



Flexural Strength Evaluation of Prestressed Concrete Beams with Partial Replacement of Cement by Metakaolin and Flyash

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Abstract: *The present study deals with the effects of mineral admixtures, by partial replacement of cement, in terms of improved performance on compressive and flexural strengths and durability of prestressed concrete beams.*

Experimental work was carried out to investigate the effect of Metakaolin(MK) and Fly ash(FA) by partial replacing cement and using same quantity of water i.e. increasing W/C ratio to OPC+MK and OPC+FA. In this program 90 cube samples of size 150mmx150mmx150mm for different percentages of MK and FA with partial replacement of cement were casted and tested. The concrete mixes had 0%,10%,20%,30% of FA and 0%,5%,10%,15%,20%,25%,30% of MK, replacing cement partially, so as to determine the best proportion, which would give maximum compressive strength(CS). It reveals that with 10% MK and FA each partial replacement of cement were found to be most favorable combinations for casting of prestressed concrete flexural members. Using the optimum mix proportion giving the best results in CS of cube testing, prestressed beam specimens were casted and tested for their flexural strength. Three, four and three beam specimens of the same dimensions were casted for various mix proportions viz OPC 100% ,MK 10%+OPC 90% and FA 10%+OPC 90% respectively. The dimensions of each beam were 75mm X 100mm X 1000mm. The beams were tested on universal testing machine (UTM) to verify their flexural strength after 28 days of curing with single point load and strains measured on prestressed tendons at different time intervals. The results were compared with the beams of varying strains for prestressed losses and flexural strength of OPC, OPC+MK, OPC+FA.

Key Words: *Prestressed concrete beam, metakaolin, fly ash, strains, prestressed losses, flexural strength.*

I. INTRODUCTION

Ordinary Portland Cement (OPC) and pozzolonas are commonly used in concrete production. Originally the term pozzolona was associated with naturally formed volcanic ashes and calcined earths, which react with lime at ambient temperatures in the presence of water. In recent times the term has been extended to cover all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react chemically with calcium hydroxide (CH) to form compounds that possess cementitious properties (Bezrra et.al 2006). This generalized definition covers waste products such as fly ash (FA), rice husk ash, silica fume (SF) and calcined clay in the form of MK. The utilization of supplementary cementing materials or pozzolonas results in added technical advantages manifested in reductions in temperature rise and durability and strength enhancement (Sayed et.al.2009). With the utilization of calcined clay in the form of metakaolin (MK) as a pozzalonic addition for mortar and concrete, much of the interest has focused on removal of the CH, which is produced due to the hydration of cement and is associated with poor durability (Sabir et.al.2001). CH removal has a major influence on resistance of sulphur attack and alkali silica reaction (ASR), and also provides enhanced strength, which is derived from the additional cementitious phases generated by reaction of CH with MK (Sidiqqi et.al.2008). MK is produced from high purity Kaolin clay by calcinations at moderate temperature (650-800°C). It contains silica and alumina in an active form which will react with the CH and enhanced strength and durability of concrete (Sayed et.al 2009).

II. RESEARCH SIGNIFICANCE

The presented research is aimed at studying the mechanical/index properties like optimum percentage of MK and FA with partial replacement of cement, to determine the optimum concrete mix. The optimum concrete mix is used to determine the compressive, flexural strength. The present study is also aimed at determining and

verifying the hypothesis that the prestressed losses increase with time interval. The study also aims at determining the flexural strength of the prestressed concrete beams based on the cross sectional dimensions, span and amount of steel used and compared with actual strength obtained based on experimental results. The research findings will help engineers to understand the overall performance of prestressed concrete for flexural strength.

III. EXPERIMENTAL PROGRAM AND SETUP

The experimental programme is divided in four phases a) Concrete mix design as per IS 10262-1982 for M30 grade of concrete. MK, FA after partial replacement of cement with varying percentages. So as to determine the optimum combination of MK and FA, which will give the maximum compressive strength (CS)? b) Two prestressed strands of 4 mm diameter each and with a prestressing force 6789.185N (1081 MPa) in each strand. c) Installation of strain gauges on stressed tendons to carry out strain measurements before and after casting of concrete beam specimens and later on transferring the stress entirely on beam specimens after cutting the strands. d) Testing of all prestressed beam specimens with single point loading for flexural strength and comparison of results along with measurement of strains at different time intervals to evaluate prestress losses.

IV. SPECIMEN DESIGN:

All ten specimens were designed to have the same nominal cross sectional dimensions width 75mm, depth 100mm and span 1000mm. The cross section details are shown in figure.1.

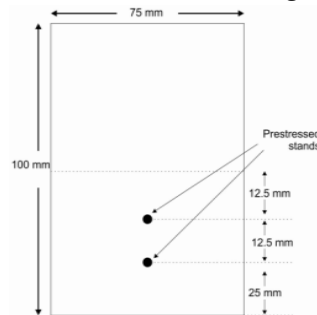


Figure 1: Cross section details

All specimens were designed to have same prestressing force $P_u = 13578.37\text{N}$ and same amount of prestressed steel (25.11 mm^2). Two strands were used each having 4mm diameter.

V. MATERIALS

Prestressed strand (IS:1786-1979) having ultimate tensile strength 175 kg/mm^2 , proof stress at 0.2 percent extension 169.1 Kg/mm^2 , modulus of elasticity 21485 Kg/mm^2 . Cement of 53 grade. Fineness of cement = $5\% < 10\%$ (IS:269-1976). Standard Consistency Test = $29.25\% < 30\%$ (IS:4031-1968), Initial Setting Time = 115 minutes > 30 minutes (minimum) (IS:269-1976), Final Setting Time = 258 minutes > 600 minutes (maximum) (IS:269-1976). Batch type concrete mixing (IS:4634:1968) was carried out. Coarse aggregate consisted of a 20mm maximum size with crushing value = $(\text{Weight of fraction passing through } 2.67\text{mm I.S. sieve} / \text{Weight of aggregate}) \times 100 = 18.73\%$ (IS:2386-Part-4) and Aggregate impact value = $(\text{Weight of fraction passing through } 2.67\text{mm I.S. sieve} / \text{weight of sample}) \times 100 = 11.50\% < 45\%$ (IS 283-1970). Fine aggregate (IS 2386-(Part-I)-1963) specific gravity = 2.6 and fineness modulus = 2.9. Potable water was used for mixing and curing of concrete (IS:456-2000). Water/cement (W/c) ratio was $0.48 < 0.6$ (IS 456-2000). MK (IS:1489(PT2):1991, for physical and chemical properties Refer Appendix Table No.3,4,5. FA (IS 3812 – Part I– 2003) for physical and chemical properties Refer Appendix Table No.1&2. For M30 mix as per IS code method the mix proportions 1:1.499:3.06 and W/c ratio 0.48. The concrete batch weights were 387.5 Kg/Cum cement, 581 Kg/cum river sand, 1185 Kg/cum coarse aggregates (20mm nominal size), 186 Kg/cum water.

VI. SPECIMEN CASTING:

90 cube samples of size $150\text{mm} \times 150\text{mm} \times 150\text{mm}$ for different percentages of MK and FA in partial replacement of cement were casted. The concrete mixes had 0%, 10%, 20%, 30% FA and 0%, 5%, 10%, 15%, 20%, 25%, 30% of MK with partial replacement of cement. All cubes were casted in one lift and consolidated using machine vibrator. After final setting of cubes, the cube moulds were removed and cubes were kept in water tank for curing up to 28 days.

All specimen beams size 75mmx100mm x1000mm were casted with optimum compressive strength for the specific mix in single lift and consolidated using tamping rods. After setting, the beams were covered with wet gunny bags. The burlap was kept for 3days. At the end of the third day, the forms were stripped. And beams were kept for curing up to 28days.

VII. STRESSING PROCEDURE

The prestressing strands were tensioned a day prior to casting. The strand force was calculated by elongated length as well as by pressure transducer installed on the hydraulic jack. Strain gauges were attached to the strands to monitor strains. Seven days after casting, the prestress force got transferred to the concrete. A gradual release procedure was used to cut the strands by mechanical cutter simultaneously. Immediate losses due to prestress release were measured by monitoring the strain gauge on the strands before and after the release. Changes of the strains on prestressed tendons with respect to losses were observed. Beams were tested for flexural strength after reaching an age of 28 days. The variation of strain at various stages were measured and shown in figure 6.

VIII. TEST SETUP AND PROCEDURE

The beam specimen was simply supported with a concentrated load applied at mid span, as shown in figure-2. Load was applied by using UTM (100 tons capacity) in 100kg increments up to failure load. At each load increment, cracks were inspected and marked, and the beam was photographed. Continuous monitoring was carried out all through the testing.

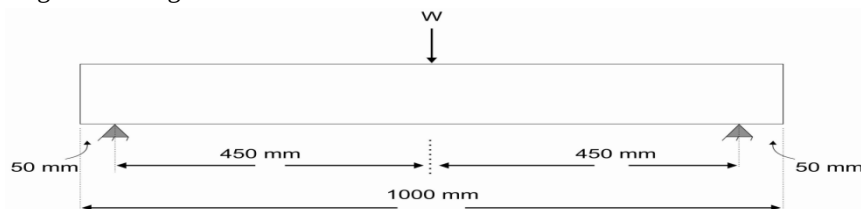


Figure 2: Test set up

IX. STRUCTURAL BEHAVIOUR

All the beams specimens exhibited identical response as the beam size and prestressing force were approximately same. The calculated single point load capacity varied slightly from specimen to specimen due to compressive strength variation and this variation is actually observed. The average carrying load for OPC was 7133N, for OPC+MK was 6000N, for OPC+FA was 5333N (refer figure 4). In the second stage, strains were observed on prestressed tendons, after tensioning of the strand so it was higher and reducing after one day interval before casting of beam specimen due to anchorage slip and steel relaxation. It was slightly linear after casting and before transferring the prestressing force to concrete beam specimen. After cutting strands it drastically increased and later it started reducing gradually due to prestressing losses. Average strain patterns were same for all beam specimens. The beam specimens PC-O-B-1,2,3 were having average strains slightly high than PC-CMK-B-1,2,3 and PC-CFA-B-1,2,3 respectively.

X. TEST RESULTS

As above discussed, flexural strength of prestressed concrete beam specimens were found to be less by using analytical methods than experimental results. Further it was found that OPC+MK based on experimental results were less than that of OPC. Also, strains V/s time curves were indicated more strains in OPC than OPC+MK and OPC+FA curves coincide to with each other.

XI. ANALYSIS OF TEST RESULTS

By comparing the specimens tested it is evident that the compressive strength was reduced for the cubes and beam specimens using MK and FA partially replacing to cement. When quantity of water kept same for all mixes i.e. w/c ratio was increased when MK and FA partially replaced to cement. Refer Figure 3.

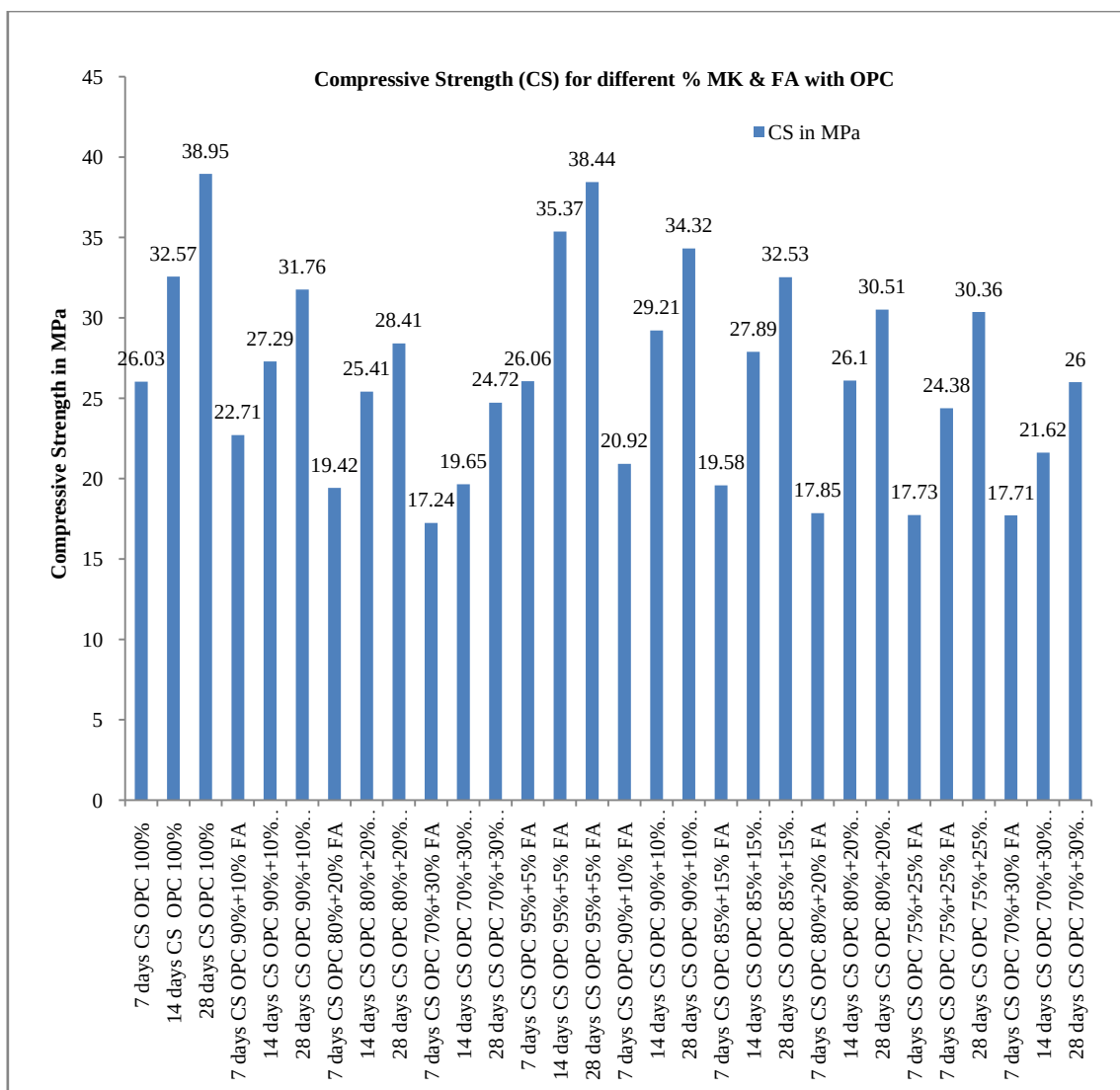


Figure 3: Compressive Strength of different percentage of OPC,MK,FA

From above test results it reveals that Metakaolin and Fly Ash with **10% replacement of cement (by weight)** are most favorable combination for concreting of flexural member as proposed in the present work.

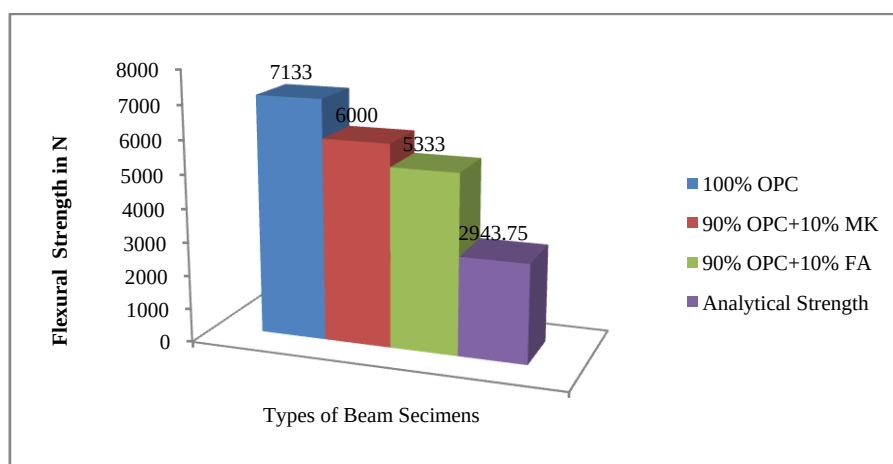


Figure 4: Flexural Strength of 100%OPC,90%OPC+10%MK,90%OPC+10%FA

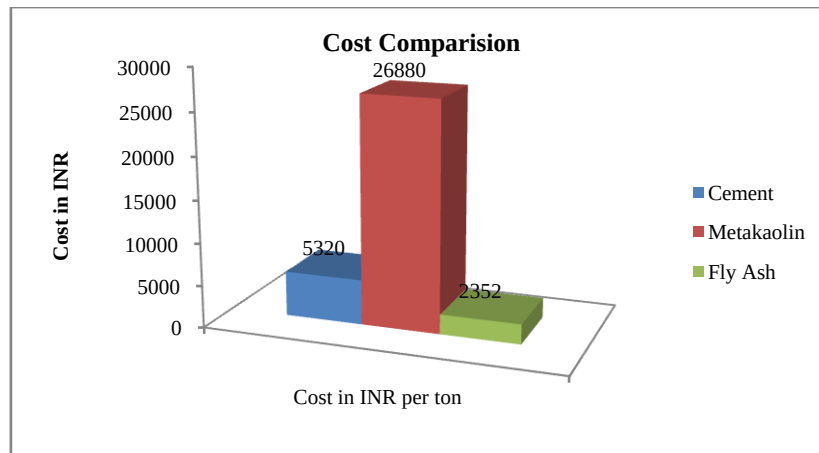


Figure 5: Cost Comparison of Cement, MK and FA in Ton/INR

XII. STRAIN ANALYSIS

Strains were measured on the strand after tensioning, before casting beam specimens, after transferring prestressing force to beams specimen, at the age of 7, 14 and 28 days respectively of prestressed concrete beam specimens. As discussed, earlier ten numbers of beam specimens were casted.

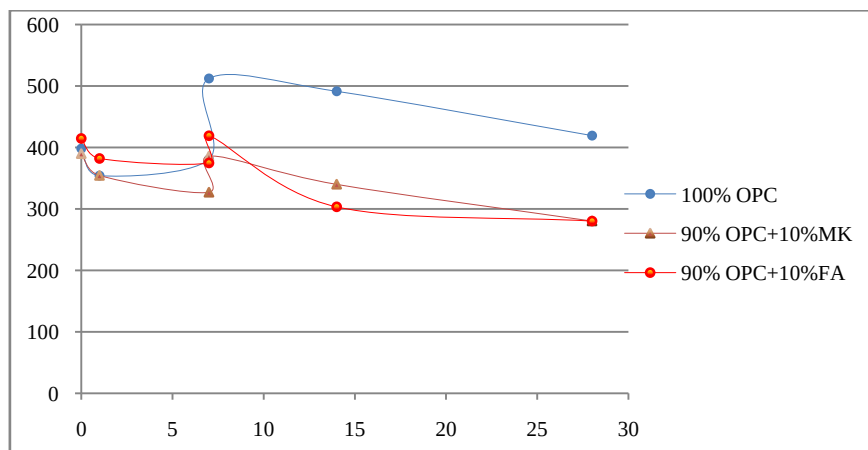


Figure 6: Micro-Strain Comparison of All Beam Specimens

After reviewing and analyzing the results following points are predominantly revealed which are mentioned / discussed as given below:-

With the help of Monostrand Hydraulic Jack, strand is pretensioned as per required extension and it is observed that the strain in each type of beam specimens (i.e. OPC, MK & FA) is almost same range. After casting the beam specimens with M30 grade of concrete, it seems that the strain in each type of beam is reduced by an amount of 30 to 45 micro strains. After 7 days of casting and before cutting the strands, the strain in OPC beam is slightly increased, whereas strain in the MK and FA beam specimen got reduced. Similarly after 7 days of casting and cutting the strands, the strain in each type of specimen is suddenly increased (particularly in OPC beams) as compared to strain before cutting the tendons. Thus strain exceeds and attains its original strain in each type of beam specimen as observed. But after 14 days of casting, the strain values in each type of beam is gradually reduced as compared to the previous strain values by a range of 115 to 20 micro strains. Lastly after 28 days of casting, the strain values in each type of beam has been found to be continuously reducing as observed earlier within the range of 60 to 20 micro strains.

In first phase of prestressing i.e. from first day of tensioning the tendon to 7 days after casting (before cutting the tendons) the strain in OPC beam got reduced and with time and again increased whereas micro strain

in MK and FA beam specimen got reduced. In second phase of prestressing i. e. after concrete got prestressed i.e. at age of 7 days after casting and cutting the tendons to 28 days prestressing, the strain in OPC and FA beam specimens are drastically increased to an extent that it exceeds its original value just after tensioning of the strands, whereas the strain in MK beam specimen is found to be either below or original value. Subsequently the strain in OPC and FA beam specimen rapidly increased until the maturity period of concrete on the other hand, the strain in MK decreased at steady pace. From study of result as shown in figures 6,7,8,and 9 respectively .It is seen that the strain in OPC & FA beam specimens displaced considerable fluctuation in their strain values with respect to time, whereas MK beam specimen show steady variation with respect time.

XIII. CONCLUSIONS

- 1) The Flexural strength of OPC concrete prestressed beam is more than the Flexural strength of metakaolin containing concrete prestressed beam.
- 2) Flexural strength of metakaolin containing concrete prestressed beam is more than fly ash containing concrete prestressed beam.
- 3) Micro strains in all beam specimens show the same pattern and indicate the prestress losses in prestressed concrete beam specimen.
- 4) MK and FA shows better strength results compared to OPC⁽⁵⁾, but in our study it is not reflecting due to increased in w/c ratio to OPC+MK and OPC+FA i.e. same quantity of water were used for OPC,OPC+MK and OPC+FA.
- 5) FA is having maximum benefit than MK in terms of cost and strength comparison

XIV. ACKNOWLEDGMENTS

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APPENDIX A

LIST OF SYMBOLS AND WORD MEANING

Symbol	Description
E_s	Modulus of elasticity of steel in MPa = 200×10^3 MPa
E_c	Modulus of Elasticity of Concrete in MPa = $5000 \sqrt{f_{ck}}$ as per IS 456-2000
F_{ck}	Characteristic compressive strength of concrete in MPa
F_{pu}	Ultimate tensile strength of steel in MPa = 1800 MPa
F_{cr}	Flexural and splitting tensile strengths of concrete = $0.7 \sqrt{f_{ck}}$
PC-O-B-1,2,3	Prestressed concrete beam specimens 1,2,3 respectively with 100% OPC
PC-CMK-B-1,2,3	Prestressed concrete beam specimens 1,2,3 respectively with 90% OPC + 10% MK
PC-CFA-B-1,2,3	Prestressed concrete beam specimens 1,2,3 respectively with 90% OPC + 10% FA
OPC	Ordinary Portland Cement
MK	Metakaolin
FA	Fly Ash
INR	Indian Rupees
f_{ci}	The cube strength at the time of transfer

APPENDIX B

Table 1: Chemical requirements of Fly Ash as per IS: 3812 – Part-1 : 2003

Sr. No.	Characteristics	Requirements
1	Silicon dioxide (SiO ₂) plus iron oxide (Fe ₂ O ₃) percent by mass, Min	70.0
2	Silicon dioxide (SiO ₂), percent by mass, Min	35.0
3	Reactive silica in percent by mass, Min	20.0
4	Magnesium oxide (MgO), percent by mass, Max	5.0
5	Total sulphur as sulphur trioxide (SO ₃), percent by mass, Max	3.0
6	Available alkalis, as sodium oxide (Na ₂ O), percent by mass, Max	1.5
7	Total chloride in present by mass, Max	0.05
8	Loss on ignition, percent by mass, Max	5.0

Table 2 : Physical requirements of Fly Ash as per IS: 3812 – Part-1 : 2003

Sr. No.	Characteristics	Requirements Grade I	Requirements Grade II
1	Fineness – Specific surface in m ² /kg by Blain's permeability method, Min	320	250
2	Lime reactivity – Average comp. strength in N/mm ² , Min	4.5	3.0
3	Comp. strength at 28 days in N/mm ² , Min	Not less than 80 percent of the strength of corresponding plain cement mortar cubes	Not less than 80 percent of the strength of corresponding plain cement mortar cubes.
4	Soundness by Autoclave test expansion of specimens, percent, Max	0.8	0.8

Table 3: Requirements of Metakaolin

Sr. No.	Specifications	Range
1	Lime Reactivity (Chappell Test)	740-1000 g/gm
2	+300 mesh w/w % (Max)	10%
3	Moisture w/w % (Max)	0.5-1.0
4	XRD	Metakaolin
5	Loss on Ignition (%)	0.2 - 0.5%

Table 4: Physical Requirements of Metakaolin

Sr. No.	Physical Requirement	Remarks
1	Appearance	Off- White
2	pH (10% solids)	4.0-5.0
3	Bulk Density (Kg/1)	0.4-0.5
4	Blaine value (cm ² /g)	22000-25000
5	Specific Gravity	2.6

Table 5: Percentage of Chemical compounds in Metakaolin

Sr. No.	Chemical Compounds	Percentage
1	Silicon Dioxide- SiO ₂	52.0-54.0
2	Aluminium Oxide- Al ₂ O ₃	44.0-46.0
3	Ferric Oxide- Fe ₂ O ₃ (Max)	0.60-1.2
4	Titanium Dioxide -TiO ₂ (Max)	0.65
5	Calcium Oxide -CaO (Max)	0.09
6	Magnesium Oxide -MgO (Max)	0.03
7	Sodium Oxide -Na ₂ O (Max)	0.10
8	Potassium Oxide-K ₂ O (Max)	0.03