

# Study on Strength Characteristics of Pervious Concrete Using Mineral Admixtures

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## Abstract

Pervious concrete is a special type of concrete emerged out in the concrete world. It is referred as porous concrete or no fines concrete. The porous concrete has wide applications in the pavement with low traffic intensity, sidewalks, pathways, platforms, parking lots etc. Since the pervious concrete allows the groundwater replenishment and prevents the pool of water standing on the earth surface during rainfall-runoff, it helps in the stormwater management. In the present work, the partial replacement of cement with silica fume (SF) and metakaolin (MK) as mineral admixtures to an extent from 10 to 30 % by varying water-cement (w/c) ratio from 0.36 to 0.40 was done to study the effect on the performance of pervious concrete. From the results, an optimum w/c ratio was found to be as 0.38 along with 1.5% of the superplasticizer. The experimental results reveal that the compressive strength of pervious concrete containing mineral admixtures was found to be better than the compressive strength of conventional pervious concrete. Among three different percentage of substitutes used, 20% was found to be an optimum value in both the cases. Pervious concrete with SF as admixture exhibited better strength among the two admixtures.

**Keywords:** Pervious concrete, metakaolin, silica fume, w/c ratio, compressive strength.

## 1. Introduction

Among many types of concrete, pervious concrete (PC) has marked its importance in pavement applications. Pervious concrete is a special type of concrete with high porosity, generally 30-40% by volume of mix. Hence the strength in pervious concrete is mainly due to the bonding between thin cement pastes and aggregate which results in lesser compressive strength when compared with normal concrete. PC enhances the permeable land cover mainly in roadways and built-up environment. The main advantages of using pervious concrete are an increase in groundwater recharge, reduction in noise pollution and UHI effect. It is used for stormwater management; the first flush of water could be quickly percolated through these pores which help in reduction of rainwater contamination. The key ingredient in the pervious concrete mix is cement, which helps in binding and achieving strength. Cement production is responsible for about 1% of the greenhouse gases emitted in the US. So an alternative for reducing cement usage in concrete makes concrete partially eco-friendly. Thus there comes an idea of partially replacing cement with mineral admixtures. The material used as partial replacement of cement should possess cementitious properties, and the effect of it on the environment should be minimal. In this study, cement is partially replaced with metakaolin (MK) and Silica fume (SF) to improve one of the mechanical properties namely compressive strength. The compressive strength of pervious concrete mainly depends on its mix proportions, cement and size of the coarse aggregate used per volume ( $m^3$ ) of concrete. The pervious concrete mixture designs are still evolving, standardized designs and procedures have yet to be established. Ghafouri and Dutta [1] have investigated on the no-fines concrete and inferred that with

the aggregate-cement ratio of 4.5: 1 or less has obtained the compressive strength of 20.7 MPa and the similar trend was observed in split tensile strength. Swaminathan [2] has studied the partial replacement of cement with metakaolin and rice husk ash for the high strength concrete. The author has reported that the 10% partial cement replacement was found feasible for obtaining the highest compressive strength and the obtained tensile strength was in the range of 8.5% of compressive strength. Karthik [3] has conducted the experimental study on the pervious concrete in which the percentage of voids was in the range of 18 to 35% and the compressive strength obtained was in the range of 400 to 4000 psi. The author has also suggested the pervious concrete applications namely at the pedestrian path, light traffic roads and parking lots could help in the sustainable development in construction. Rama and Shanthi [4] have researched the pervious concrete properties. The authors have reported that decrease in compressive strength was due to increase in porosity in turn increase in permeability of concrete. The coarse aggregate was used in two series (S1 & S2). In S1, the size adopted was between 9.5 mm and 4.75 mm whereas in S2 the aggregate size was between 12.5 mm to 9.5 mm respectively. The aggregate to cement ratio varies from 3:1 to 7:1. The authors have concluded that the mix proportion of 4:1 has obtained the better compressive strength (12 MPa and 10 MPa) with the porosity of 22% and 23% for S1 and S2 aggregate series. Ahmed et al. [5] have studied the mechanical and hydrological properties of Portland cement pervious concrete (PCPC). The authors have inferred that the maximum compressive strength of 6.95 MPa was obtained from the mixtures containing the quantity of cement as 250 kg/m<sup>3</sup> and the size of coarse aggregate used was 9.5 mm. Further, the average density of pervious concrete adopted was 1716 kg/m<sup>3</sup> and with the percentage of porosity as 37%.

Anush and Krishna [6] have done the review on pervious concrete for pavement material by considering mechanical, durability, and hydrological properties, environmental and cost-benefit aspects. The authors have suggested the significance of pervious concrete, their benefits on urbanization, and future road applications. Cosic et al. [7] have studied the effect of aggregate properties viz. type and size on pervious concrete. The authors found that the porosity was higher for dolomite aggregate than the steel slag aggregate in pervious concrete. Hence, the aggregate size in the range of 4 to 8 mm increased the concrete density and obtained highest flexural strength. Tennis et al. [8] have researched the pervious concrete. It was reported that the void percentage in pervious concrete varies between 15-25% by volume and flow rates of water through pervious concrete is approximately 1219 cm/hr. The applications of pervious concrete were in low volume streets, noise barriers, and slope stabilization. From the above literature review conducted on the pervious concrete, the study was carried out in the direction of the partial substitute of cement by silica fume (SF) and metakaolin (MK) with three replacement percentages (from 10% to 30%), total six mixes were developed. The trial mixes were cast and tested for three w/c ratios (0.36, 0.38 & 0.40)

and the optimum w/c ratio of 0.38 was adopted. Further, comparison of the compressive strength was made between control pervious concrete (CPC), i.e. without cement replacement and with the six mixes of the partial cement replacement using SF and MK at par with 1.5% of Superplasticizer (SP) dosages.

## 2. Materials Used

Materials used in the pervious concrete mix are cement, coarse aggregate and water. No fines are used for the mix in pervious concrete. Cement used was OPC 53 grade as per ASTM C150 [9] and the coarse aggregate used was the locally available well-graded aggregate of size varying from 10 to 12.5 mm was used. Superplasticizer (SP) was used to develop the workability of freshly prepared pervious concrete. In present work, the partial substitute of cement using metakaolin (MK) and silica fume (SF) as per ASTM C1240-99 [10]. Here the cement was partially replaced by MK and SF from 10% to 30% (with an increment of 10%) along with control pervious concrete (CPC).

**Table 1:** Pervious concrete prepared by constituent materials

Mix	Cement kg/m <sup>3</sup>	SF kg/m <sup>3</sup>	MK kg/m <sup>3</sup>	CA kg/m <sup>3</sup>	w/c ratio	SP (l/m <sup>3</sup> )
CPC	415	-	-	1750	0.36, 0.38 & 0.40	-
C+10% SF	373.5	41.5	-		0.38	6.3
C+20% SF	332	83	-			
C+30%SF	290.5	124.5	-			
C+10%MK	373.5	-	41.5			
C+20%MK	332	-	83			
C+30%MK	290.5	-	124.5			

## 3. Experimental Programme

In this section, the basic tests on material properties used for the experimental study were discussed. It includes the determination of water-cement ratio (w/c) of fresh pervious concrete and fixing of optimum water-cement ratio. The physical observation was made on the pervious concrete by passing water through their top surface and noticed the ingress of water at the bottom surface. In hardened state, the cube compression test was conducted, and the results were illustrated.

### 3.1 Basic Test on Materials

The constituent materials used for developing pervious concrete were subjected to the basic material properties tests namely specific gravity, fineness modulus, initial and final setting time of cement, etc. By conducting those tests on materials, could help to achieve the better quality of pervious concrete.

#### Mix Design

The pervious concrete was designed mainly using coarse aggregates along with the cement paste used. The selection of water-cement (w/c) ratio and the dosage of Superplasticizer (SP) also got the significant role in developing the necessary workability and the strength characteristics of PC. The voids were developed in the PC by the narrow gradation of coarse aggregate particles.

#### Casting of Specimens

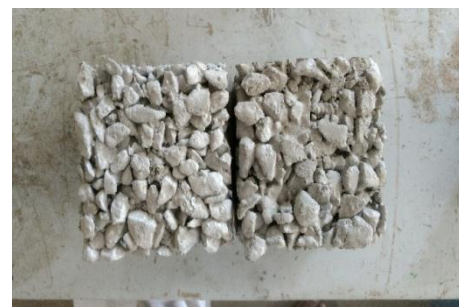
The cube moulds are made from plywood of dimensions 100 mm (inside). The moulds are lubricated properly and made leak-proof, before pouring concrete into the mould. The homogeneity of concrete has been ensured after pouring into the desired mould as shown in Figure 1.



**Fig. 1:** Casting of cube specimens

#### Curing of Specimens

The specimens were removed from the mould after 24 hours of casting and subjected to the hydration period of 28 days. Before testing, the cubes were placed at the atmospheric temperature for the duration of three hours for drying of surfaces completely as shown in Figure 2a. The surface porosity also observed in Figure 2b.



**Fig. 2a:** Pervious concrete at hardened state



Fig. 2b: Porosity observation in the cube specimen

### Cube Compression Test

The test specimens were kept dried in atmosphere for 2 hours after subjected to curing for the age of 28 days. The mass of the specimens were measured. Using the digital automatic compression testing machine (CTM) with the rate of loading as 2.9 kN/s, the load was applied to the specimen until it fractures and the load reversal took place. Finally, the ultimate load applied, and the direct compressive stress of the specimen was observed using digital recorder connected with CTM.

## 4. Results

The preliminary investigation resulted on the determination of physical properties of constituent materials used for PC. In the

next stage, the optimum water-cement ratio (w/c) was arrived based on the strength of PC mixes with three w/c ratios (0.36, 0.38 and 0.40). Finally, the compressive strength was illustrated for CPC mixes, the partial cement replacement using SF (three mixes) and MK (three mixes) based CP mixes for the optimum w/c ratio and SP dosages considered.

### Tests on Constituent Materials

The ingredients used for the preparation of pervious concrete were subjected to the physical tests and mentioned in the Table 2.

Table 2 Test results of basic material properties

Materials	Basic physical tests
Coarse aggregate	Fineness modulus:7.25
Cement(OPC)	Initial setting time:35 minutes
	Std. consistency:33%
	Specific gravity:3.13
Metakaolin (MK)	Specific gravity: 2.47
Silica fume(SF)	Specific gravity:2.12

### Effect of Water-Cement Ratio

The effect of water-cement ratio has got significance in obtaining the mechanical properties of concrete. For the control pervious concrete (CPC), three water-cement ratios namely 0.36, 0.38 and 0.40 was used. In CPC mix, the mineral and chemical admixtures were not used. The cube specimens were cast with these three w/c ratios and tested for the compressive strength as shown in Figure 3.

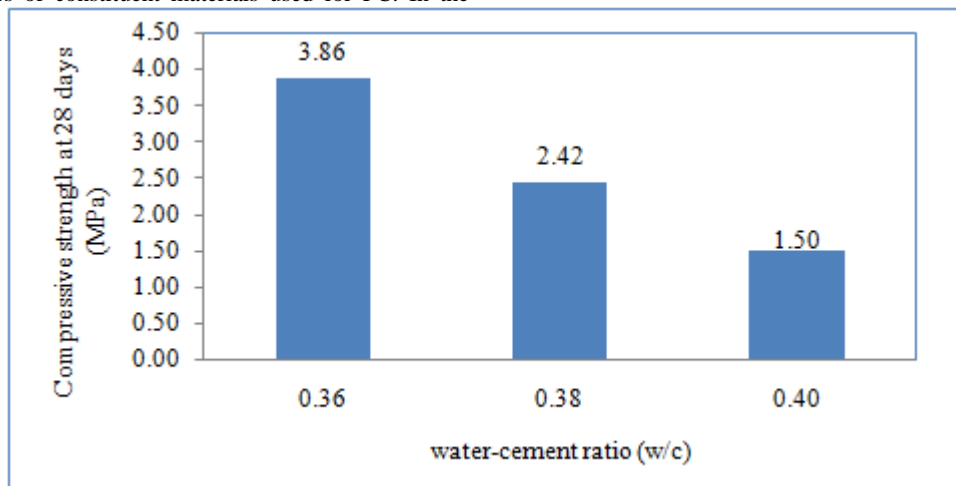


Fig. 3: Compressive strength of CPC mixes with three w/c ratios

From the Figure 3, it was observed that the CPC mix has obtained the highest compressive strength with w/c ratio of 0.36 and lowest strength was obtained with w/c ratio of 0.40. The strength obtained by the w/c ratio of 0.36 has got 59.5% increase than the w/c ratio of 0.38. The strength achieved by w/c ratio of 0.38 has got 61.3% increment than w/c ratio of 0.40. The reason for the more strength attained was due to the better conglomeration of particles in the mix along with reduced w/c ratio of 0.36. But the degree of workability was low. To improve the workability property of PC at green state, the powder content namely MK and SF was used with optimum w/c ratio of 0.38 is considered at par with SP dosage of 9 litres/m<sup>3</sup> of SCC.

### Cube Compressive Strength Of Pervious Concrete

The compressive strength of cube specimens was obtained at the age of 28 days as shown in Figure 4. Before subjected to the compression test, the permeation of water through the void spaces was ensured. It was observed from the Figure 4, the highest compressive strength was attained by SF 20% with 14.09 MPa and SF 30% with 11.71 MPa respectively. The size of the silica fume was much less than the size of cement particle could be the

reason for gaining the early age compressive strength. The presence of SF in the PC mixes encapsulates the coarse aggregate, and the volume of cement paste resulted in the formation of the strong paste-aggregate interface. Thus in SF based PC mixes the strength gain obtained was in the range of 2.4 to 5.8 times than the control pervious concrete mix (CPC) respectively. Among all MK based PC mixes, MK 20% has obtained the highest compressive strength of 8.95 MPa. The strength gain obtained in MK based PC mixes were in the range of 1.7 to 3.7 times than CPC mix. In an overall view, the blended pervious concrete mixes using MK and SF has developed better strength characteristics than CPC mix was inferred.

Based on the results obtained from the present work, there is a future scope of producing pervious concrete using other conventional mineral admixtures and also by supplementary cementitious materials. Since these mineral admixtures cause high pozzolanic activity leads to strength gain at early ages. Thus pervious concrete could be suitable for pavement applications comprise of low-duty, foot paths in garden lands and pedestrian path in urban areas.

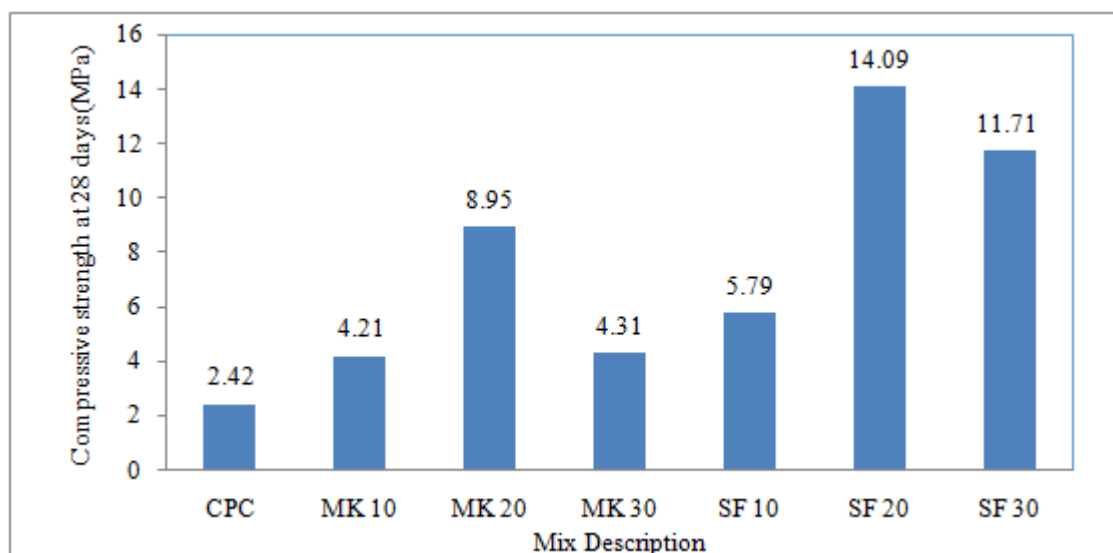


Fig. 4: Compressive strength of CPC, MK and SF based pervious concrete

## 5. Conclusions

Based on the results obtained from the experimental investigation on pervious concrete using partial substitute of cement by SF and MK, the following conclusions were made:

- From the three w/c ratios of pervious concrete, mix with w/c ratio= 0.38 gave an optimum compressive strength with moderate workability.
- It was inferred from the compressive strength of cube specimens, the partial substitute of cement by 20% of MK and 20% of SF has shown better performance in comparison with CPC.
- It was inferred that 20% of weight of cement replaced by metakaolin has obtained the compressive strength 3.7 times higher than CPC.
- It was also observed that SF20 has obtained the compressive strength 5.8 times higher than CPC.
- Hence, it was suggested that 20% SF as partial substitute to the cement with w/c ratio of 0.38 along with 1.5% dosage of Superplasticizer found to be feasible blended CP mix.

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