EFFECT OF METAKAOLIN ON PERVIOUS CONCRETE

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Abstract - *In recent years, lot of research focus on developing new Supplementary cementitious material to strengthening the concrete. These materials are used as a part of cements. Metakaolin is one of the supplementary cementitious materials which are partially replaced for cement. Properties of concrete with metakaolin are mostly preferred additives in concrete. Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. The special properties of pervious concrete like compressive strength, split tensile strength, flexural strength and permeability are studied in this paper for 4:1 aggregate to cement ratio with constant water to cement ratio was 0.33. Metakaolin was added at different percentages by the weight of cement. The effect of metakaolin at various percents in pervious concrete without inhibiting the permeability characteristics of pervious concrete was studied in this paper.*

Key Words*: *Metakaolin, Porous Concrete or Pervious Concrete, Compression Strength, Split Tensile Strength, permeability

1. INTRODUCTION

Cement is a binder, a substance used for construction that sets, hardens, and adheres to other materials to bind them together. Cement mixed with fine aggregate produces mortar for masonry, or with sand and gravel, produces concrete. Concrete is the most widely used material in existence and is behind only water as the planet's most-consumed resource [1]. Cement manufacture causes environmental impacts at all stages of the process. The cement industry produces about 10% of global human-made CO_2 emissions, of which 60% is from the chemical process, and 40% from burning fuel [2]. A Chatham House study from 2018 estimates that the 4 billion tonnes of cement produced annually account for 8% of worldwide CO_2 emissions [3]. Nearly 900 kg of CO_2 are emitted for every 1000 kg of Portland cement produced.

Metakaolin is the well known supplementary cementitious material all over the world. Metakaolin is a pozzolan, probably the most effective pozzolanic material for use in concrete. It is a product that is manufactured for use rather than a by-product and is formed when china clay, the mineral kaolin, is heated to a temperature between 600 and 800ºC. metakaolin is a valuable admixture for concrete/cement applications. Replacing portland cement with 8–20% (by weight) metakaolin produces a concrete mix that exhibits favorable engineering properties in conventional concrete, including: the filler effect, the acceleration of OPC hydration, and the pozzolanic reaction. The filler effect is immediate, while the effect of pozzolanic reaction occurs between 3 and 14 days.

Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. Pervious concrete is traditionally used in parking areas, areas with light traffic, residential streets, pedestrian walkways and greenhouses [4][5]. It is an important application for sustainable construction and is one of many low impact development techniques used by builders to protect water quality. Pervious concrete functions like a storm water infiltration basin and allows the storm water to infiltrate the soil over a large area, thus facilitating recharge of precious groundwater supplies locally [6]. All of these benefits lead to more effective land use. Pervious concrete can also reduce the impact of development on trees. A pervious concrete pavement allows the transfer of both water and air to root systems to help trees flourish even in highly developed areas [6]. The other environmental benefits of pervious concrete in pavements are reduced noise level and urban heat-island effect and improved skid resistance [7-8]. The mechanical and hydraulic properties of pervious concrete were studied in this paper.

2. Materials

The locally available construction materials were used for making pervious concrete. For casting Blue granite crushed stone passing through 12.5 mm sieve and retained on 10 mm sieve were used in this paper. For casting the specimens OPC 53 grade of cement were used. Metakaolin is the supplementary cementitious material which is partially replaced for cement. Potable water available in laboratory was used for mixing and curing the specimens. The preliminary tests for cement, metakaolin and coarse aggregate were conducted.

2.1 MATERIAL PROPERTIES

From test results the physical properties for all materials are reported in table1, table 2 and table 3.

Table1. Physical Properties of Cement

PHYSICAL PROPERTIES	OBTAINED VALUE
Specific gravity	3.15
Fineness	8%
Standard consistency	29%
Initial setting time	32 mins
Final setting time	364 mins
Bulk density	1417 kg/m^3

Table2. Physical Properties of Metakaolin

PHYSICAL PROPERTIES	OBTAINED VALUE
Specific gravity	2.6
Fineness	0.2%
Colour	White

Table3. Physical Properties of Coarse Aggregate

PHYSICAL PROPERTIES	OBTAINED VALUE
Specific gravity	2.68
Bulk density	1534 kg/m^3
Water absorption	1%

2.2 MIX PROPORTION

Aggregate and proper cement pastes are the important constituents in pervious concrete. The coarse aggregate is the strongest and least porous component of pervious concrete. The aggregate size passing through the 12.5 mm sieve and retained on the 10 mm sieve were used in the present work. The strength and permeability characteristics of pervious concrete are depending upon the thickness of cement paste. While selecting the mix proportion some important properties of coarse aggregate as well as cement paste to be considered.

Based on trial and error, two trial mixes were prepared for aggregate to cement ratio of 4:1, as per ACI 522R-10. A constant water to cement ratio of 0.33 was considered in the trial mixes. The seven days compressive strength test and permeability tests of pervious concrete were conducted and the test results are given in table 5.1. As a result, Trail mix-2 was considered for this experimental study because of their low compressive strength and increased permeability rate than the trial mix-1. Metakaolin were added upto 4% by the weight of cement. Various properties of pervious concrete, such as the compressive strength, split tensile strength, flexural strength and permeability are studied at every percents of metakaolin. The properties of trial mixes were reported in table 4.

Table4. Properties of Trial Mixes

Trial Mix	Mix-1	Mix-2
Aggregate to Cement Ratio	4:1	
Cement (kg/m^3)	320	240
Coarse Aggregate (kg/mm^3)	1280	1280
Compressive Strength (N/mm^2)	9.62	8.15
Permeability (cm/sec)	1.07	1.15

2.3 SAMPLE PREPARATION

Pervious concrete is prepared only for Trial Mix-2, because of their low compressive strength and increased permeability rate. Pervious concrete specimens are prepared according to the ASTM C192 guidelines for one conventional mix and four MK mixes by mixing proper quantities of water, cement, metakaolin and coarse aggregate. A total of 45 cube specimens, 15 cylindrical specimens and 15 prism specimens were prepared to conduct the test. The mixing was done by hand mixing.

3. Test Methods

3.1 Compressive Strength

According to ASTM C-39 [9], the compressive strength test was conducted on cube specimens having size of 150 mm x150 mm x150 mm. The average compressive strength of three cube specimens was noted.

3.2 Split Tensile Strength

According to ASTM C-496 [10], the split tensile strength test was conducted after 28 days of curing on cylindrical specimen having size of 150 mm diameter and 300 mm height.

3.3 Flexural Strength

According to ASTM C-78 [11], the flexural strength test was conducted on prism specimens having size of 100 mm x 100 mm x 500 mm.

3.4 Permeability

The permeability test setup was shown in figure 1. It comprise of three cells (4) square in cross section mounted on stands (2). Each cell assembly consists of one base plate, one metal funnel (3), on top plate (5). A groove is provided on the top for the cell 'O' ring. These cells are connected with connecting pipe (6) through valve (7). A pressure regulator (9) is mounted on a Pressure Chamber (11) with two pressure gauges on 0-21 kg/cm^2 is the input pressure gauge and other 0-17.5 kg/cm^2 is the test pressure gauge. A pressure chamber (11) fitted with a schreader valve water inlet for pouring water and a valve is provided as a water source.

Cast 150 mm cube specimen of concrete by standard method. After demoulding and 28 days curing, the specimen shall be thoroughly cleaned with a stiff wire brush to remove all laitance, lightly chisel the end faces. Paste the top surface of the specimen with a piece of paper to prevent the sealing compound from blocking the face.

The test should preferably be carried out at a temperature of 27ºC$\pm$2ºC. Weight the glass bottle and keep it in position to collect the water percolating through the specimen. Fill the pressure chamber, cell assembly with water. Start the compressor. Apply 0.5 kg/cm^2 air pressure to the water column at the top of the specimen, pressure being regulated by turning the handle of pressure regulator clockwise direction and then opening the release valve. Collect the quantity of water passing through the cube at the bottom in the glass bottle through the funnel being maintained in humid atmosphere to prevent losses due to evaporation. Record the operating pressure, quantity of water collected and time observation etc. at intervals and continue the test till a uniform rate of flow is obtained. A typical pervious concrete setup was designed based on the constant head method as shown in figure1.

The coefficient of permeability may be calculated as follows:

$$K = Q / A\,T*(H/L)$$

Where, K = Coefficient f Permeability in cm/s

T= Area of the Specimen face in cm^2

H/L= Ratio of Pressure Head to the Thickness of Specimen

Q= Quantity of water in milliliters

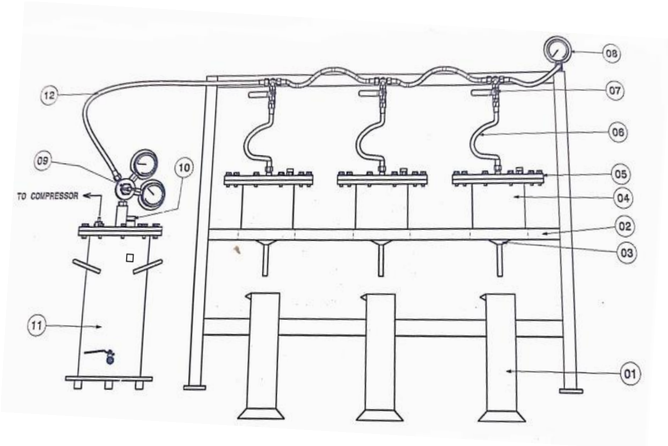

Figure1. Permeability Test Setup

4. Results and Discussion

Testing of fresh and hardened concrete is important in concrete construction. The tests concerned with fresh concrete to check the workability of concrete. Compressive strength, flexural strength, split tensile strength and permeability tests are conducted for hardened concrete. The fresh and hardened properties of pervious concrete were tested and their test results are tabulated in table 5 and figures 2 to 5.

Table5. Properties of Pervious Concrete

Mix	Compressive Strength (N/mm²)		Split Tensile Strength (N/mm²)	Flexural Strength (N/mm²)	Permeability (cm/s)
	7 Days	28 Days			
CM	8.15	9.56	3.04	2.89	1.150
MK-1	7.67	9.10	3.60	3.65	1.148
MK-2	7.45	8.30	3.20	2.75	1.150
MK-3	6.45	6.89	2.64	2.63	1.153
MK-4	5.89	6.37	2.36	2.28	1.154

4.1 Workability

The workability of pervious concrete was evaluated by conducting slump cone test. The slump value of pervious concrete at different replacement level of metakaolin of conventional mix, 1%, 2%, 3% and 4% are respectively was 170 mm, 173 mm, 178 mm, 180 mm and 183 mm. As a result the workability of pervious concrete is high .The slump values of pervious concrete are represented by graph as shown in figure 2.

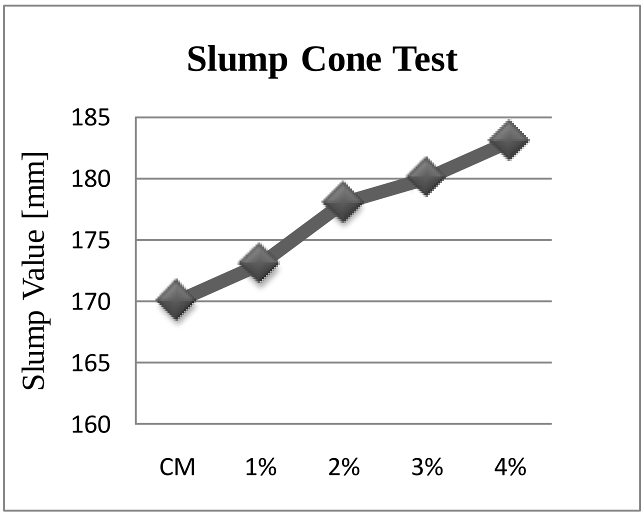

Figure2. Slump values on pervious concrete

4.2 Compressive Strength

The compressive strength of pervious concrete at 7 days and 28 days for conventional mix, MK Mix-1, MK Mix-2, MK Mix-3 and MK Mix-4 are respectively 8.15 N/mm², 7.67 N/mm², 7.45 N/mm², 6.45 N/mm² and 5.89 N/mm², 9.56 N/mm², 9.10 N/mm², 8.30 N/mm², 6.89 N/mm² and 6.37 N/mm². The compressive strength of pervious concrete was decreased gradually at all ages when increasing the rate of metakaolin content. The variations in compressive strength of pervious concrete as shown in figure 3.

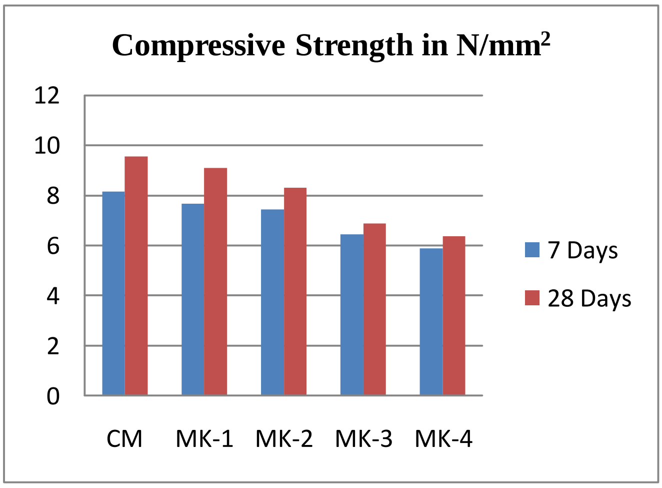

Figure3. Compressive Strength of pervious concrete

4.3 Split Tensile Strength

The split tensile strength of pervious concrete at 28 days for conventional mix, MK Mix-1, MK Mix-2, MK Mix-3 and MK Mix-4 are respectively 3.04 N/mm², 3.60 N/mm², 3.20 N/mm², 2.64 N/mm² and 2.36 N/mm². The optimum split tensile strength was obtained at MK Mix-1 as 3.60 N/mm². The variations in split tensile strength of pervious concrete as shown in figure 4.

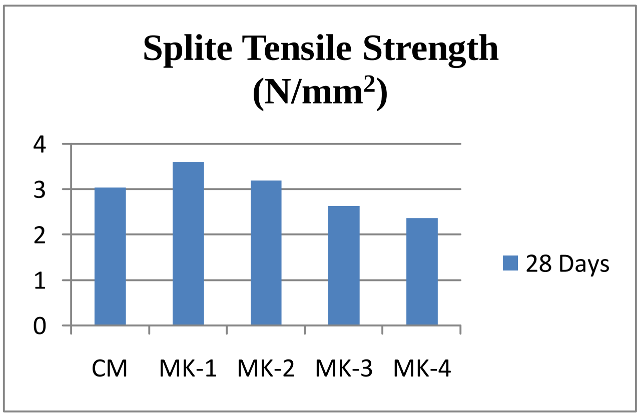

Figure4. Split Tensile Strength of pervious concrete

4.4 Flexural strength

The flexural strength of pervious concrete at 28 days for conventional mix, MK Mix-1, MK Mix-2, MK Mix-3 and MK Mix-4 are respectively 2.89 N/mm², 3.65 N/mm², 2.75 N/mm², 2.63 N/mm² and 2.28 N/mm². The optimum flexural strength was obtained at MK Mix-1 as 3.65 N/mm². The variations in flexural strength of pervious concrete as shown in figure 5.

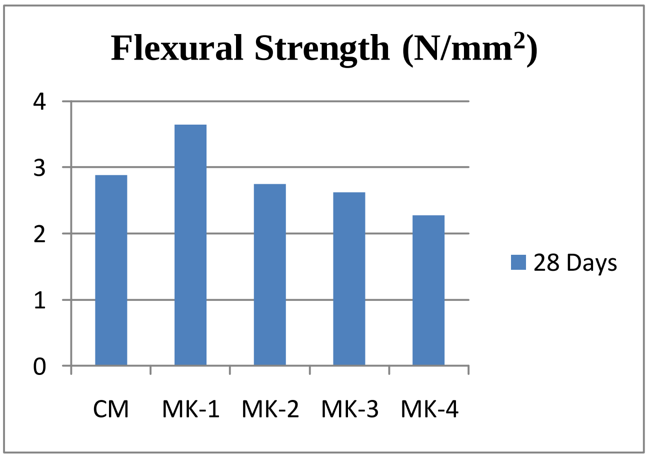

Figure5. Flexural Strength of pervious concrete

4.5 Permeability

Permeability of concrete is mainly depends only on the characteristics of the porous medium [12]. Large size aggregates having more permeability values than the small size aggregates. All mixes having more or less similar permeability values. The obtained permeability values for all mixes as shown in figure 6.

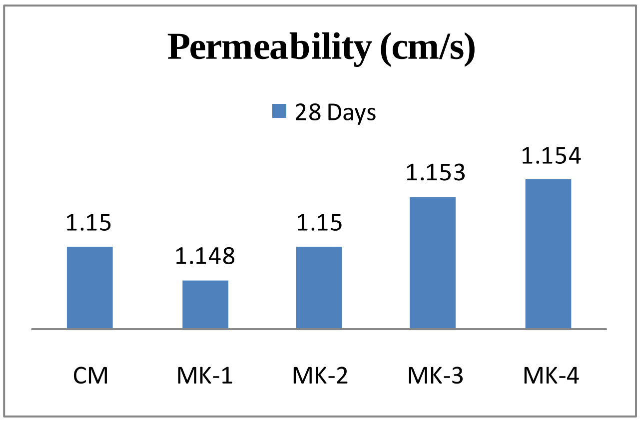

Figure6. Permeability of pervious concrete

5. Conclusion

The fresh and hardened properties of pervious concrete were studied in this paper. The experimental studies were carried out to determine the workability, compressive strength, split tensile strength, flexural strength and permeability. The slump value of pervious concrete was gradually increased by increasing the metakaolin content in pervious concrete. So MK content improves the workability of concrete. The compressive strength of pervious concrete was decreased gradually at all ages when increasing the rate of metakaolin content. The optimum value of split tensile strength and flexural strength were obtained at MK Mix-1 are respectively 3.60 N/mm² and 3.65 N/mm². All mixes having more or less similar permeability values. So metakaolin does not affect the permeability characteristics of pervious concrete.

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