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Effect of Fly Ash and Fibres on Strength and Permeability Characteristics of Pervious Concrete

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Abstract*: Conventional normal cement concrete is generally used as construction material of buildings. The impervious nature of concrete contributes to the increased water runoff into drainage system, over-burdening the infrastructure and causing excessive flooding in built-up areas. Pervious concrete has become significantly popular during recent decades, because of its potential contribution in solving environmental issues. Pervious concrete is a type of concrete with significantly high water permeability compared to conventional concrete. It has been mainly developed for draining water from surface to underground, so that storm water runoff is reduced. Due to high water permeability then normal concrete, pervious concrete has very low compressive strength. The characteristic of high permeability of pervious concrete contributes to its advantage in storm water management. However, the mechanical property such as low compressive strength limits the application of pervious concrete to the roads having light volume traffic. It is observed form previous studies that the strength of pervious concrete can be enhanced by substituting some of the cement with other materials, such as fly ash and fibres. The objective of present study was to make pervious concrete mix with high strength and pore properties by partial replacement of cement with fly ash and using steel and glass fibres. For this purpose cubes beams were casted with and without replacement of cement with flyash and addition of steel and glass fiber by total weight of concrete mix. Test such as compressive strength, flexural strength, total porosity and Infiltration rate were performed. It was observed addition of fly ash decreased the compressive as well as flexural strength of the pervious concrete. Further, incorporation of 1% steel fibres by weight of concrete mix was found adequate in achieving high strength and permeability, when compared to control mix concrete

Keywords: Pervious Concrete, glass fibers, steel fibers, fly ash.

I. INTRODUCTION

Pervious concrete is a concrete which has relatively high water permeability compare to conventional concrete due to interconnected pore structure. Pervious concrete is also termed as porous concrete and permeable concrete. It can be produced using conventional concrete-making materials, namely cement, cement supplementary materials, all types of coarse and no fine or less fine aggregates, and water.

Due to rapid urbanization most of the places are covered with impermeable surfaces like cement concrete. This has a major impact on the ground water table. Pervious concrete pavement is an effective ways to minimize this issue. Pervious concrete is an open graded structure with interconnected voids through which rain and storm water is permitted to percolate into the aquifer. Common applications for pervious concrete are parking lots, sidewalks, pathways, tennis courts, patios, slope stabilization, swimming pool decks, green house floors, zoo areas, shoulders, drains, noise barriers, friction course for highway pavements, permeable based under a normal concrete pavement, and low volume roads. The permeability characteristic of pervious concrete depends on pores size and its interconnectivity. These are affected by the type, size hand gradation of aggregate, paste volume, and consolidation energy [1]. Due to high water permeability then normal concrete, pervious concrete has very low compressive strength. In general, the compressive strength of pervious concrete ranges from 2.8–28 MPa, which is lower than that of conventional concrete of 17–40 MPa [2]. Thus, it is generally not used solely for concrete pavements for high traffic and heavy wheel loads.

Several researchers are working on improving the properties of the pervious concrete by addition of various reinforcing elements or additives. For example, nano-sized materials were added to pervious concrete mix design as fillers to improve microstructure and overall quality and performance [3–5]. Hesami [6] studied the effects of rice husk on mechanical properties of concrete. Increase in residual flexure strength of pervious concrete on addition of polypropylene fibers was reported by Rehder et al. [7]. In addition to strength, polypropylene fibers were found to enhance the freeze thaw durability [8-9]. In another study [10] , it was found that the addition of styrene butadiene rubber latex improves the compressive strength and abrasion resistance. Supplementary cementitious materials (SCMs) are often used in pervious concrete. Kevern et al. [11] recommended that fly ash use be restricted to 10% and silica fume to 5% replacement to avoid very low early-age strength and rapid drying, respectively.

In this study steel and glass fibers are used to potentially improve the various properties of pervious concrete. The objective of this study is to understand the behaviour of pervious concrete mix on addition of different type of materials like fly ash, steel fibre and glass fibre on the strength and permeability characteristics of pervious concrete.

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II. MATERIALS USED

The materials used for pervious concrete include ordinary portland cement (OPC), coarse aggregate, fly ash, steel fibre, glass fibre and superplasticizer. No fine aggregates were included in the concrete mixture.

A. Ordinary Portland Cement

OPC of 53-grade (marked under the name Double emami cement) conforming to IS: 12269-1999 was used. The specific gravity of OPC cement was found to be 3.14.

B. Coarse Aggregates

Coarse aggregate of maximum size restricted to 10 mm conforming to IS:383 (1970) was used in study. Coarse aggregates used for concrete were crushed aggregates which are predominantly angular in shape. The properties of coarse aggregates are shown in Table I.

Table- I: Coarse aggregates properties

Physical Properties	Aggregate Size (10 mm)
Specific Gravity	2.78
Los Angeles abrasion value (%)	20.34
Water absorption (%)	2.29

C. Fly Ash

Fly ash or pulverized fuel ash (PFA) is a byproduct of the combustion of pulverized coal collected by electrostatic precipitator from the fuel gases of thermal power plant. Normally fly ash is spherical in shape having diameter varying from 1 micron to 100 micron. As per ASTM, Fly Ash is divided into Class F (low Calcium fly ash generally Ca<5%) and Class C (high Calcium Fly Ash, Ca>10%). In this study Class F Fly Ash were used.

D. Steel Fibers

Mild steel fibres hooked end (marketed under the name SHAKTIMAN®) with tensile strength 1100 MPa and conforming to ASTM-A820M was used .The maximum length of steel fibres is 60 mm, minimum length is 12.5 mm and maximum diameter is 1mm. The picture of hooked end steel fibre is shown in Fig 1.

Fig. 1.Steel fibers with hooked end

E. Glass Fiber

A Glass fiber improves the tensile strength, durability, impact, shrinkage, fatigue and erosion resistance characteristics of concrete. Glass fibre (marketed under the name OCV Reinforcements) was used. The picture of glass fibre is shown in Fig 2.

Fig. 2. Glass fibers

F. Superplasticizers

Superplasticizer used in the study was Sikament -98R. It is a brown colour liquid which disperses instantly in water. The advantages of Sikament 98R superplasicizer are:

- Reduction in water content without causing segregation.
- Significant improvement in workability without increasing water content.
- Easy placement due to its plasticity, leading to reduction in the need for vibration.
- Reduced shrinkage and creep.

G. Water

The water used in the project for making concrete is the ordinary tap water with a pH within the range of 6-8.

III. MIXTURE PROPORTIONS

The range of mix proportions for pervious concrete is given in ACI 522R-15 Table no 6.2 as shown in Table II. Four mixture proportions based on the ACI 522 method were studied as shown in Table III. The water cement ratio is 0.30.

Table- II: ACI recommendation for mixture proportion

	Proportions (kg/m^3)
Cement	270 to 415
Aggregate	1190 to 1480
Aggregate : Cement ratio	4 to 4.5:1
Fine : Coarse Aggregate ratio	0 to 1:1
w/c ratio	0.27 to 0.34

Table- III: Mixture Proportion of Pervious concrete

Mixture ID	w/c ratio	Cement	Coarse aggregate	Pozzolona (% by weight of Cement)	Fibre(%)	Superplasticizer (% by weight of binder)	Density of Pervious concrete (Kg/m3)
Pervious 0-0%	0.30	1	4	0	0	1	1985
Pervious10-0%	0.30	1	4	1	0	1	1790
Pervious 0-1%S	0.30	1	4	0	1	1	2045
Pervious 0-0.1%G	0.30	1	4	0	0.1	1	1950

The four mixtures ID indicate:

- Pervious 0-0% - mixture with no fly ash and no fibres.
- Pervious 10-0% - mixture with 10% fly ash as a replacement of cement and no fibres.
- Pervious 0-1%S - mixture with no fly ash and 1% Steel fibres by weight of total concrete mixture.
- Pervious 0-0.1%G - mixture with no fly ash and 0.1% Glass fibre by weight of total concrete mixture.

Four sets of specimen consisting of nine cubes each of size 150 mm were cast to test the compressive strength, porosity and infiltration rate. Beams of 100 x 100 x 500 mm size were cast to test the flexure strength as shown in Fig 3.

Fig. 3. Cubes and Beams specimens

A. Preparation of Specimen

A concrete mixer was used for this purpose. The mixing was carried by adding Portland cement, and coarse aggregate in sequence into the mixer and dry-mixed for about 5 minutes. For other mix Fly ash, steel and glass fibres were added according to mixture ID. Then, premixed blend solution of water and superplasticizer was added to the dry mix and the blended till the mixture attained sufficient flow ability. Water cement ratio 0.30 was used (typically ranging from 0.27 to 0.34 in permeable concrete). All cubes and beams were casted. The slump of the concrete mixture was not measured as it is of no significance for permeable concrete because of its flowable nature. The specimens were kept in a controlled lab temperature of 27°C + 2°C for 24 hours and demoulded after this period. Then these specimens were cured in a water tank. Testing was done after 7, 14 and 28 days.

IV. EXPERIMENTAL STUDY

Tests to study the compressive strength, porosity, infiltration rate and flexure strength were performed.

A. Compressive strength test

The compressive strength of pervious concrete was determined as per the IS: 516 (1959) code [12]. At the age of 7, 14 and 28 days, cubes were tested using universal testing machine. For each mixture, three specimens were cast and tested, and the average of three is reported as their compressive strength.

Due to its porous nature compressive strength of pervious concrete mix is lower than conventional concrete and varies in the range of 3.8-30MPa.

B. Total porosity

The total porosity is the total void space of a pervious concrete mix and includes the amount of permeable and impermeable pores. The total porosity was calculated as per ASTM C1754 [13]. The total porosity was measured by finding the difference in weight of the cube submerged in water and weight after oven drying it for 24hrs at 50 degree Celsius. The difference in weight measured was then divided by the sample volume (mm^3) as given in equation below:

$$P = \left(\mathbf{1} - \frac{(W_1 - W_2)}{\rho w * v_1}\right) * 100\%$$

where, P is the total porosity of the concrete in %,
W_1 is the specimen weight air-dried for 24h (kg),
W_2 is the specimen submerged underwater weight (kg),
v_1 is the specimen volume (mm^3) and
ρw is density of water (kg/mm^3).

C. Infiltration rate

Infiltration rate of previous concrete majorly depends upon porosity of concrete which is again related with presence of void in concrete. Infiltration rate of pervious concrete is much higher i.e., about 70-80% than conventional concrete. In this study, the cube was sealed all around with impervious sheet except top and bottom layer. Then, known volume of water poured on the top surface of cube and the water percolating through cube was measured in one minute and after that infiltration rate is calculated.

D. Flexural strength test

The flexural strength of concrete was determined as per the IS 516 (1959). The bending test for beam specimens was performed using two-point loading. The beams were tested at the age of 7, 14 and 28 days. For each mixture, three specimens were cast and the average of three is reported as their flexural strength.

V. RESULTS AND DISCUSSIONS

A. Compressive strength test

The results for the compressive strength tests are tabulated in the Table IV. From the table, it is clearly seen that, with the addition of steel and glass fiber there is increased in strength, where as reduction in strength was seen in specimen when fly ash was added.

When compared to control mix concrete (i.e. Pervious 0-0%), with addition of steel fibers by 1% and glass fibers by 0.1% the compressive strength increased up to 20% and 7%, respectively. The decrease in strength was observed up to 23% with the addition of fly ash.

Table- IV: Compressive Strength for different mixtures

Mixture ID	7 Days (MPa)	14 Days (MPa)	28 Days (MPa)
Pervious0-0%	7.4	10.3	16.4
Pervious10-0%	6.5	9.2	12.5
Pervious 0-1%S	10.5	14.6	19.5
Pervious 0-0.1%G	9.3	13.2	17.5

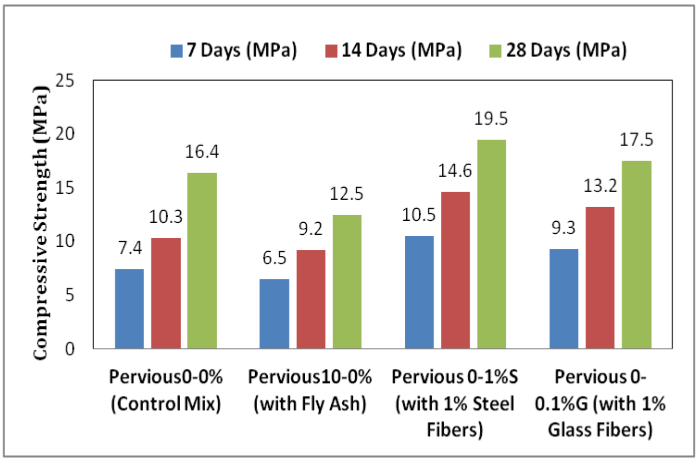

Fig. 4.Comparison of compressive strength

B. Total porosity

The results for the total porosity are tabulated in the Table V. From the table, it can be observed that, with the addition of steel and glass fiber, there is a increased in porosity upto 30% and 18%, respectively, when compared to control mix concrete. For specimen with fly ash upto 11% increase is observed.

Table- V: Porosity for different mixtures

Mixture ID	Porosity (%)
Pervious0-0%	27
Pervious10-0%	30
Pervious0-1%S	35
Pervious0-0.1%G	32

C. Infiltration rate

The results for the infiltration rate are tabulated in the Table VI. From the table, it is clearly seen that, with the addition of steel and glass fiber there is a increased in infiltration rate up to 27% and 20% when compared to control mix concrete. For specimen with fly ash no significant improvement in infiltration rate is observed.

Table- VI: Infiltration rate for different mixtures

Mixture ID	Infiltration rate(mm/sec)
Pervious0-0%	2.6
Pervious10-0%	2.8
Pervious0-1%S	3.3
Pervious0-0.1%G	3.1

D. Flexural strength test

The results for the flexure strength at 7 days are tabulated in the Table VII. From the table, it is clearly seen that, with the addition of steel and glass fiber there is an increased in flexure strength upto 28% and 15%, respectively, when compared to control mix concrete. For specimen with fly ash upto 15% decrease in strength is observed.

Table- VII: Flexure Strength for different mixtures

Mixture ID	Flexural strength (MPa)
Pervious0-0%	2.1
Pervious10-0%	1.8
Pervious0-1%S	2.7
Pervious0-0.1%G	2.4

E. Mode of failure

The image of non-fibred and fibred specimen just after compression test is shown in Fig 5, 6 and 7. From the figures it can be seen that non-fibred mixture exhibited very brittle failure on reaching its strength, where as fibred mixtures tend to keep the composite matrix together even when the failure load was reached and prevented brittle failure.

Fig. 5.Specimen containing no fibre

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Fig. 6.Specimen containing glass fibre

Fig. 7. Specimen containing steel fibre

VI. CONCLUSIONS

Experimental study was performed to investigate the effect of addition of fibers and fly ash in pervious concrete. The main conclusions are summarized below:

1. The addition of steel fiber increases the compressive and flexural strength upto 28%.
2. The addition of glass fiber increases the compressive strength and flexural strength upto 15%.
3. The use of steel fibers results in significant increase in both compressive and flexure strength of pervious concrete along with its porosity and infiltration capacity.
4. Presence of fly ash decreased the compressive strength as well as flexural strength of the pervious concrete.

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