1660	0.35	117.85	3
11	**PV2F15**	284.75	50.25	1660	0.35	117.85	3
12	**PV2F20**	268	67	1660	0.35	117.85	3
13	**PV2F25**	251.25	83.75	1660	0.35	117.85	3
14	**PV2F30**	234.5	1005	1660	0.35	117.85	3
15	**PV3**	335	-	1676	0.35	117.85	3
16	**PV3F5**	318.25	16.75	1676	0.35	117.85	3
17	**PV3F10**	301.5	33.5	167	0.35	117.8	3

				6		5	
18	**PV3F15**	284.7 5	50.2 5	167 6	0.35	117.8 5	3
19	**PV3F20**	268	67	167 6	0.35	117.8 5	3
0	**PV3F25**	251.2	83.7	167	0.35	117.8	3
		5	5	6		5	
21	**PV3F30**	234.5	100 5	167 6	0.35	117.8 5	3

Experimental program:

Compressive Strength:

Compressive strength of the pervious concrete was determined using 2000kN compression testing machine specified by the code IS:519. 150x150x150mm cube specimens were prepared and cured for 28 days.

Hydraulic Properties:

Porosity:

Porosity of a pervious concrete was determined based on Archimedes principle. It is the ratio of weight difference of the concrete before and after placed in water to the volume. The majority of the porosity contributed by the active pores, which means they are interconnected. The experimental setup consist of stand connected with weighing machine and hanger. The hanger provided for the weighing balance helps to hold the specimen whilein air or in water.

P = porosity of the pervious concrete

W_1 = Weight of the pervious concrete sample in air

W_2 = Weight of the pervious concrete sample in waterP_W = Density of water

V = Volume of the sample

Permeability of pervious concrete:

Variable Head method:

Permeability coefficient can be evaluated by means of two ways one is constant head method and other is variable head method. The experimental used for the both the methods was same. However, the head maintained above the concrete sample may be constant for one method and variable with time in other method. It consists of three cambers, upper chamber used to maintain the water head, middle chamber helps to hold the concrete sample and lowerchamber collects water and sent out through pipe.

Variable Head method:

Constant head method:

Results and Discussions:

Compressive strength:

Among the three conventional mixes PV1, PV2 and PV3, PV3 achieved the highest compressive strength. Fig.1(a) depicts the effect of fly ash on the PV1 mix. With the rise of fly ash in cement content, the strength of pervious concrete also enhanced. PV1F20 attained 18.53MPa compressive strength at 28 days curing period, which was about 14.1% compared to reference mix PV1. However, at the maximum replacement level of cement attained the similar results to the conventional mix. At 5%, 10%, 15%, 20%, 25% and 30% FA content in cement has 16.81MPa, 17.36MPa, 18.04MPa, 18.53MPa, 17.31MPa and 16.43MPa

respectively.

Fig.1(b) presents the pervious concrete compressive strength results for PV2 mix with and without FA in cement at different levels. In this mix, the aggregate size with 12.5-10mm enhanced the strength parameters than the aggregate mix with 16.5-12mm. Approximately, 5% strength has been enhanced with lower sized aggregates. With the help of FA in the cement increased about 18% compressive strength than the conventional mix. The change in strength varied from 4% to 18% with increase of FA upto 20%. Beyond 20% FA, the trend reversed and ended above the reference mix. Fig.1(c) showed the results of PV3 mix. It was observed that the maximum strength has attained in this mix only, even without FA in the cement. It may be due to the reduction of voids by decreasing aggregate size. FA palys additional advantage by pozzolonic action with cement. Similar trends were observed in the PV3 mix with FA. About 13% strength was augumented with the 20% FA. 13% strength development is lower then PV2 and PV1 mix but, the magnitude is higher than the remaining.

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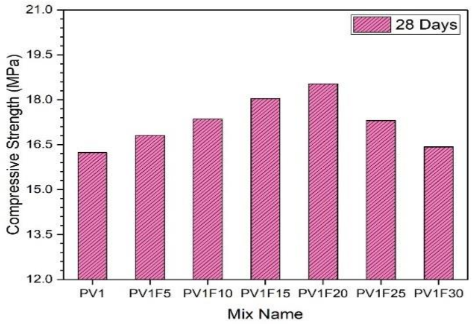

Fig.1(a) PV1 with FA

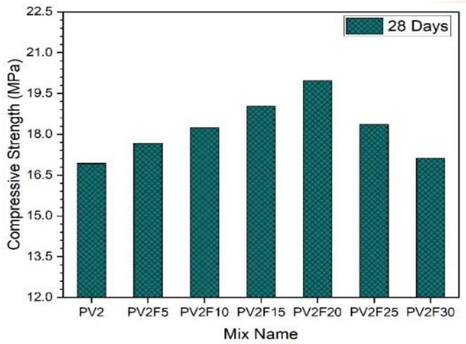

Fig.1(b) PV2 with FA

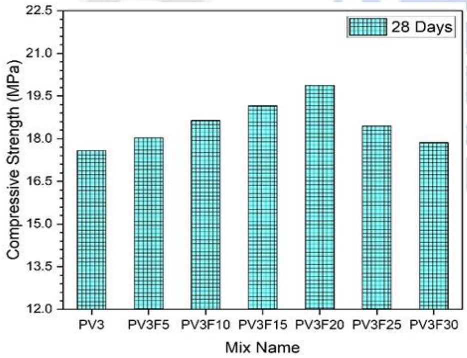

Fig.1(c) PV3 with FA

Hydraulic Properties:

Porosity

The porosity of the pervious concrete with fly ash was presented in fig.2, In PV1 FA from 5 to 30% affected the porosity. FA in the cement improved the paste content, the enhanced paste content reduced the voids in the pervious concrete. The porosity decreased at 6.49%, 10.5%, 14.58%, 19.48%, 25.28%, and 31.85% for 5%, 10%, 15%, 20%, 25% and

30% FA levels respectively. The similar trends were observed in both PV2 and PV3 mixes with FA. However, the porosity was reduced in value with usage of 12-10mm and also by 10-4.75mm sized aggregates.

In addition to the reduction of aggregate sizes in PV2 and PV3, the FA greatlyeffected the voids content in the pervious concrete. FA as secondary cementitious material deduced the porosity. Fig.3 and Fig.4 depicted the PV2 and PV3 mixes porosity respectively. 10-4.75mm aggregated pervious concrete has 17.39% lesser porosity than the 16-12mmaggregated concrete at 0% fly ash. Similarly, 30% FA has about 25% lower perculation than the PV1 mix. With this, FA effected the porosity from 18% to 25% at 0 to 30% levels in cement. For PV2 mix, the change in porosity with respective to the PV1 was low compared tothe relation between PV3 and PV1, which was about 5 to 8%. It may be due to the size ratio of aggregate as well as the fly ash replacement levels in cement.

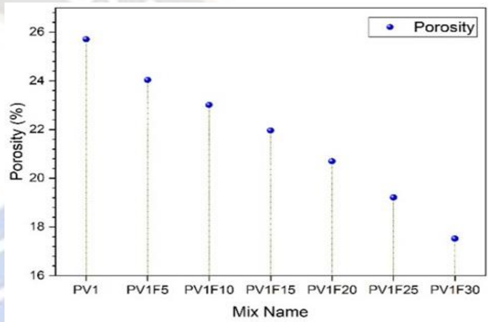

Fig.2. Porosity Vs PV1 mix

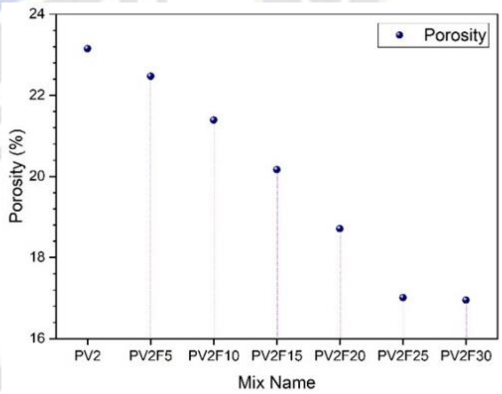

Fig.3 Porosity Vs PV2 mix

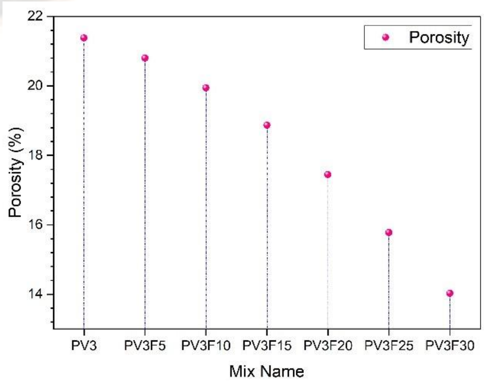

Fig.4 Porosity Vs PV3 mix

Permeability:

The permeability of the pervious concretes were tested against the variable head and also using constant head methods. It was clearly observed that the permeability of the pervious concrete varies for both the methods. However, constant head method exhibited the highest permeability than the variable head method. In the line, PV1 has the enhancedpermeability among PV2 and PV3 mixes. The coarse aggregate with 16-12mm pervious concrete has showed the top in all the mixes. Aggregate with 10-4.75mm mix exhibited the lowest permeability among all mixes. For PV1 mix, the change in permeability of both methods were varied from 10% to 20%, for PV2 has 10 to 35%, and PV3 has 25 to 45%. This may be due to the change in the aggregate size. The coarse aggregate size showed a major effect on the permeability of the pervious concrete, which was a important role for a perviousconcrete. For PV2 mix there was a difference of 1.9, 2.1, 2.8, 2.9, 3.2, 4.4, and 4 mm/min permeability for variable head and constant head at 0, 5, 10, 15, 20, 25, and 30% FA respectively. While PV1 has 2.4, 2.5, 3.3, 1.7, 1.7, 3.2, and 2.6mm/min for various levels of fly ash. Similarly, PV3 has 3, 4.3, 4.6, 3.8, 3.3, 4.1 and 3 mm/min perculation has been observed the difference in both the methods.

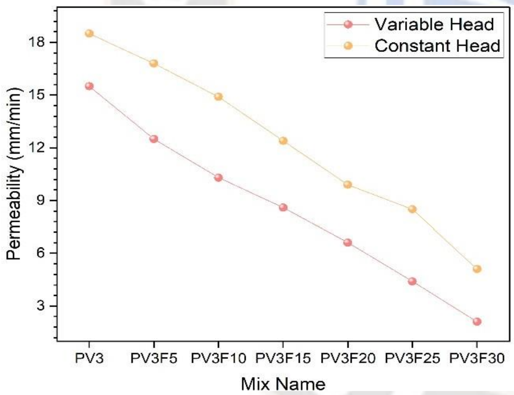

Fig.5. Permeability of PV1 mix

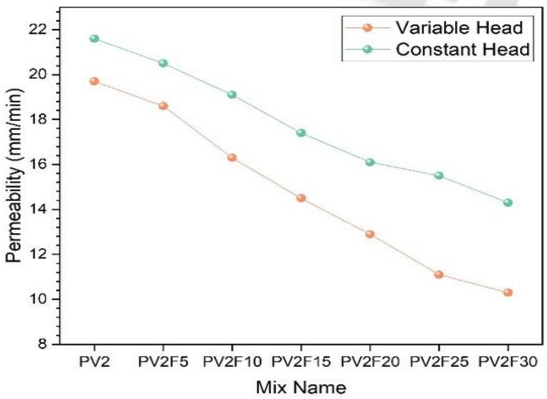

Fig.6 Permeability of PV2 mix

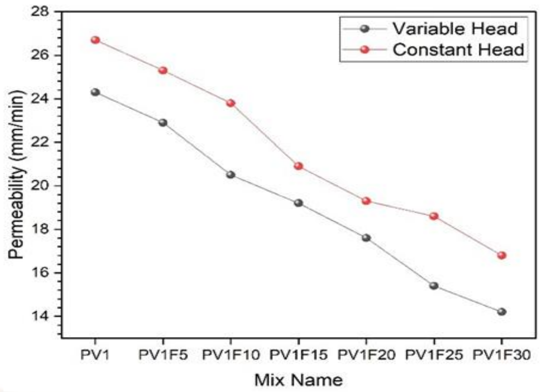

Fig.7 Permeabilty of PV3 mix

6. Conclusions

The following conclusions were drawn after conducting the mechanical and hydraulic test methods.

- The pervious concrete attained with 16-12mm coarse aggregate has the compressive strength of 16.24MPa, for 12-10mm aggregate pervious concrete has 16.93MPa, and 10-4.75mm aggregate concrete attained 17.58MPa. FA in the cement enhanced the compressive strength of about 13 to 18% in all the three mixes.
- The porosity of the pervious concrete with maximum size of aggregate showed the ultimate void contents in the concrete compared to the other two mixes. FA implicates the porosity in the reduction of voids by increasing the paste content.
- The hydraulic property interms of permeability of concrete using variable head method as well as constant head method were adopted. The maximum permeability was observed for the PV1 mix. The lowest was obtained for PV3 and moderate for thePV2 mix.
- The sustainable utilization of FA in the pervious concrete as a secondary cementitious material was feasible, which helps in the reduction of solid waste.

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