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Compressive Strength and Performance Evaluation of Pervious Concrete with Various Binders

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Abstract

This study investigates the compressive strength of pervious concrete, focusing on the effects of various mix designs and material variations. The analysis of experimental results showed that the optimal mix, with a water-cement ratio of 0.29 and a binder content of 250 kg/m³, produced a compressive strength of 17.9 MPa. In comparison, mixes with higher water-cement ratios (ranging from 0.30 to 0.40) exhibited lower compressive strengths, with values decreasing to 10.6 MPa. The use of angular aggregates led to superior strength, with a compressive strength of 14.2 MPa observed, while rounded aggregates resulted in a lower strength of 9.3 MPa. Additionally, lower binder content (less than 200 kg/m³) significantly reduced compressive strength, with values dropping below 8.0 MPa. The findings emphasize the importance of selecting appropriate water-cement ratios, binder content, and aggregate characteristics to achieve optimal compressive strength in pervious concrete. These results also highlight the potential for pervious concrete to be effectively utilized in sustainable construction, offering a balance between structural strength and permeability for diverse applications.

Keywords: Pervious concrete, ordinary portland cement (OPaC), Portland Pozzolana Cement (PPC), Fly Ash-based Geopolymer (GP), Fly Ash-Lime-Gypsum (FaL-G), compressive strength, splitting tensile strength, flexural tensile strength, aggregate size, sustainable construction

INTRODUCTION

Pervious concrete is a type of concrete that consists of cement, coarse aggregates, and water, without the inclusion of fine aggregates, which is why it is often referred to as "no fines" concrete. It is also known by other terms such as gap-graded concrete, porous concrete, or permeable concrete. The material features a network of interconnected pores ranging in size from 2 mm to 8 mm, with void content typically varying between 15% and 25%. The compressive strength of pervious concrete generally falls within the range of 2.8 MPa to 28 MPa, with strengths between 2.8 MPa and 10 MPa being most common [1-8].

The rate at which water penetrates pervious concrete pavements ranges from 81 liters per minute per square meter (lit/min/sq.m) to 730 lit/min/sq.m, depending on factors such as aggregate size and the density of the mixture. This type of concrete offers a groundbreaking solution for managing stormwater runoff. When used in pavements, it effectively captures and allows stormwater to percolate into the ground, thus reducing pollutants and aiding in the recharge of groundwater tables [9-14].

Objectives

- To investigate the compressive strength of pervious concrete using different binders: Ordinary

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Portland Cement (OPC), Portland Pozzolana Cement (PPC), Fly Ash-based Geopolymer (GP), and Fly Ash-Lime-Gypsum (FaL-G).
- To examine the effect of different aggregate sizes (6.3 mm, 8 mm, 10 mm, and 12.5 mm) on the performance of pervious concrete.
- To compare the mechanical performance of pervious concrete mixes based on OPC, PPC, GP, and FaL-G binders at different curing ages (7, 28, and 56 days).

Material

Ordinary portland cement (OPC): Ordinary Portland Cement (OPC) of 53 grade, conforming to IS: 12269-2013, was sourced from the local market. Its physical and chemical properties were evaluated in accordance with the procedures outlined in IS: 4031-1988. Fly Ash (Class 'F')

Class 'F' fly ash, conforming to IS: 3812-2013, was obtained from Mandideep, Madhya Pradesh, India, for use in preparing fly ash-based geopolymer pervious concrete. The specific gravity of the fly ash was determined to be 2.30. Its chemical properties were analyzed as per IS: 1727-1967[15-19]

Alkaline liquids (AL): To prepare the alkaline solutions required for geopolymer concrete, sodium hydroxide in flake form and sodium silicate solution were procured from local distributor of Bhopal, Madhya Pradesh, India.

Sodium hydroxide (NaOH): Sodium hydroxide solution (SHS) is the primary alkali used in producing fly ash-based geopolymer concrete. In this study, an 8M concentration of SHS was utilized to produce geopolymer pervious concrete. The solution was prepared by dissolving sodium hydroxide flakes[20-24]

Sodium silicate (Na_2SiO_3): Sodium silicate, also known as water glass or liquid glass, was procured in its translucent liquid form from chemical suppliers. Its reactivity varies depending on its mixing ratio with sodium hydroxide (NaOH), referred to as the liquid ratio [25-29].

Portland pozzolana cement (PPC): Portland Pozzolana Cement (PPC), conforming to IS: 1489 (Part 1)-1991 (Reaffirmed 2014), was sourced from the local market. Its physical and chemical properties were evaluated according to IS: 4031-1988[26-29]

Fly ash (Fa)class 'C': Class 'C' fly ash, conforming to IS: 3812-2013, was obtained from Mandideep, Madhya Pradesh, India, for the preparation of FaL-G binder pervious concrete. The specific gravity of the fly ash was measured as 2.62. Its chemical properties were analyzed according to IS: 1727-1967[30-31]

Lime (L): Commercial "A" grade lime, conforming to IS: 712-1984, was sourced from a limestone quarry in Bhopal District, India. Quicklime was produced by hydrating lime powder with water, resulting in hydrated lime.

Phosphogypsum (Gypsum - G): Phosphogypsum, is a by-product obtained from phosphate fertilizer plants or fluoride industries. Unlike lime, phosphogypsum does not require hydration for its use.

Coarse aggregate: The coarse aggregate used in this study consisted of naturally available crushed blue granite metal, with sizes ranging from 6.3 mm to 12.5 mm, as recommended by ACI 522 R-10. These aggregates were procured locally from APAT Services.

Water: Water, a crucial component in concrete mixing, facilitates chemical reactions with binders, leading to concrete hardening. Potable water conforming to IS 456-2000 standards was used in the study [32-35].

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RESULTS

The compressive strength test results for pervious concrete incorporating Ordinary Portland Cement (OPC), fly ash-based geopolymer (GP), Portland Pozzolana Cement (PPC), and Fly Ash-Lime-Gypsum (FaL-G) binders are provided in Tables 1, 2, and 3. The graphical representations of these results are depicted in Figures 1, 2, and 3.

Table 1. Compressive Strength of Pervious Concrete with Fly Ash-Based GP Binder.

S.N.	Designation	Compressive strength		
		7 Days	***28 Days***	***56 Days***
1	OPC-6.3	17.89	23.15	24.70
2	OPC-8	14.96	20.51	22.29
3	OPC-10	12.13	18.10	19.55
4	OPC-12.5	10.00	14.75	16.62
5	GP-6.3	21.79	25.15	26.38
6	GP-8	19.31	22.33	23.92
7	GP-10	17.00	19.87	21.26
8	GP-12.5	15.38	17.59	18.72

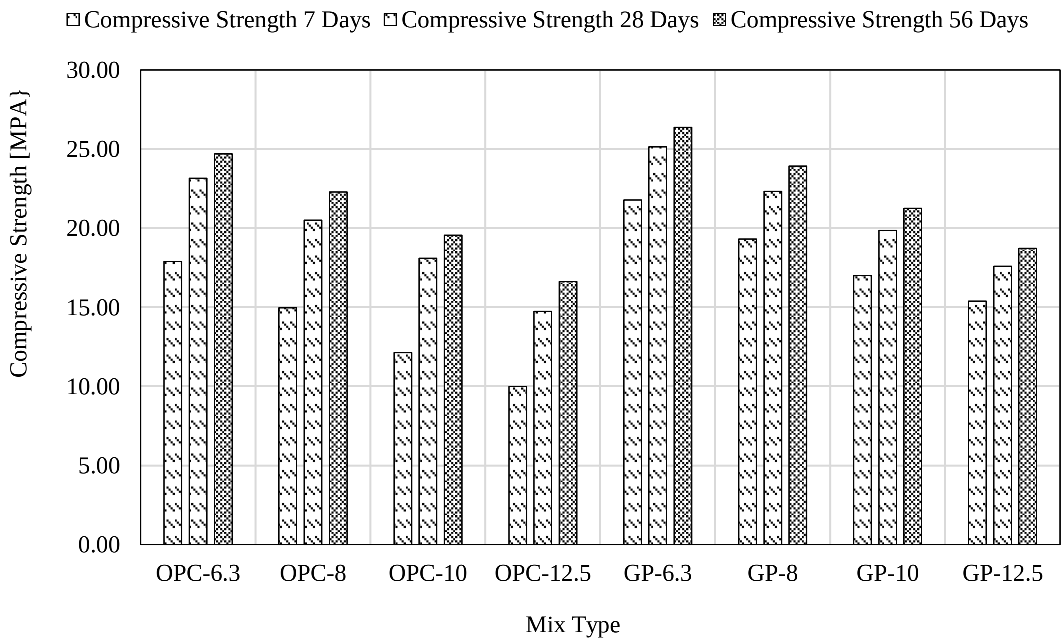

Figure 1. Comparative analysis of OPC and GP binders with aggregate size dependency.

GP-based mixes outperform OPC in compressive strength across all curing periods and aggregate sizes. The improved matrix and enhanced reactivity of geopolymer binders contribute to this superior performance. Smaller aggregate sizes (6.3 mm and 8 mm) consistently yield higher compressive strength for both OPC and GP binders, making them preferable for applications requiring higher compressive strength.

Over time, PPC demonstrates a slightly slower rate of strength gain compared to OPC. For example, PPC-6.3 shows a 52.7% strength gain from 7 to 56 days, compared to OPC-6.3's 38.1%. This reflects the pozzolanic reaction in PPC, which enhances long-term strength while contributing less to early-age strength

Table 2. Compressive Strength of Pervious Concrete with PPC Binder.

S.N.	Designation	Compressive strength		
		7 Days	***28 Days***	***56 Days***
1	OPC-6.3	17.89	23.15	24.70
2	OPC-8	14.96	20.51	22.29
3	OPC-10	12.13	18.10	19.55
4	OPC-12.5	10.00	14.75	16.62
5	PPC-6.3	15.14	21.96	23.12
6	PPC-8	13.29	19.38	20.51
7	PPC-10	11.50	15.91	18.41
8	PPC12.5	8.55	12.23	14.13

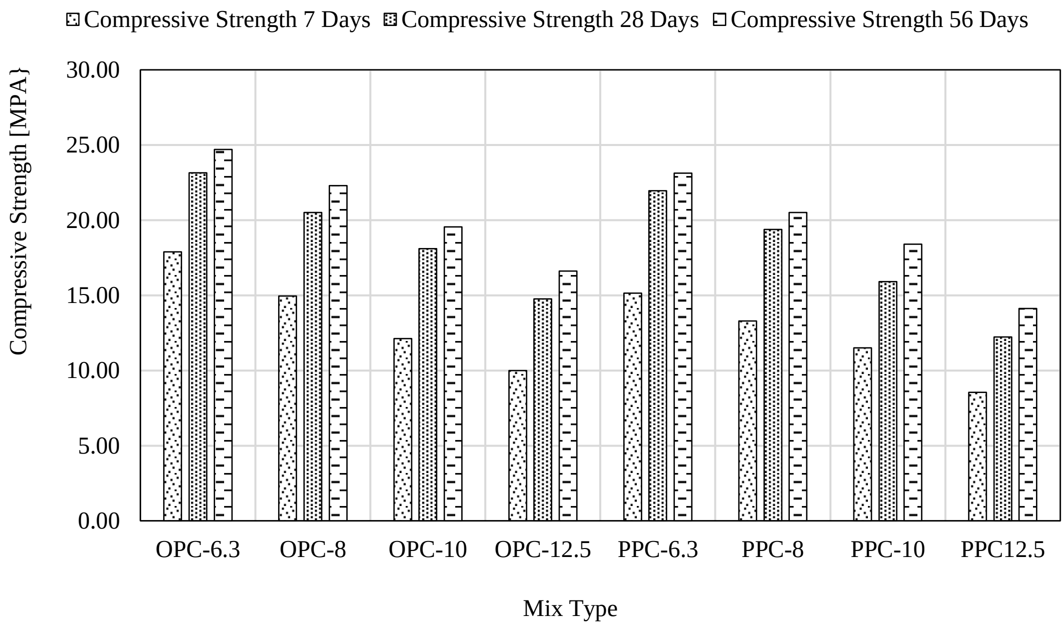

Figure 2. Comparative Analysis of OPC and PPC Binders with Aggregate Size Dependency.

Table 3. Compressive Strength of Pervious Concrete with FaL-G Binder.

S.N.	Designation	Compressive strength		
		7 Days	***28 Days***	***56 Days***
1	OPC-6.3	17.89	23.15	24.70
2	OPC-8	14.96	20.51	22.29
3	OPC-10	12.13	18.10	19.55
4	OPC-12.5	10.00	14.75	16.62
5	Fg-6.3	9.08	16.32	17.14
6	Fg-8	8.33	13.04	13.99
7	Fg-10	7.19	11.80	12.85
8	Fg-12.5	6.12	10.97	11.99

FaL-G binder exhibits slower strength development compared to OPC. For instance, FaL-G-6.3 shows an 88.8% strength gain from 7 to 56 days, whereas OPC-6.3 gains 38%. This indicates that FaL-G's hydration process and chemical reactions significantly contribute to its strength over extended curing periods but are less effective in early-age strength development.

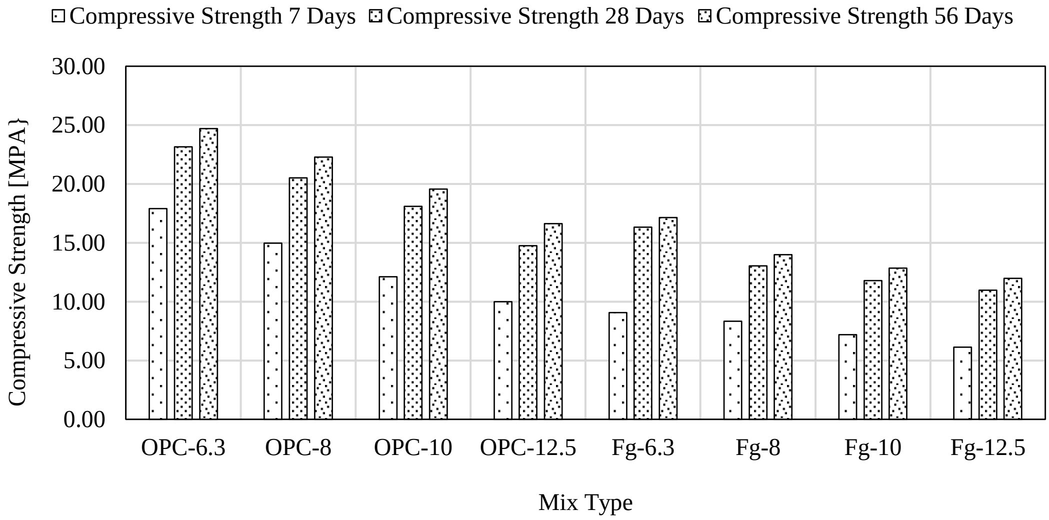

Figure 3. Comparative analysis of OPC and Fg Binders with aggregate Size dependency.

CONCLUSIONS

The work focused on evaluating the compressive strength of pervious concrete made with different binders (OPC, PPC, GP, and FaL-G) and varying aggregate sizes (6.3 mm, 8 mm, 10 mm, 12.5 mm).

Compressive Strength

- The highest compressive strength was observed for OPC-based pervious concrete with a value of 24.70 MPa at 56 days for the 6.3 mm aggregate size.
- The GP-based pervious concrete showed significant strength, with a peak compressive strength of 26.38 MPa at 56 days for the 6.3 mm aggregate size.
- PPC-based concrete exhibited lower compressive strength, with the maximum value being 23.12 MPa at 56 days for 6.3 mm aggregates.
- FaL-G-based concrete had the lowest compressive strength, reaching 17.14 MPa at 56 days for 6.3 mm aggregates.

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