Study On Porous Concrete Using Fly Ash As A Partial Replacement For Cement

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Abstract: : In this study, porous concrete mixes with varying proportions of aggregate, cement, and fly ash were prepared to identify the mix design that provides improved compressive strength. The research focuses on evaluating the effect of fly ash on both the compressive strength and permeability of pervious concrete. Materials used in this investigation were selected based on a detailed literature review and recommendations from local sources. Unconfined compressive strength tests were conducted on porous concrete specimens incorporating fly ash at 0%, 10%, 20%, and 30% replacement levels by weight of total cementitious materials. In addition, infiltration rate tests were performed to assess permeability. The outcomes of this study contribute to understanding how fly ash influences the mechanical and hydraulic performance of porous concrete. The results indicated the porous concrete containing 20% fly ash can achieve compressive strength greater than 15 N/mm2, and a compressive strength 14.43 N/mm2 with a infiltration rate of 0.651 cm/sec. The porous concrete with 30% fly ash had a compressive strength of 8.84 N/mm2 and the infiltration rate of 0.626 cm/sec. The failure surfaces of specimens with 20% fly ash developed through the coarse aggregates, indicating the high strength of cement bonds. The failure of specimens containing 30% fly ash was observed to be along the coarse aggregate's surfaces, indicating a lower strength of the paste. Although it was expected for porous concrete with 30% fly ash to reach a higher compressive strength at lower void content, the failure mode indicated that it may not reach the value as high as that of porous concrete with 20% fly ash.

Index Terms -: Porous concrete, Flyash, Mechanical properties, permeability

I. Introduction

Porous concrete, sometimes known as pervious or no-fines concrete, is a cutting-edge building material created to solve issues with sustainable pavement systems and stormwater management [1-2]. The linked void structure of porous concrete, in contrast to normal concrete, permits water to enter the material immediately [3]. Because of this unique characteristic, it is ideal for uses including parking lots, walkways, low-traffic roadways, and groundwater recharge systems [4]. One of the main drawbacks of porous concrete, despite its advantages for the environment, is its relatively low compressive strength, which limits its utilization in high-load or structural pavement applications [4-5]. To overcome this limitation, supplementary cementitious materials (SCMs) such as fly ash have gained significant attention in recent years [5]. Fly ash, a by-product generated from coal combustion in thermal power plants, exhibits pozzolanic properties that can enhance the performance of concrete [6]. When partially replacing cement, fly ash contributes to improved workability, long-term strength development, and durability while simultaneously reducing the carbon footprint of cement production. Several studies have demonstrated the potential of fly ash to enhance the microstructure and mechanical properties of conventional concrete; however, its influence on porous concrete requires further systematic investigation [7-8]. In addition to supporting sustainable building objectives, the use of fly ash in porous concrete may help solve the dual problems of managing solid waste and lowering cement usage. It might be able to increase compressive strength without sacrificing permeability, a crucial functional need of porous concrete systems, by adjusting the fly ash content [9]. The purpose of this study is to investigate how the mechanical and hydraulic characteristics of porous concrete are affected when fly ash is used in place of some of the cement [10]. Finding the ideal fly ash replacement levels that improve compressive strength while preserving sufficient infiltration capacity is the major goal of the study [11]. It is anticipated that the results of this study will aid in the creation of porous concrete combinations that are more resilient, sustainable, and effective [12-14].

Pervious concrete has been used in a wide range of applications including: greenhouse floors, structural wall applications, surface course for parks and tennis courts, floor for zoo areas and animal barns, bridge embankments, swimming pool decks, beach structures, sea walls, sewage treatment plant sludge beds, solar energy storage systems, slope stabilization and rigid drainage layers under exterior mall areas [15-17]. Pervious concrete has been used as a surface course for parking lots and minor road strips, drainable base or sub base material and roadway surface or friction course, permeable bases and edge drain, shoulder and sidewalks [19].

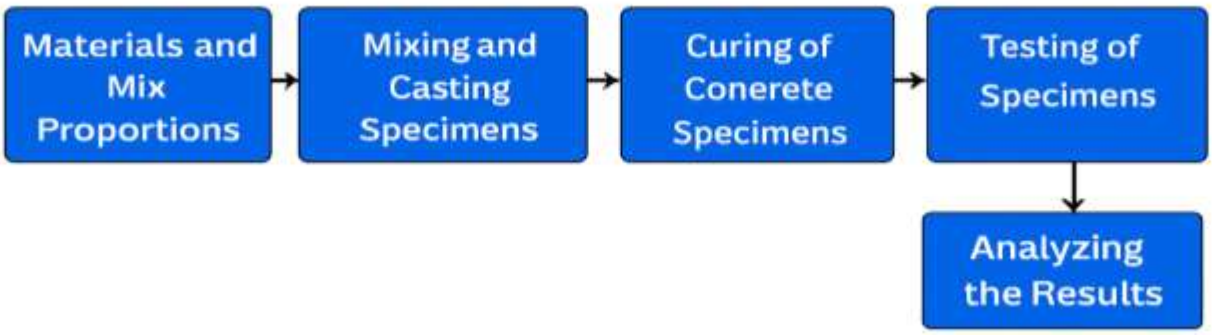
Figure.1 Typical Parous concrete

II. OBJECTIVE OF THE STUDY

The objective of this research is to investigate the effects on the important engineering properties of pervious concrete with the use of fly ash. The physical properties examined include compressive strength and permeability of porous concrete. The parameters that affect the strength and the hydraulic conductivity of porous concrete will be analysed. The potential use of porous concrete containing a large portion of fly ash will also be discussed.

1. To assess the impact on the characteristics of porous concrete by substituting fly ash for cement at different percentages (up to 30%).
2. To examine the permeability and compressive strength properties of porous concrete with varying fly ash replacement percentages.
3. To determine and suggest, using data from experiments and analysis, the ideal mix ratio that offers a balanced increase in strength and permeability.

III. METHODOLOGY



IV. RESEARCH SIGNIFICANCE

This work is important because it encourages the use of fly ash in place of some of the cement in porous concrete, so promoting sustainable construction. Cements replacement cuts CO2 emissions, lowers material costs, and efficiently uses an industrial waste product. Because porous concrete lowers surface runoff and permit rainfall infiltration, the research also contributes to better urban stormwater management. The study determines the ideal replacement levels that strike a balance between mechanical performance and high porosity by assessing the effects of fly ash on strength, permeability, and durability. The results will encourage wider adoption of low-carbon, resource-efficient concrete technologies and offer useful mix design guidelines for environmentally friendly permeable pavements.

V. EXPERIMENTAL PROGRAM

In the experimental program, fly ash is used to partially substitute cement in porous concrete mixtures at percentages of 0%, 10%, 20%, and 30%. OPC cement, Class F fly ash, single-sized coarse aggregates, water, and admixtures as needed are among the components utilized. Standard cube specimens are cast for each mix to measure compressive strength at 3,7 and 28 days, and cylindrical or slab specimens are made using ASTM C1701/C1781 procedures to assess permeability. At 28 days, tests for porosity, unit weight, and water absorption are carried out using conventional gravimetric techniques. Following air or moist curing in accordance with pervious concrete rules, all mixes are cast with controlled compaction to preserve the required void content. Strength and permeability test data are examined to ascertain.

VI. MATERIAL PROPERTIES

1. Flyash:

The residue from burning coal, known as fly ash, is frequently utilized as a component of cement. Both the environment and the cement itself benefit from it. It is easier to work with the cement because of its little, spherical chunks. Additionally, by using less cement, carbon dioxide emissions are reduced and the finished product is strengthened and prolonged. Fly ash improves the mix's flow, strengthens the concrete's cohesiveness, and reduces the number of holes in the mixture.

This has an impact on its strength and water-permeability. For a satisfactory mix, fly ash is often used in place of around 30% of the cement. Depending on the type of coal (bituminous, sub bituminous, or lignite), fly ash comprises a variety of oxides with different amounts. The following are the main chemical components:

Table-1 Typical chemical components of flyash

Chemical Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O)	K_2O	LOI
Percentage	15–60%	5–35%	4–15%	1–40%	0–10%	0–10%	0–6%	0–4%	0–15%

1. Cement:

In this study, 43-grade Ordinary Portland Cement (OPC) of the UltraTech brand was used as the main binder in this investigation. In accordance with IS 12269:1987, the cement's quality was assessed using tests for compressive strength, soundness, and fineness. These common tests were carried out to make sure the cement fulfilled the necessary performance standards and to determine whether it was appropriate for use in the experimental concrete mixtures. These tests' outcomes gave the research a solid foundation for accuracy and consistency.

Table-2 Test results of cement

Properties	Test Results	IS code
Fineness (dry sieving)	3.7	IS 4031 (Part 1)
Standard consistency	32%	IS 4031 (Part 4)
Initial & final setting time	64min & 236 min	IS 4031 (Part 5)
Soundness test (Le Chatelier)	4.3mm	IS 4031 (Part 3)

Figure-2 Cement test set up

2. Coarse aggregate:

In this study, 20 mm nominal size of coarse aggregate was used to make porous concrete. The IS 383 recommendations were followed in the selection of aggregates to guarantee proper grading, strength, and compaction properties for the experimental mix. Following are the test values used in the study.

Table-3 Test results of CA

Properties	Test Results	IS code
Specific Gravity	2.67	IS 2386 (Part III): 1963
Water absorption	1.3%	IS 2386 (Part III): 1963
Aggregate impact value	16.56%	IS 2386 (Part IV): 1963
Aggregate crushing value	20.52	IS 2386 (Part IV): 1963
Fineness modulus	2%	IS 2386 (Part I): 1963

Figure-3 Aggregate test setup

VII. Mix design:

There is no special codal provision available for porous concrete mix design, and it does not adhere to the traditional mix proportioning methods used for normal concrete." As a result, the mix proportion used in this investigation was developed after a thorough analysis of earlier research. The chosen mix ratio for porous concrete was Cement: Coarse Aggregate: Water/Cement 1: 4: 0.3, taking into account the suggestions from earlier studies. It was discovered that this ratio was appropriate for obtaining the necessary permeability and structural performance for the experimental study.

Table-3 Mix design of porous concrete

% Replacement	Water cement ratio	Cement (kg)	Fly ash (kg)	Coarse aggregates (kg)	Water content (ltr)	Plasticizer (2%) (Kg)
0	0.3	30.482	0	121.94	9.136	0.609
10	0.3	27.433	3.04	121.94	9.136	0.609
20	0.3	24.385	6.09	121.94	9.136	0.609
30	0.3	21.337	9.14	121.94	9.136	0.609

VIII. Results and Discussion

1. Compressive strength

Standard cube specimens measuring 150 × 150 × 150 mm were used to test porous concrete's compressive strength in compliance with IS 516:1959. Porous concrete usually has a lower cube strength than conventional concrete because of its high interconnected void content; the measured values are determined by aggregate interlock, paste content, and pore structure.

Fly Ash Replacement (%)	7 Day's Average Compressive strength (Mpa)	14 Day's Average Compressive strength (Mpa)	28 Day's Average Compressive strength (Mpa)
0	11.07	13.39	17.91
10	11.07	12.91	8.48
20	11.60	14.2	14.43
30	7.13	8.78	8.84

Table-3 Compressive strength of porous concrete

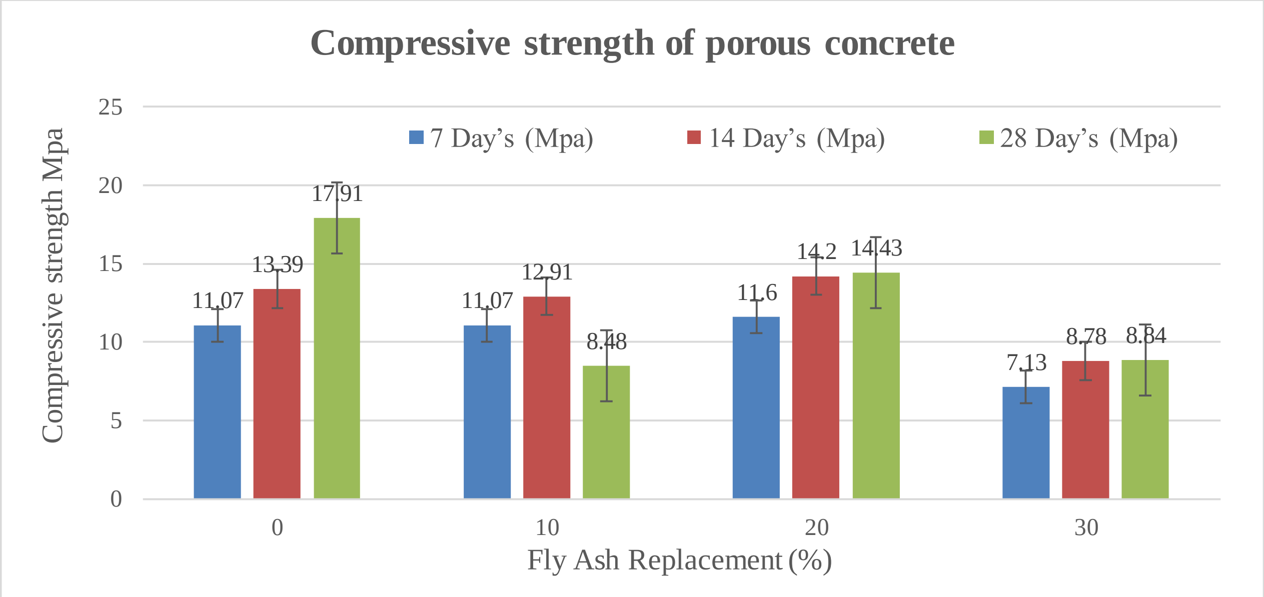


Figure-4 Concrete cube specimens and testing

The above graph shows that replacing fly ash affects porous concrete's compressive strength after 7, 14, and 28 days. The concrete shows the greatest strength development at 0% fly ash, reaching 17.91 MPa after 28 days. The strength dramatically decreases when 10% fly ash is added, especially at 28 days (8.48 MPa), suggesting less cementitious action at this replacement level. Nevertheless, the compressive strength rises once more at 20% fly ash, reaching 14.43 MPa at 28 days, indicating that this level offers the ideal balance where pozzolanic activity favorably contributes to strength gain. The strength declines at 30% replacement throughout all curing times, indicating that too much fly ash lowers the total binding capacity. Overall, the findings suggest that a moderate replacement level of roughly 20% is better suited for preserving sufficient compressive strength in porous concrete.

2. Flexural strength of porous concrete.

The flexural behavior in this study was assessed in compliance with IS 516:2018, which outlines the standard method for figuring out the concrete's modulus of rupture. A two-point loading arrangement was used to test beam specimens measuring 100 mm by 100 mm by 500 mm with an effective span of 400 mm. The standard modulus of rupture formula was used to determine the flexural strength:

$$f_b = \frac{P \times L}{b \times d^2}$$

where P is the maximum applied load (N), L is the span length (mm), b is the width, and d is the depth of the beam specimen (mm).


Table-5 Flexural strength of porous concrete

Fly Ash Replacement (%)	7 Day's Average Compressive strength (Mpa)	14 Day's Average Compressive strength (Mpa)	28 Day's Average Compressive strength (Mpa)
0	5.5	4.5	6.5
10	3.75	2.0	3.5
20	5.0	4.8	5.0
30	5.0	6.0	4.0

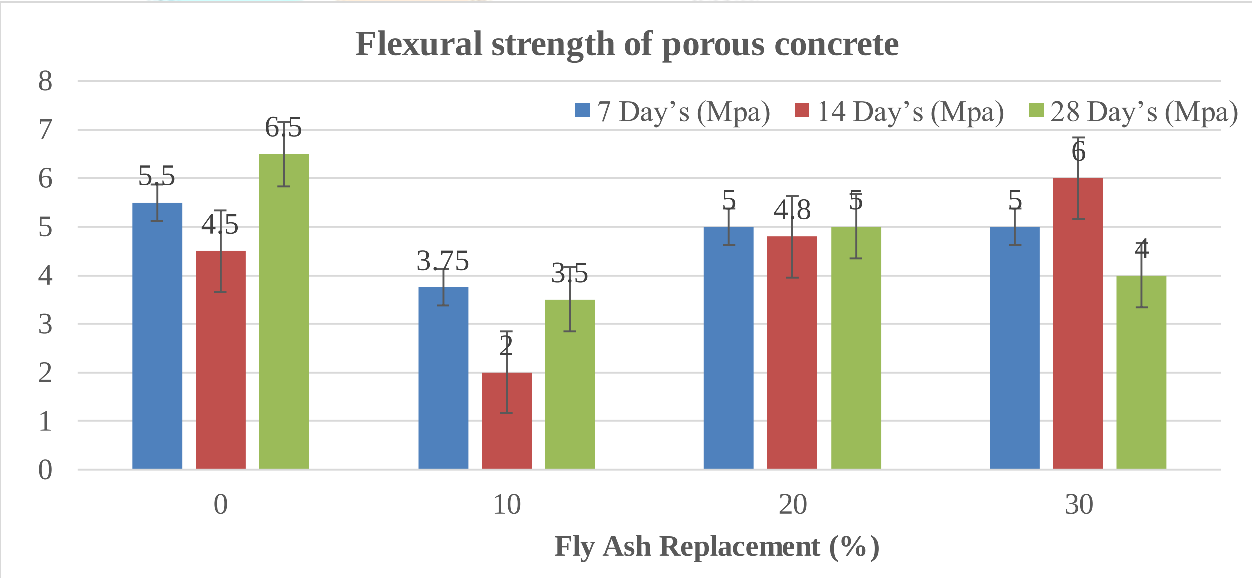


Figure-5 Flexural testing on porous concrete

The flexural strength of porous concrete with varying fly ash percentages at 7, 14, and 28 days is shown in the above chart. Strong bending resistance with conventional cement is demonstrated by the concrete's highest 28-day flexural strength of 6.5 MPa at 0% fly ash. All ages experience a significant decrease in flexural strength when 10% fly ash is used; the 28-day value drops to 3.5 MPa, indicating poorer tensile performance. Flexural strength increases once more at 20% fly ash, reaching 5.0 MPa after 28 days, indicating improved pozzolanic contribution and an ideal range for strength development. The 14-day strength for 30% fly ash peaks at 6 MPa, but the 28-day value drops to 4 MPa, suggesting uneven long-term performance. Overall, the graph indicates that while very low or very high replacements result in decreased bending capacity, moderate fly ash replacement (about 20%) preserves better flexural strength.

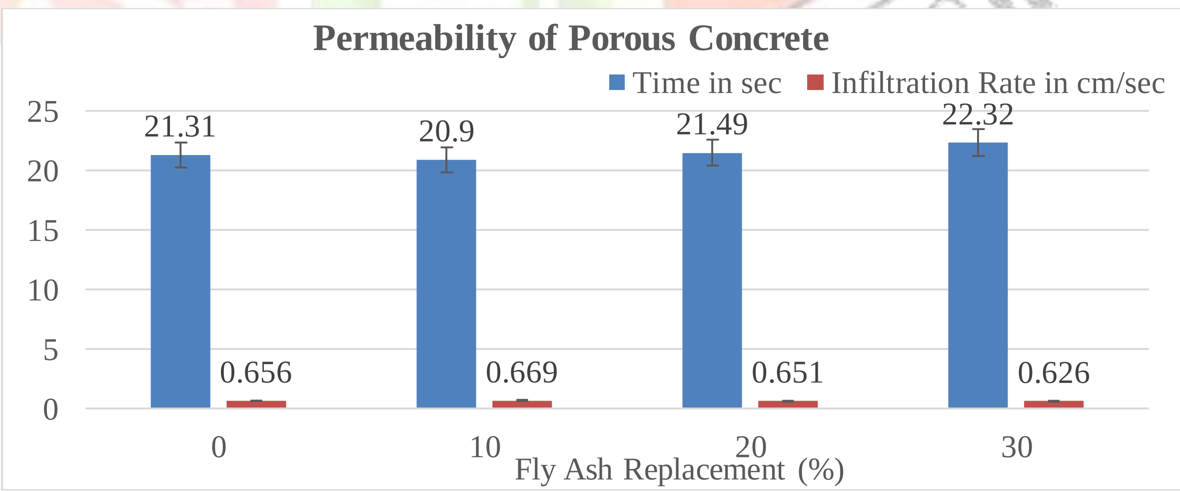
3. Permeability of Porous Concrete

A crucial characteristic of porous concrete is permeability, which establishes the material's capacity to permit water to flow through, making it appropriate for pavement and stormwater management applications. According to ASTM C1701, Standard Test Method for Infiltration Rate of In-Place Pervious Concrete, falling head or constant head permeability tests are frequently used to assess the permeability of porous concrete. Cylindrical specimens measuring 100 mm in diameter by 200 mm in height or 150 mm by 150 mm are commonly utilized in laboratory settings. The permeability coefficient is calculated using the standard falling head formula:

$$k = \frac{aL}{At} \ln\left(\frac{h_1}{h_2}\right)$$

Table-6 Infiltration Rate of porous concrete

Fly Ash Replacement (%)	Time (Sec)	Infiltration Rate (Cm/Sec)
0	21.31	0.656
10	20.90	0.669
20	21.49	0.651
30	22.32	0.626



The permeability properties of porous concrete with varying fly ash replacement levels are displayed in the above chart. At 0%, 10%, and 20% fly ash, the time needed for water infiltration stays almost the same (about 21–21.5 seconds), but at 30% replacement, it slightly increases to 22.32 seconds, suggesting a slight decrease in permeability at higher fly ash content. Similar trends can be seen in the infiltration rate, which falls to 0.626 cm/sec at 30% replacement but stays comparatively constant between 0.651 and 0.669 cm/sec for 0–20% fly ash. Overall, the findings show that while higher replacement levels may marginally lower the infiltration capacity of porous concrete, moderate fly ash replacement (up to 20%) has no discernible effect on permeability.

XI CONCLUSION

This study shows that the shape of coarse aggregates really matters for how porous concrete works, especially its strength and how well water filters through it. A good porous concrete mix needs to be strong enough to handle weight but still let water drain through quickly, which is important for roads and parking lots that need to support loads and manage rain.

The control mix did the best in tests, with a top compressive strength of 15 N/mm² and an infiltration rate of 0.626 to 0.669 cm/sec. Using 10%, 20%, and 30% fly ash, an industrial waste, is a cheaper way to make sustainable pervious concrete. But, more fly ash usually meant less compressive strength. Adding too much fly ash seems to weaken the porous concrete's cement.

The results also show that less water in the mix makes the concrete stronger, and 0.3 was the best water-cement ratio. The mix with 20% fly ash worked the best when balancing strength and how well water flows through it.

Different amounts of fly ash didn't really change how water flowed through the concrete. This means the pore structure, not what the binder is made of, matters most for permeability. Also, smaller coarse aggregates made the concrete less porous because they packed together better, which made the concrete stronger. The results show that more empty space means less strength. So, picking the right aggregate size and mix is important for getting the right balance between strength and permeability in pervious concrete.

X RESEARCH NEEDS.

1. To measure the effects of aggregate angularity, texture, and shape indices on pore connectivity, mechanical strength, and long-term durability of pervious concrete, more thorough research is required.
2. In order to improve strength and infiltration capacity, more research should examine the use of fly ash in combination with other supplementary cementitious materials (SCMs) like GGBS, silica fume, or metakaolin, even though 20% fly ash demonstrated optimal performance.
3. Further research is necessary to evaluate the impact of clogging potential, chemical exposure, abrasion resistance, and freeze-thaw cycles, especially for parking and road applications.
4. Rheological analysis, performance-based mix proportioning, and machine learning-based optimisation may aid in the creation of more effective pervious concrete mixes suited to particular site circumstances.
5. To attain the best possible balance between void ratio, strength, and infiltration rate, research should concentrate on multi-sized aggregate blends and packing models.
6. The sustainability and affordability of pervious concrete can be improved by more research into the use of waste materials and industrial byproducts as coarse aggregates or binder substitutes.

AUTHOR CONTRIBUTION

All authors made a substantial contribution to the advancement on this study. The primary author was responsible for conceptualising and formulating the research objectives. The research team worked together to design the experiment, prepare the materials, and conduct laboratory testing. Collaboratively, data collection, statistical analysis, and result interpretation were carried out. To ensure technical accuracy and clarity, all authors worked on the manuscript's draughting, critical review, and final editing. The final draft of the manuscript has been reviewed and approved by all authors.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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