MECHANICAL AND DURABILITY STUDIES ON PERVIOUS CONCRETE USING DIFFERENT TYPES OF BINDERS

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This study deals with the evaluation of mechanical and durability studies on pervious concrete produced with Ordinary Portland Cement (OPC), Portland Pozzolana Cement (PPC) and FaL-G (Fly ash, Lime & Gypsum) as binder. This study was conducted at constant aggregate to binder ratio as 3.3 and water to binder ratio as 0.35 with aggregate size ranging from 6.3 mm to 12.5 mm. As a result of this, the mechanical properties of PPC binder pervious concrete results rate was reduced slightly from the conventional control mix OPC. Durability studies such as chemical resistance test and impact resistance test has been evaluated and it was found that significant improvement in chemical resistance was observed in PPC mix, whereas for impact resistance it is vice versa. As a final, this paper demonstrates an adequate mechanical and durability of pervious concrete with OPC, PPC binder and FaL-G binder for low traffic applications.

Keywords: *Pervious concrete, Binders, Wetability, Impact resistance, Durability*

1. Introduction

Pervious concrete is also known as porous concrete with high porosity and permeability because of its interconnected voids structure. Higher porosity in the concrete captures the storm water which would recharge ground water level. It is one of the most widely used materials by the concrete industry for providing storm water management, pollution control, noise control and sustainable design [1]. The increased awareness in pervious concrete is mainly due to the benefit of storm water management which leads in sustainable development. Typically, pervious concrete is suitable to be used in areas subjected to low traffic intensity and load. Apart from this, the general application of pervious concrete are pathways, drive ways, parking lots, sidewalks, tennis courts, decks in swimming pool, green house floors, zoo pathways and areas, shoulders, drains, noise barriers, friction course for highway pavements, permeable bases under normal concrete pavements and rain gardens [2].

The smaller amount of sand addition in the mix improves the mechanical and durability properties when subjected to low compaction. Furthermore, this mixtures favoured in improving admissible stresses up to +70% in tensile strength and +35% in stiffness [3]. The replacement of 50% fly ash in Portland cement results in decrement of compressive strength by 40% while it helps in reducing drying shrinkage [4]. It has been assessed that among surface abrasion test, loaded wheel abrasion test and cantabro tests loaded wheel method shows the better results in finding the abrasion resistance property of the specimens with best sensitivity [5]. Portland Pozzolana Cement is commonly known as PPC a pozzolanic material which has cementitious properties by itself when it is added to cement like material. In India, the abundantly available fly ash as pozzolanic material is the main constituent used in the production of PPC. The mixing of fly ash as pozzolanic material in the preparation of PPC should be between 15 to 35% [6]. The performance of FaL-G binder pervious concrete has been observed and concluded that FaL-G binder pervious concrete is suggested to be used in low traffic area conditions [7]. It is essential to maintain pervious concrete pavement in effective manner through periodic vaccum cleaning and pressure washing [8]. Intermixed and interpenetrated matrix structure developed by latex and cement hydration products improves the abrasion resistance of pervious concrete [9]. Aggregate with higher angularity number produces better permeability rather than other mixes [13]. Fly ash, Lime and Gypsum mixed in the ratio of 50:40:10 produced effective paste which results in enriched bonding between the aggregates. The critical literature review states that it is essential to produce pervious concrete with desired strength and durability by adopting optimizing mix design [14]. Nowadays numerous Supplementary Cementitious Materials (SCMs) are used in concrete to minimize the cement quantity and improves the properties [15]. Cement content between 350 kg/m^3 to 400 kg/m^3 seems to be optimum for producing pervious concrete with enough mechanical and permeability properties [16].

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2. Research objective

The objective of this study is to investigate the mechanical and durability properties of various parameters. The various parameters are binders and aggregate sizes with the same aggregate binder ratio and water binder ratio. The effect of these parameters on mechanical properties such as compressive strength, split tensile strength and flexural strength. Besides chemical resistance and impact resistance of all the mixes were also studied.

3. Materials

3.1 Cement

The cement OPC of 53 grade conforming to IS: 12269 - 2013 used for pure general purpose with 53 MPa in compressive strength was used. Portland Pozzolana Cement conforming to IS: 1489 (1) -1991 was procured locally from the market with compressive strength of 33 MPa.

3.2 Fly ash

To prepare FaL-G (Fly ash – Lime – Gypsum) binder pervious concrete, Fly ash of Class 'C' confirming to IS: 3812-2003 was obtained from Neyveli Lignite Corporation India Limited, Neyveli, India. The specific gravity of fly ash was found to be 2.62. The chemical properties were carried out in and the results are presented in Table 1.

3.3 Lime

Commercial 'A' grade lime confirming to IS: 712-1984 was procured from limestone quarry at Kangeyam, Tirupur district, India and the chemical properties are presented in Table 2.

3.4 Phospho Gypsum

Phospho Gypsum is the material which is obtained as a by-product from phospho fertilizer factory or fluoride industry. Phospho-gypsum used in this study was collected from Cuddalore, India. The chemical properties were carried out the results are presented in Table 3.

4. Mix proportion

In this study, twelve different concrete mixtures were prepared with four sizes of coarse aggregates. Pervious concrete mix named OPC was considered as conventional control mix and the results of the same are kept as bench mark for comparing the results with various binder pervious concrete. The designation OPC, PPC and Fg represents the mix made with Ordinary Portland Cement, Portland Pozzolana Cement (PPC) and FaL-G (Fly ash, Lime and Gypsum) and the suffix value indicated with respective mix ID represents the aggregate size which is used in the mix. By conducting various trial mixes, Aggregate to Binder ratio (A/B) and Water to Binder ratio (W/B) were maintained as 3.3 and 0.35 by weight basis

Table 1

Chemical properties of Fly ash - Class 'C'

S.No	Constituents	Test results (%)	Recommended values as per IS 3812-2013
1.	Silica (SiO_2)	34.55	Min.25%
2.	Iron oxide (Fe_2O_3)	4.02	-
3.	Calcium oxide (CaO)	15.25	-
4.	Magnesium oxide (MgO)	2.89	Max.5%
5.	Alumina as ($Al2O_3$+SiO_2)	30.22	Min.50
6.	Sulphate (SO_3)	2.85	Max.3%
7.	Sodium (Na_2O)	0.89	Max.1.5%
8.	Potassium (K_2O)	0.08	-
9.	Chloride (Cl-)	-	Max.0.05%
10.	Loss on Ignition (LOI)	3.85	Max.5%

Table 2

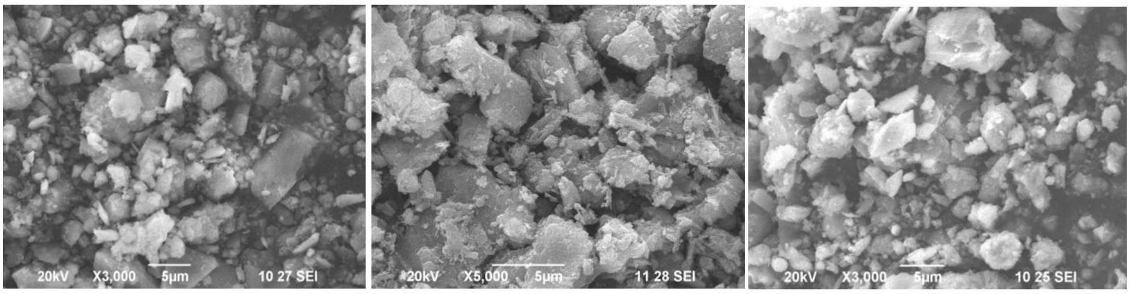
Chemical properties of lime

S. No	Constituents	Test results (%)	Recommended values as per IS 712-1984
1.	Magnesium oxide MgO	1.60	-
2.	SiO_2+ Al_2O_3	23.15	Min 23%
3.	CaO	63.72	Min 60%
4.	Loss on Ignition	3.65	-

Table 3

Chemical properties of Phospho Gypsum

S.No	Constituents	Test results (%)
1.	Alumina (Al_2O_3)	0.82
2.	Iron oxide (Fe_2O_3)	0.85
3.	Magnesium oxide (MgO)	1.08
4.	Sulphate (SO_3)	48.25
5.	Calcium oxide (CaO)	45.82
6.	Insoluble residue	0.4
7.	Loss on Ignition (LOI)	1.83



OPC mix **PPC mix** **Fg mix**

Figure 1 SEM analysis of various binders

Table 4

Mix proportion of various binder pervious concrete

S.No	Mix ID	Cement (kg/m^3)	Fly ash (kg/m^3)	Lime (kg/m^3)	Gypsum (kg/m^3)	Coarse Aggregate (kg/m^3)	Water (kg/m^3)	W/B ratio
1	$OPC_{6.3}$	475	-	-	-	1570	166.2	0.35
2	OPC_{8}	454	-	-	-	1500	158.9	
3	OPC_{10}	421	-	-	-	1390	147.3	
4	$OPC_{12.5}$	412	-	-	-	1360	144.2	
5	$PPC_{6.3}$	475	-	-	-	1570	166.2	0.35
6	PPC_{8}	454	-	-	-	1500	158.9	
7	PPC_{10}	421	-	-	-	1390	147.3	
8	$PPC_{12.5}$	412	-	-	-	1360	144.2	
9	$Fg_{6.3}$	-	237.5	190.0	47.5	1570	166.2	0.35
10	Fg_{8}	-	227.0	181.6	45.4	1500	158.9	
11	Fg_{10}	-	210.5	168.4	42.1	1390	147.3	
12	$Fg_{12.5}$	-	206.0	164.8	41.2	1360	144.2	

respectively for irrespective of all the mixes. To make FaL-G binder, Fly ash, Lime and Gypsum were mixed in ratio of 50:40:10 [12]. Mix proportions arrived for various mixes are presented in Table 4.

5. Experimental Results

5.1 Micro structural study on various binders

Micro structural study on various binder paste was carried out to study the hydration behaviour and presented in Figure 1. The SEM image of OPC binder mix shows the formation of C-S-H gel (fibrous shape) calcium hydroxide $Ca(OH)_2$ (plate shape) and rare presence of ettringite (needle shape) and thus improves the binding and hardening process of OPC blend and formation of dense surface coverage on the cement particles indicated that this paste has high degree of hydration.

Regardless of PPC mix , formation of C-S-H gel (fibrous shape) and calcium hydroxide $Ca(OH)_2$ (plate shape) is identified through SEM image. Moreover, unreacted fly ash particles are also present in the matrix thus slows down the hydration process at initial stage. Furthermore, SEM image of Fg mix reveals the ettringite formation and calcium sulpho aluminate hydrates which support the binding and hardening process for FaL-G blend.

5.2 Mechanical behaviour of various binder pervious concrete

Table 5 demonstrates hardened concrete test results at the age of 28 days. Compressive strength, Split tensile strength and Flexural strength results are presented with their standard deviations. Irrespective of all the aggregate sizes, pervious concrete produced with PPC mix followed by Fg mix have demonstrated lesser mechanical strength properties than conventional control mix OPC. Lower strength observed in PPC and Fg mix is due to low rate of hydration than OPC mix that slows down the improvement of strength at earlier ages. Furthermore, micro structural examination also reveals less amount of C-S-H gel formation in PPC and Fg mixes when compared to OPC mix.

In the case of aggregate size, increased specific surface area observed in smaller size aggregate promotes the binding property between the aggregate phases that results in higher strength properties. Higher the aggregate size would lead to decrease in mechanical strength property test results. Moreover, the graphical representation of hardened pervious concrete test results is represented in Figure 2-4. Furthermore, linear regression analysis have been found out for all the binders and incorporated in corresponding figures with R^2 values to know the best fit in curve.

Table 5

Mechanical properties of various binder pervious concrete

S. No	Mix Id	Compressive strength		Split tensile strength		Flexural strength	
		Mean	SD	Mean	SD	Mean	SD
1.	$OPC_{6.3}$	22.05	1.38	2.42	0.23	3.33	0.43
2.	OPC_{8}	19.53	2.03	2.14	0.24	3.12	0.26
3.	OPC_{10}	17.24	1.79	1.89	0.24	2.95	0.30
4.	$OPC_{12.5}$	14.05	1.28	1.54	0.18	2.63	0.36
5.	$PPC_{6.3}$	20.91	1.88	2.12	0.27	3.12	0.37
6.	PPC_{8}	18.46	2.37	1.89	0.27	3.01	0.33
7.	PPC_{10}	15.15	2.04	1.55	0.24	2.75	0.38
8.	$PPC_{12.5}$	11.65	1.57	1.29	0.13	2.39	0.29
9.	$Fg_{6.3}$	15.54	1.19	1.70	0.17	2.73	0.38
10.	Fg_{8}	12.42	1.24	1.42	0.20	2.45	0.29
11.	Fg_{10}	11.24	1.05	1.30	0.19	2.34	0.30
12.	$Fg_{12.5}$	10.45	1.22	1.23	0.20	2.14	0.31

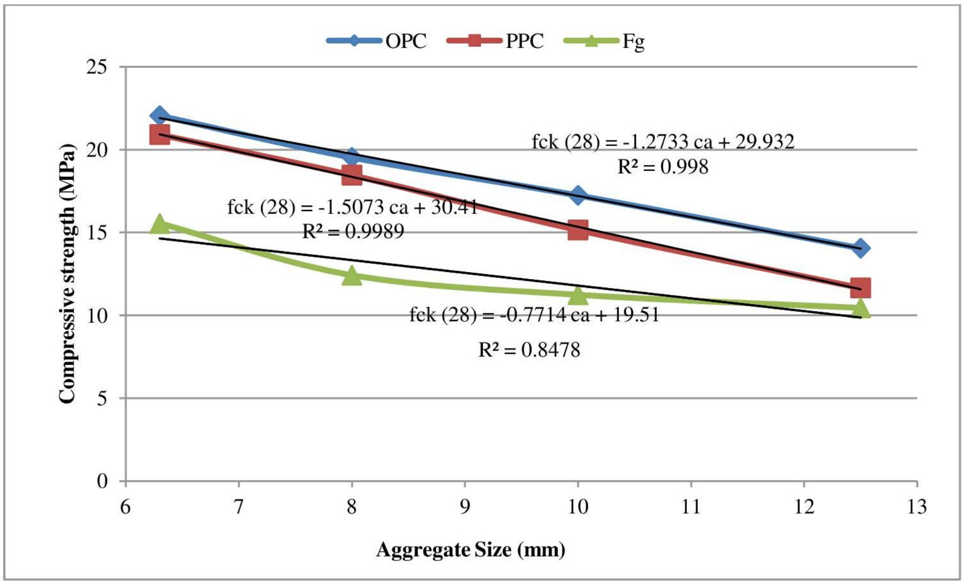


Figure 2 Compressive Strength of various binder pervious concrete

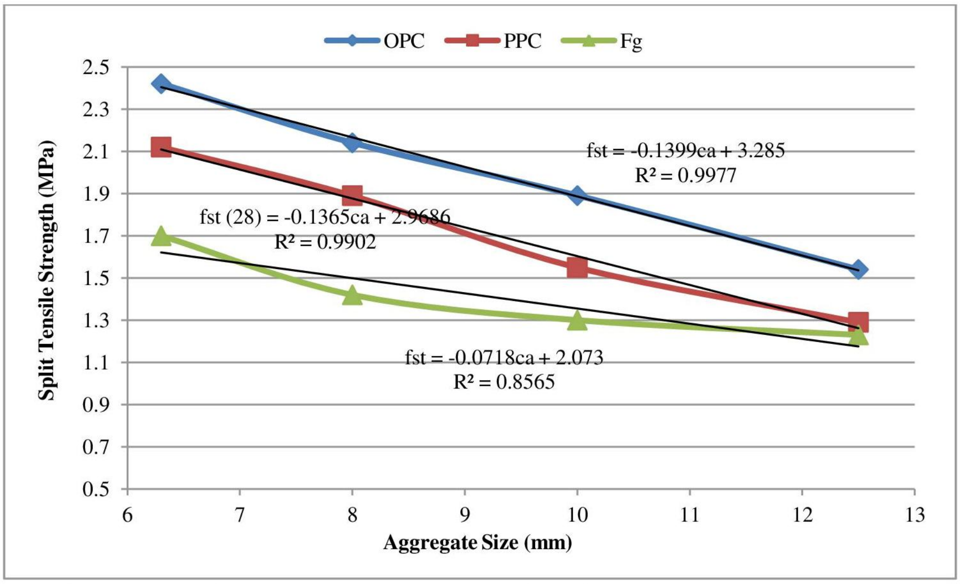


Figure 3 Split Tensile Strength of various binder pervious concrete

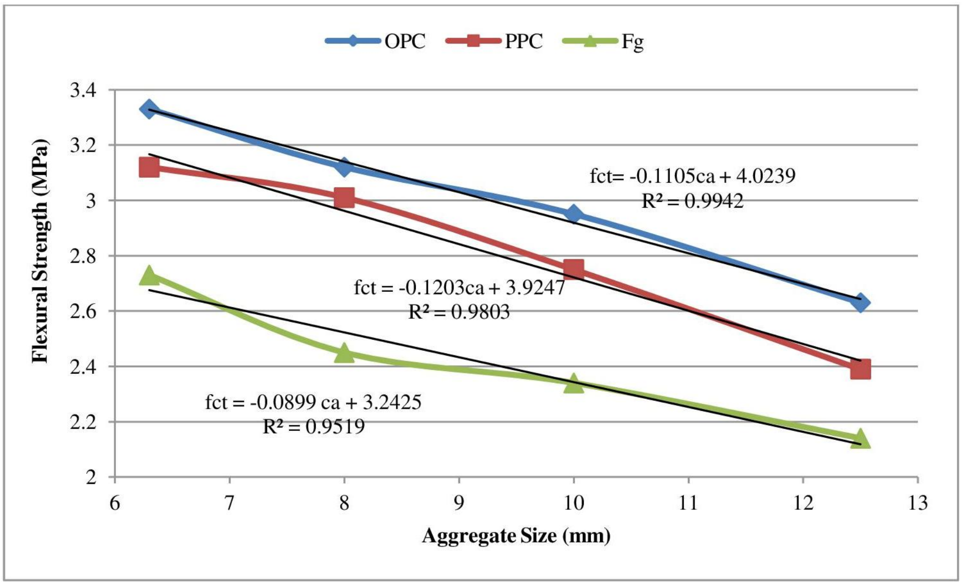


Figure 4 Flexural Strength of various binder pervious concrete

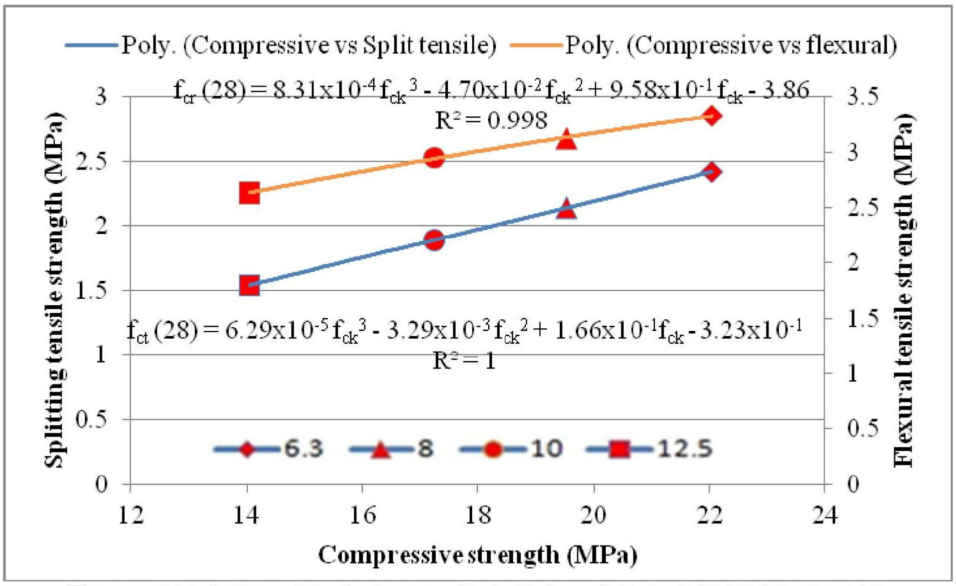


Figure 5 Relationship between 'f_{ck}', 'f_{ct}' and 'f_{cr}' of OPC binder PC

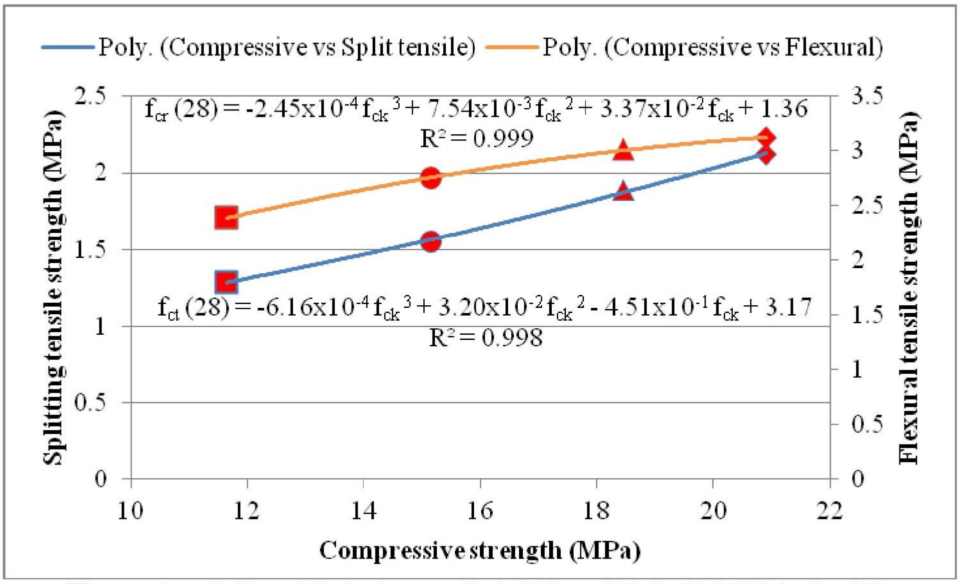


Figure 6 Relationship between 'f_{ck}', 'f_{ct}' and 'f_{cr}' of PPC binder PC

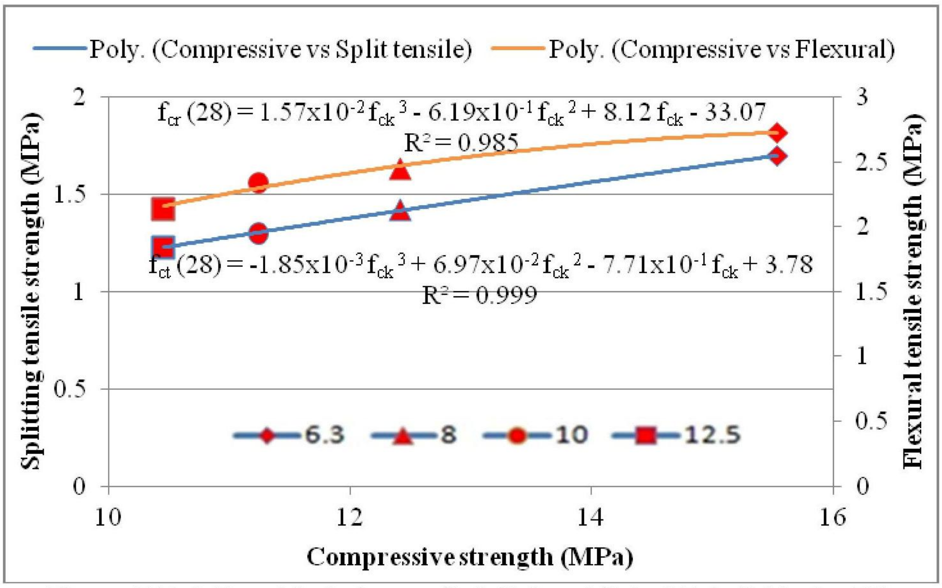


Figure 7 Relationship between 'f_{ck}', 'f_{ct}' and 'f_{cr}' of FaL-G binder PC

5.3 Relationship between mechanical properties of various binder pervious concrete

In order to understand the strength behaviour of OPC, PPC and FaL-G binder pervious concrete (PC), relationships among various mechanical properties were examined. From Figure 5-7 it was observed clearly that that compressive strength and splitting tensile strength, compressive strength and flexural tensile strength values of pervious concrete made with all the binders are closely related. Further, linear regression analysis have been found and incorporated in corresponding figures with R^2 values.

5.4 Chemical resistance of various binder pervious concrete

An attempt has been made to study the salt resistance, sulphate resistance and acid resistance of pervious concrete made of OPC, PPC and FaL-G binders. The specimens subjected to chemical attack solutions with 3.5% concentration of NaCl, 5% concentration of $MgSO_4$ and 2 % concentration of HCl were continuously monitored over a period of 28 days, 56 days, 90 days and 180 days. At every age, parameters such as visual observation, percentage of weight retention and residual compressive strength were observed at the age of 180 days and finally results are discussed elaborately.

5.4.1 Visual observation

During visual observation of NaCl exposed solutions, there is an occurrence of little blending at the sharp edges on the specimens. This happens because leaching of calcium compound from cement, fly ash and lime reacts with chloride ions which lead to crumbling. With respect to the colour change, there was no change in colour of the specimens when compared to the condition before it was soaked in NaCl solution.

In regard of Magnesium sulphate ($MgSO_4$) solution exposure white precipitation of salt appeared on the surface of the specimens for all the mixes. The white salt precipitation observed in OPC, PPC and Fg mixes is because of replacement of calcium by magnesium to form of Brucite (magnesium hydroxide) and magnesium hydroxide silicates. Formation of the above said compounds decays hydrated calcium silicates. The displaced calcium precipitates mainly as gypsum that forms whitish layer.

The visual sign of the specimens exposed to acid solution exhibits slight reddish colour formation on the surface of the specimens of all the mixes. This is due to the presence of iron content (Fe_2O_3) in fly ash and presence of free lime and iron content in the hydrated cement matrix. Further it was observed that sharp edges were blended after 180 days of exposure.

5.4.2 Percentage of weight retention

PPC mix exhibits better weight retention than the conventional control mix. In the case of PPC, soluble calcium hydroxide is converted to insoluble cementitious products resulting in reduced permeability to offer better resistance against aggressive water attack. Further it was noticed that Fg mix specimens possess substantial weight loss among all mixes. With respect to Fg mix, it was observed that FaL-G slurry has lesser interfacial bonding with the coarse aggregates due to inadequate wetability of the binder. So it possesses higher weight loss than other mixes. The graphical representation of test results is showed in Figure 8-10.

Regardless of aggregate size, larger size aggregate shows higher porosity and permeability and it makes a gateway for penetration of chloride,

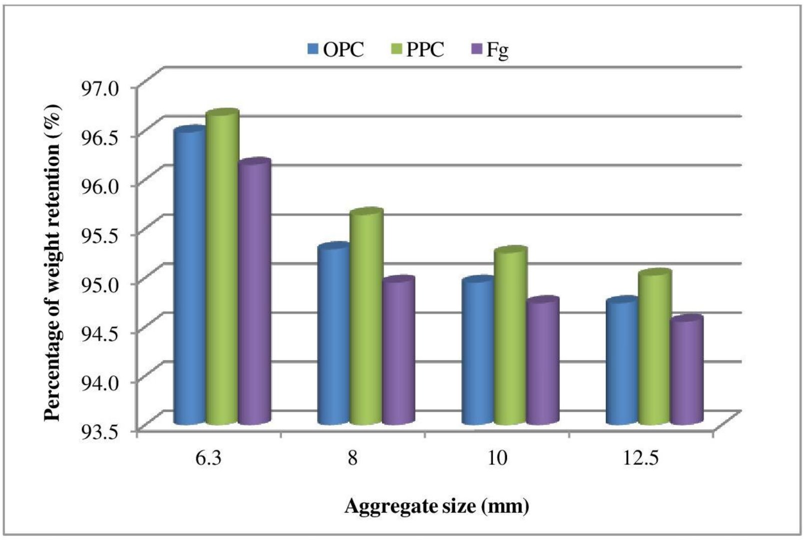


Figure 8 Percentage of weight retention on exposure to chloride attack

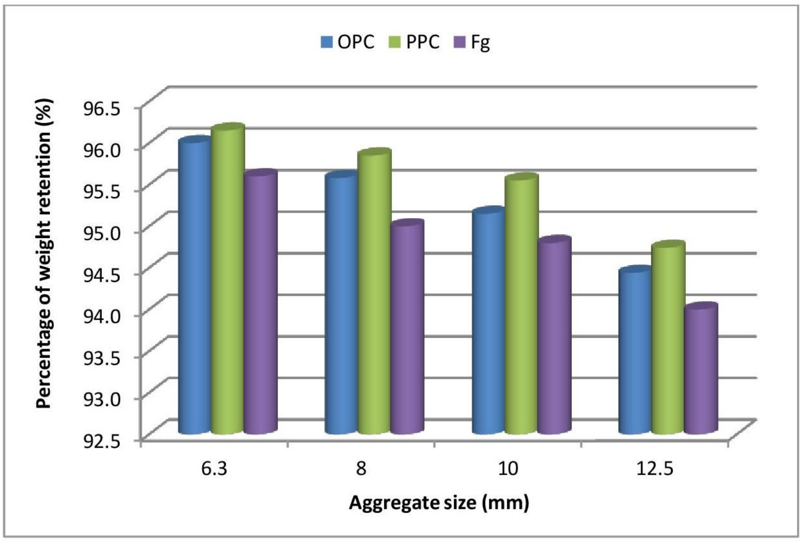


Figure 9 Percentage of weight retention on exposure to sulphate attack

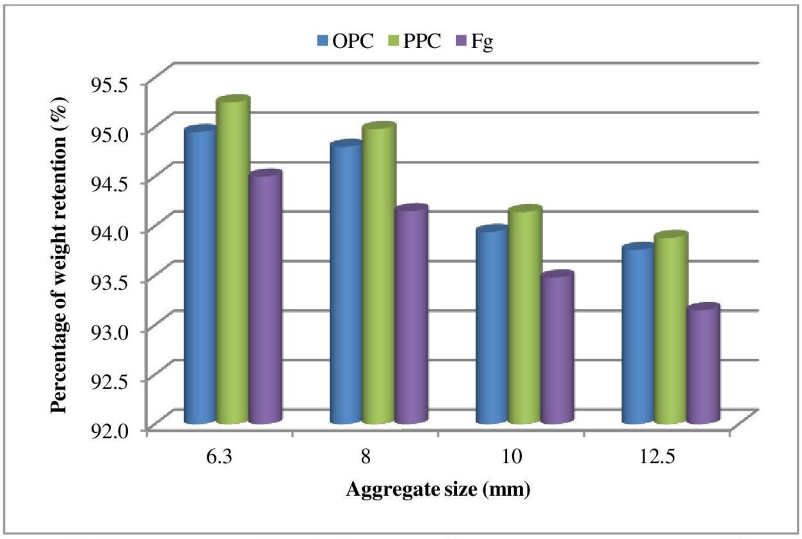


Figure 10 Percentage of weight retention on exposure to acid attack

sulphate and acid ions. So it shows higher weight loss in all the mixes.

5.4.3 Residual compressive strength

It is evident from the result that all the pervious concrete mix specimens exhibited the loss in compressive strength when exposed to NaCl solution. In the case of PPC mix, minimum loss of compressive strength was observed than the conventional control mix followed by Fg mix. At the age of 180 days immersion in NaCl solution, compressive strength loss observed in PPC mix prepared with 6.3 mm to 12.5 mm size aggregate was 2.55%, 4.23%, 4.85% and 5.15% respectively.

While making a comparative study on other mixes, the trend observed in chloride (salt) attack test is also noticed in sulphate attack test. While immersing in $MgSO_4$ solution, PPC mix prepared with 6.3 mm to 12.5 mm size aggregate showed 3.90%, 4.25%, 4.98% and 5.15% compressive strength loss. Strength degradation observed in all the specimens is due to dissolving of calcium and hydroxide ions from the cement matrix.

In the case of acid attack test the trend which is observed in chloride and sulphate attack test is seen clearly here. Specimens immersed in Hydrochloric acid (HCl) solution with aggregate size ranging from 6.3 mm to 12.5 mm have demonstrated in to 4.97%, 5.85%, 6.65% and 7.02% compressive strength loss.

5.5 Impact resistance of various binder pervious concrete

The impact resistance of the various binder pervious concrete was determined by using drop weight hammer test which is recommended by ACI committee 544.2 R-89 (Reapproved 1999). The impact strength test was determined at the age of 28 and 56 days respectively. To conduct this test, cylindrical specimen of size 150 mm diameter and 64 mm thickness was cast and the specimen was placed on the base plate and lugs were provided around the specimen to avoid slipping while subject to impact force [1]. The impact resistance energy is determined using Equation 1 and the schematic representation of test setup is shown in Figure 11.

$E_{imp} = N.m.g.h$ ----------- (1)

Where, E_{imp} - Impact Energy in J,
N - Number of blows,
m - Mass of drop hammer in kg,
$g = 9.81 m/s^2$,
h - Releasing height of drop hammer in m.

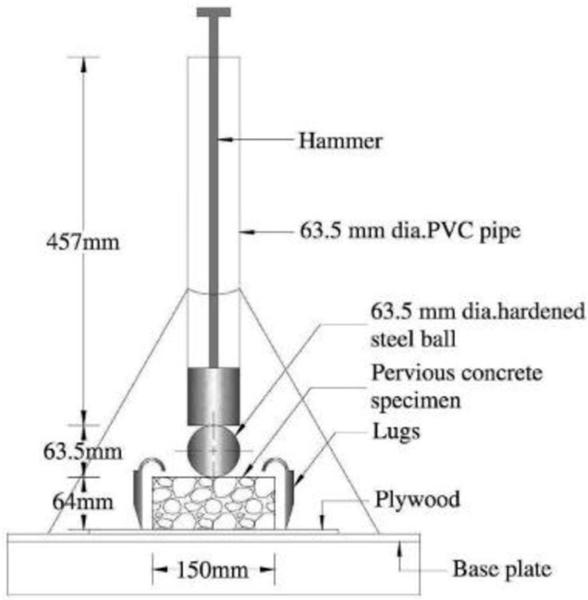


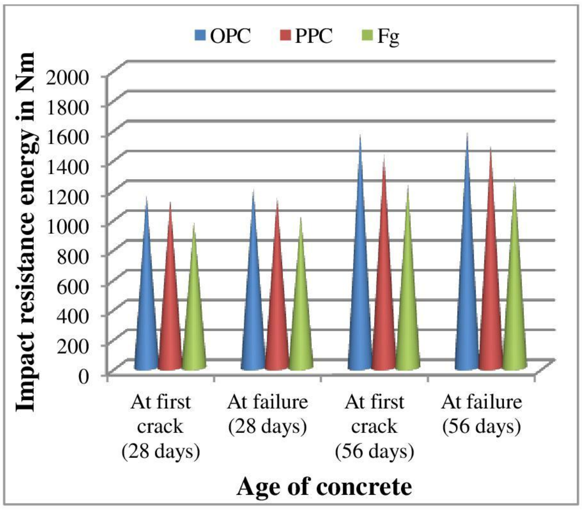
Figure 11 Impact strength test setup

The impact resistance energy of OPC, PPC and FaL-G binder pervious concrete specimens at 28th day and 56th day are presented in the Table 6 and graphically presented in the Figure 12 (a-d). $PPC_{6.3}$ has 6.4% decreased impact strength than $OPC_{6.3}$. 8.8% lesser impact strength was observed in PPC_8 mix specimens when compared to OPC_8 mix specimens. PPC_{10} mix is showing 8.1% lesser impact strength than conventional control mix OPC_{10}. Further $PPC_{12.5}$ mix has 10.5% decreased impact strength when compared to $OPC_{12.5}$ mix.

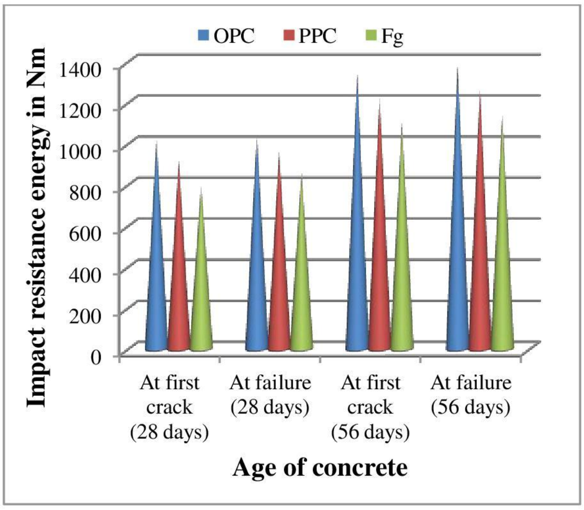
Table 6

Impact energy of different binder pervious concrete

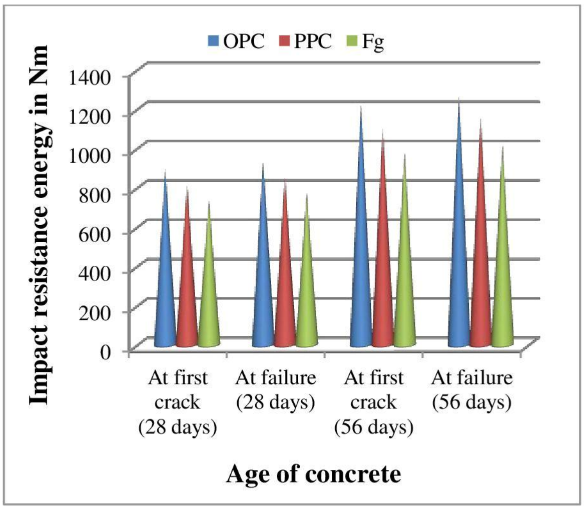
S. No	Mix ID	Number of blows (N)				Impact Energy (Nm)			
		28 days		56 days		28 days		56 days	
		First crack	Failure crack	First crack	Failure crack	First crack	Failure crack	First crack	Failure crack
1.	$OPC_{6.3}$	57	59	77	78	1160.15	1200.86	1567.23	1587.58
2.	OPC_8	50	51	66	68	1017.68	1038.03	1343.34	1384.04
3.	OPC_{10}	44	46	60	62	895.56	936.27	1221.22	1261.92
4.	$OPC_{12.5}$	40	41	55	57	814.14	834.50	1119.45	1160.15
9.	$PPC_{6.3}$	55	56	70	73	1119.45	1139.80	1424.75	1485.81
10.	PPC_8	45	47	60	62	915.91	956.62	1221.22	1261.92
11.	PPC_{10}	40	42	54	57	814.14	854.85	1099.09	1160.15
12.	$PPC_{12.5}$	35	37	49	51	712.38	753.08	997.33	1038.03
13.	$Fg_{6.3}$	48	50	60	63	976.97	1017.68	1221.22	1282.28
14.	Fg_8	39	42	54	56	793.79	854.85	1099.09	1139.80
15.	Fg_{10}	36	38	48	50	732.73	773.44	976.97	1017.68
16.	$Fg_{12.5}$	32	34	44	46	651.31	692.02	895.56	936.27



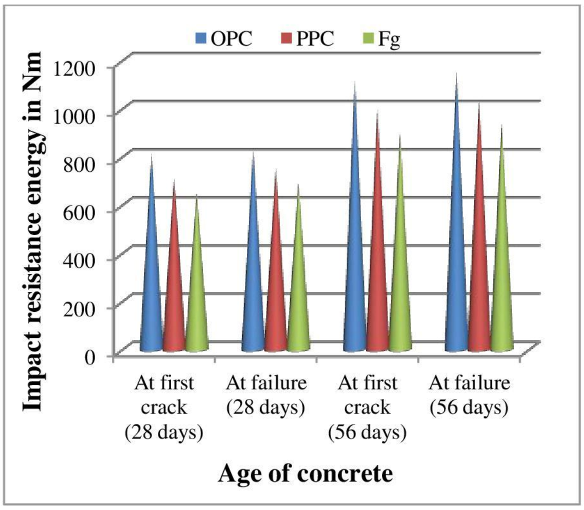
(a) 6.3 mm size aggregate



(b) 8 mm size aggregate



(c) 10 mm size aggregate



(d) 12.5 mm size aggregate

Figure 12 (a-d) Impact energy of different binder pervious concrete

With respect to Fg mix, $Fg_{6.3}$, Fg_8, Fg_{10} and $Fg_{12.5}$ mix specimens show 19.2%, 17.6%, 19.4% and 19.3% decreased impact strength values when compared to respective aggregate size conventional concrete mix OPC. Further it was observed that PPC mix specimen shows lesser impact resistance than conventional control mix followed by Fg mix. It is worth noticing that impact strength results are directly related to the compressive strength property. When compressive strength property decreases it leads to decrease in impact strength property values.

Regardless of aggregate size, when the size of aggregate increases it leads to decrease in impact strength values where the trend resembled mechanical property results.

6. Research Impact

The implementation of pervious concrete in various elements such as pedestrian pathways, sidewalks, parking lots etc. has the following impacts that would helps in sustainable construction.

1. Recharging groundwater in urban dense area without excavating the soil.
2. Effectual storm water runoff management.
3. Reduced contamination in waterways.
4. Minimized noise emissions caused by tyre – pavement interaction.
5. Abundant land use by neglecting need for maintenance of ponds and swales.

7. Conclusions

The Mechanical properties such as compressive strength, Split tensile strength, Flexural strength, Durability studies such as Salt resistance, Sulphate resistance, Acid resistance and Impact resistance of OPC, PPC and FaL-G binder pervious concrete were examined in the present study. From the test results, the following conclusions can be drawn.

1. Compressive strength of PPC mix with aggregate size ranging from 6.3 mm to 12.5 mm have demonstrated 5.2% ,5.5%, 12.1% and 17.1% lesser compressive strength when compared to respective aggregate size conventional control mix

OPC. This can be attributed to the fact that PPC mix has low rate of hydration than OPC mix that slows down the improvement of strength at earlier ages.

2. Less degree of hydration observed in FaL-G binder mix reduces the binding property between the aggregate phases and thus indirectly decreases the strength property of the concrete.

3. It was noticed that Fg_8 mix has 36.4% lesser compressive strength when compared to OPC_8 mix. Fg_{10} mix has 34.9% lesser compressive strength than conventional control mix OPC_{10}. Further, 25.7% lesser compressive strength was observed in $Fg_{12.5}$ mix than $OPC_{12.5}$ mix.

4. Further, it was worth noting that pervious concrete made with PPC binder exhibited better performance against chemical attack than conventional control mix OPC binder followed by FaL-G binder.

5. In the case of PPC mix, soluble calcium hydroxide is converted to insoluble cementitious products resulting in reduced permeability to offer better resistance against aggressive water attack.

6. The pervious concrete mix made of OPC binder relatively showed better impact resistance than PPC mix followed by Fg mixes respectively. Better impact resistance under impact load because of its higher compressive strength.

7. It is evident from the test results that pervious concrete made with OPC, PPC and FaL-G binders showed better resistance against durability with adequate strength properties laid down by codal provisions.

8. The implementation of pervious concrete can be done by building elements such as pedestrian pathways, sidewalks, parking lots and areas with medium traffic flow.

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