International Journal of
Civil Engineering (IJCE)
ISSN(P): 2278-9987; ISSN(E): 2278-9995
Vol. 4, Issue 6, Oct - Nov 2015, 19-28

International Academy of Science, Engineering and Technology
IASET Connecting Researchers; Nurturing Innovations

STRENGTH AND PERMEABILITY OF HIGH PERFORMANCE CONCRETE CONTAINING METAKAOLIN

HEMA ANN MATHEW[1] & NIVIN PHILIP[2]

[1]PG Scholar, Computer Aided Structural Engineering, Department of Civil Engineering,
Mar Athanasius College of Engineering, Kothamangalam, Kerala, India

[2]Assistant Professor, Department of Civil Engineering, Mar Athanasius College of Engineering,
Kothamangalam, Kerala, India

ABSTRACT

High performance concrete is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. Use of pozzolanic materials is necessary for producing high performance concrete. These materials when used as mineral admixtures in high performance concrete can improve both strength and durability properties of concrete. This paper focus on the comparison of metakaolin and palm oil fuel ash for selecting a suitable admixture for developing high performance concrete (M60 grade). Two types of concrete mixes were prepared and compared to obtain the optimum design mix. The mechanical and permeability properties of the optimum mix were also studied.

KEYWORDS: High Performance Concrete, Metakaolin, Palm Oil Fuel Ash, Permeability

INTRODUCTION

High performance concrete (HPC) is a concrete mixture, which possess high durability and high strength when compared to conventional concrete. This concrete contains one or more of cementitious materials such as fly ash, silica fume or ground granulated blast furnace slag and usually a super plasticizer. The use of some mineral and chemical admixtures like silica fume and super plasticizer enhance the strength, durability and workability qualities to a very high extent. In recent years, metakaolin and palm oil fuel ash has been used as mineral admixtures in high performance concrete.

Metakaolin is a thermally activated alumino-silicate material obtained by calcining kaolin clay within the temperature range 650-800°C. It contains typically 50-55% SiO_2 and 40-45% Al_2O_3 and is highly reactive. Palm oil industry produces a large amount of waste in the forms of empty fruit bunches, fibers and kernels. These by-products are normally used as fuel to heat up boiler for generation of electricity in palm oil factories. The ash derived from the process has been known as palm oil fuel ash (POFA).

In this study, the experimental program consists of different stages. As the first stage, HPC mix of strength $60N/mm^2$ was developed using IS 10262-2009 and IS 456-2000. To select a suitable pozzalonic material for the mix, both metakaolin and POFA was replaced with cement in different percentages. Optimum percentage of replacement was found out by carrying out the compression test. As the next stage, different test were performed to study the mechanical and permeability properties of concrete.

MATERIALS AND MIX DESIGN

Materials

Ordinary Portland cement (53 grade) confirming to IS 12269-1999 was used for the experimental program. M-sand less than 4.75 mm size was used as fine aggregate. Laboratory tests were conducted on fine aggregate to determine the different physical properties as per IS 2386 (Part III)-1963. Aggregate of 20mm and 12.5mm size were chosen for the experiment which is clean and free from deleterious materials. Metakaolin obtained from Ashapura Minechem Limited, Trivandrum in Kerala was used in the investigation. The specific gravity of metakaolin was 2.16. Figure 1 shows metakaolin.

Table 1: Chemical Composition of Metakaolin and POFA

Chemical Composition	% in Metakaolin	% in POFA
Silicon dioxide (SiO_2)	50 – 54	33.6
Aluminium oxide (Al_2O_3)	41- 45	12.5
Iron oxide (Fe_2O_3)	0.5 – 1	4.3
Calcium oxide (CaO)	0.4 – 0.8	8.1
Magnesium oxide (MgO)	Nil	4.5
Sodium oxide (Na_2O)	Nil	0.37
Potassium oxide (K_2O)	Nil	3.5
Sulphur trioxide (SO_3)	Nil	2.8

Figure 1: Metakaolin

Figure 2: Palm Oil Fuel Ash

POFA obtained from Oil Palm India Limited, Kollam in Kerala was used in the investigation. The specific gravity of Palm oil fuel ash was 1.57. The chemical composition of POFA was tested at Sophisticated Test and Instrumentation Centre, CUSAT. The chemical composition of metakaolin and POFA is given in Table 1. Figure 2 shows Palm Oil Fuel Ash. Master Glenium SKY 8233 was used as a chemical admixture.

Mix Design

High performance concrete mix of strength 60N/mm^2 was developed using IS 10262-2009 and IS 456-2000 shown in Table 2.

Table 2: Mix Design

Materials	Content (per m^3)
Cement	478 kg
Fine aggregate	650 kg
Coarse aggregate (20 mm)	738 kg
Coarse aggregate (12.5 mm)	492 kg
Superplasticier	1 % of cement content
Water	158 litres
W/C	0.33

EXPERIMENTAL PROGRAM

Stage 1: Comparison of Admixtures

Table 3: Mix Proportions

Mix	Cement (kg/m^3)	Metakaolin / POFA (kg/m^3)	Coarse Aggregate (20mm)	Coarse Aggregate (12.5mm)	Fine Aggregate	Superplasticiser (% by Weight of Cement)	Water (kg/m^3)
CM	478	-	738	492	650	1	158
MT5/ PF5	454.1	23.9	738	492	650	1	158
MT10/ PF10	430.2	47.8	738	492	650	1	158
MT15/ PF15	406.3	71.7	738	492	650	1	158
MT20/ PF20	382.4	95.6	738	492	650	1	158

Concrete mixes where prepared with water binder ratio 0.33. First the control mix was prepared without metakaolin and POFA. Secondly, both metakaolin and POFA was used to replace a portion of ordinary Portland cement (OPC) at 5%, 10%, 15%, 20% by weight of binder. Concrete cubes of 150x150x150mm were cast in steel mould. The concrete were removed from the mould after 24 hrs of casting and cured in water. They were tested to determine the compressive strength at 7 and 28 days. The compression load was applied using a compression testing machine with 5000kN capacity. Mix proportions of different concrete mixes are shown in Table 3.

RESULTS AND DISCUSSIONS

The compressive strength of concrete specimen was calculated according to IS 516-1959. The compressive strength of control mix at 7 days and 28 days was obtained as 39.30MPa and 50.87MPa respectively. The results of compressive strength of metakaolin concrete and POFA concrete are shown in Table 4 and Table 5 respectively, where each value is an average from the results of three cubes. The results show that metakaolin used in this study is superior to palm oil fuel as in strength enhancement.

Table 4: Compressive Strength of Metakaolin Concrete

Type of mix	7 Days (MPa)	28 Days (MPa)
MT 5	55.69	73.40
MT 10	61.86	74.46
MT 15	61.50	75.26
MT 20	55.20	68.86

Table 5: Compressive Strength of POFA Concrete

Type of mix	7 Days (MPa)	28 Days (MPa)
PF 5	40.57	53.90
PF 10	44.56	55.60
PF 15	29.06	43.34
PF 20	25.13	37.25

7 days and 28 days compressive strength of metakaolin concrete was higher than the control mix for all the percentage replacement (Figure 3). For POFA concrete, 5% and 10% replacement levels shows higher compressive

strength than control mix at 7 days and 28 days (Figure 4). At 15% and 20% replacement of POFA, the compressive strength was lower than the control mix.

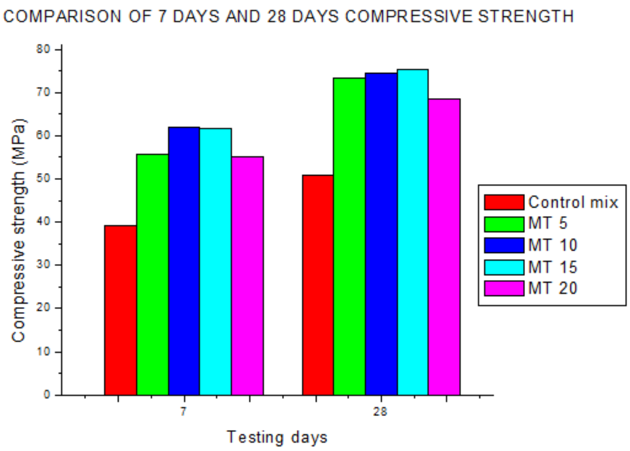

Figure 3: Comparison of Control Mix and Metakaolin Concrete

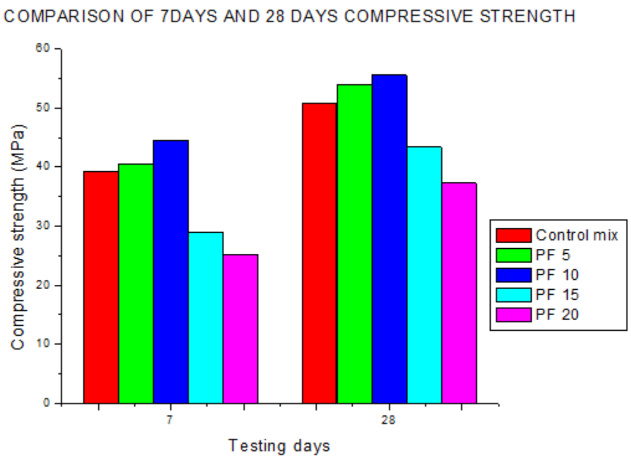

Figure 4: Comparison of Control Mix and POFA Concrete

Figure 5 shows the comparison of metakaolin and POFA concrete at 7days and 28days respectively. Among the different replacement levels, the replacement level of 10% metakaolin with cement performed the best at 7 days (61.86 MPa) and 15% replacement at 28 days (75.26 MPa). All replacement levels of metakaolin with cement performed better in strength than POFA concrete. Metakaolin contributes strength of concrete at early ages mainly by the fast pozzolonic reaction. However, the incorporation of POFA did not result in strength increase for the concrete in 7 days. The low compressive strength of POFA concrete at 7 days was due to the low cement content, resulting in a low C_3S content. Maximum compressive strength of POFA concrete at 28 days was observed at replacement level of 10% palm oil fuel ash with cement which is 55.60MPa. At 15% and 20% replacement level the compressive strength suddenly drops to 43.34MPa and 37.25MPa respectively.

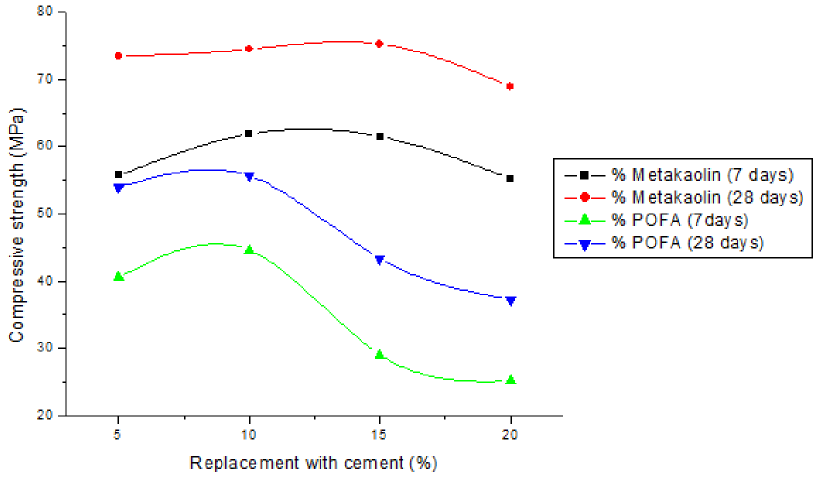

Figure 5: Comparison b/w Metakaolin and POFA Concrete

The optimum dosage of admixture for getting maximum compressive strength for M60 grade of concrete was 15% of metakaolin. So, MT 15 mix was selected as the optimum mix.

STAGE 2: MECHANICAL PROPERTY OF DESIGN MIX

Compression Test

The concrete cubes of size 150mmx150mmx150mm were cast and cured. Test was conducted for 7days, 28days and 56days using compression testing machine. Compression test was carried out according to IS 516-1959. Table 6 shows the cube compressive strength.

Table 6: Compressive Strength

Sample	Specimen (MT 15)	Compressive Strength (MPa)	Average Value (MPa)
1	7 days	60.08	61.09
2		63.44	
3		59.76	
1	28 days	73.49	75.34
2		74.25	
3		78.28	
1	56 days	76.31	78.09
2		78.54	
3		79.43	

The compressive strength at 28days was 75.34MPa which was 10.3% more than the target strength. Compared to the days of curing, after 28 days the strength increment of specimens is less than 5%. This suggests that curing of specimen after 28days doesn't have much effect in strength.

Splitting Tensile Test

Split tensile test was carried out according to IS 5816-1999 and for the same, three cylindrical specimens were tested. The concrete cylinders of diameter 150mm and of height 300mm were cast and cured. The specimens were tested on 7 days and 28 days. Table 7 shows the splitting tensile strength of specimens. The splitting tensile value at 7 days and

28 days of optimum design mix is less than the minimum value 4.8 MPa calculated by the formula $\frac{f_{tsp}}{f_c} = 0.387{f_c}^{-0.37}$ [ACI Materials Journal].

Table 7: Splitting Tensile Strength

Sample	Specimen (MT 15)	Split Tensile Strength (MPa)	Average Value (MPa)
1	7 days	3.50	3.12
2		2.75	
3		3.11	
1	28 days	4.44	4.09
2		3.76	
3		4.09	

Flexural Strength Test

Flexural strength test was conducted on a universal testing machine. Specimens of size 150mmx150mmx700mm were made following the specifications as per IS 516-1959 and stored in water curing tank for the specified period. Hand compaction technique was adopted. Three specimens were cast and tested on 7days and 28days. Table 8 shows the flexure strength of beam specimens.

Table 8: Flexural Strength

Sample	Specimen (MT 15)	Flexural Strength (MPa)	Average Value (MPa)
1	7 days	7.32	7.32
2		7.39	
3		7.26	
1	28 days	7.84	7.90
2		7.91	
3		7.96	

The flexure strength of concrete should be 8 to 11 percentage of compressive strength of concrete for high strength concrete. The relation between the compressive strength and flexure strength is given as flexural strength = $0.7\sqrt{f_{ck}}$ [16]. The value obtained using this equation was 5.77 and the flexural strength of optimum mix was greater than $0.7\sqrt{f_{ck}}$.

STAGE 3: PERMEAILITY PROPERTY OF DESIGN MIX

The test permits measurement of the water entering the specimen as well as that leaving it. Test is performed in a three cell permeability cell according to IS 3085-1965. 100mm x100mm x 100mm cube is cast and cured till the date of test. Specimen was placed in the permeability cell and sealed with sealing compound on all the four sides. A mixture of beeswax and rosin was used as sealing compound. Water pressure of 5- 10 kg/cm^2 was applied and the water flowing through the concrete specimen was collected and measured. Permeability test was continued for about 100 hours after the steady state of flow has been reached and the outflow shall be considered as average of all the outflows measured during this period of 100 hours. The test was carried out at a temperature of 27°± 2°C. The calculations are shown in Table 9.

The coefficient of permeability calculated as follows:

$$K = \frac{Q}{AT\frac{H}{L}} \quad (1)$$

Where,

K is the coefficient of permeability in m/sec;

Q is the quantity of water in millilitres percolating over the entire period of test after the steady state has been reached;

A is the area of the specimen face in $m^2 = 0.01\ m^2$;

T is the time in seconds over which Q is measured = 100 x 60 x 60 = 360000 sec;

H/L is the ratio of the pressure head to thickness of specimen, both expressed in the same units

Table 9: Coefficient of Water Permeability

Sample	Specimen (MT 15)	Pressure Head H (m)	Quantity of Water Collected Q (ml)	Coefficient of Permeability K (x 10^{-9} m/sec)	Average Value (x 10^{-9} m/sec)
1	28 days	65	1870	0.79	0.796
2		65	1910	0.81	
3		65	1850	0.79	

The value of water permeability of optimum mix at 28 days was 0.796 x 10^{-9} m/sec which was low as per IS 3085 – 1965 (Table 10). The lower water permeability may be due to the use of pozzolanic material (metakaolin) in optimum proportion and due to the conversion of $Ca(OH)_2$ into cementitious materials which makes concrete dense.

Table 10: Coefficient of Water Permeability Ranges as per IS: 3085-1965

Water Permeability	Very low	Low	Medium	High
Coefficient of permeability (x 10^{-9} m/sec)	< 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0

CONCLUSIONS

Stage 1

- 7 days and 28 days compressive strength of metakaolin concrete was higher than the control mix for all the percentage replacement.
- For POFA concrete, 5% and 10% replacement levels shows higher compressive strength at 7 days and 28 days. At 15% and 20% replacement of POFA, the compressive strength is lower than the control mix. But for all replacement levels, compressive strength is less than the target strength.
- Metakaolin concrete showed early strength compared to POFA concrete due to fast pozzolanic reaction and also performed better in strength than POFA concrete at 7 days and 28 days.
- The optimum dosage of admixture for getting maximum compressive strength for M60 grade of concrete was 15% of metakaolin. So, MT 15 mix was selected as the optimum mix.

Stage 2

- The result of the present investigation indicated that compressive strength of optimum mix was higher than the target strength and there is no significant improvement in compressive strength after 28 days when metakaolin was used as mineral admixture.
- Flexure strength of optimum mix was 36% higher than the minimum value calculated but the splitting tensile strength of optimum mix was 17.3% less than the minimum value required.

Stage 3

- Optimum mix showed lower water permeability value so it can be used for liquid retaining structures and offshore structures. The lower value may be due to the filler effect of MK particles which has substantially reduced the porosity of the concrete.

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