ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 3, Issue 4, April 2018

Strength and Durability of High Performance Concrete Using Metakaolin

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Abstract:- **In today's world concrete is probably the most extensively used construction material in the world. In this current paper, Metakaolin is used as admixture to produce high strength concrete. Metakaolin can be used as a concrete constituent, replacing part of the cement content, since it has pozzolanic properties. This paper presents experimental studies conducted on HPC mix of M-60 grade using mineral and chemical admixtures in various proportions. According to Indian Standard and Morth, the M-60 grade concrete mix has been designed. The replacement levels has been 0%, 10%, 20%, 30%, 40% and 50% (by using weight) for Metakaolin. The end results obtained from compressive strength, tensile strength, durability and Non Destructive Test (NDT) are to be compared with the conventional specimens. In this paper low water ratio of 0.30 is used and hence, chemical admixture named DARACEM 813 is used for enhancing the workability of concrete. The compressive and tensile test on the hardened concrete is done for 7 days test and 28 days test. The durability of the concrete is tested using acids (Concentrated Sulphuric Acid (H2SO4) and Hydrochloric Acid (Hcl)) and alkaline (Sodium Hydroxide (NaOH)). Finally the NDT of Rebound Hammer and Ultrasound test has been conducted for the cubes.**

Key Words: High Performance Concrete (HPC), Admixtures, Metakaoloin, DARACEM 813, Compressive strength, Tensile strength, Durability test, Acids, Alkaline, Non Destructive Testing (NDT), Rebound Hammer test, Ultrasound test.

INTRODUCTION

In presence world, world is witness of very challenging civil work in constructions and infrastructures. Concrete is the most useful material in civil work. High Performance Concrete is a concrete that possess some special characteristics such as high durability, high workability and if necessary, stronger than conventional concrete. High performance concrete reduces the CO2 level and make environment green. With the use of water reducing admixture or super-plasticizer, high performance concrete has low water-cement ratio (W/C) and low water-binder ratio (W/B). High Performance Concrete can be developed from readily available materials (used for normal concrete) using conventional techniques of mixing, transportation, and placement with the help of admixtures. Construction of several long span bridges, high rise buildings, offshore structures, TV towers and other large structures, calls for construction materials with increasingly improved properties particularly strength, stiffness, toughness, ductility and durability. The various advantages of HPC are listed below:

- Speedy construction,
- Higher seismic resistance, lower wind sway and drift,
- Higher rigidity than steel columns,
- Reduced depth of floor system, cross sections of columns and decrease in overall building height,
- High tensile strength,
- Service life greater than 100 years,
- Durability against chloride attack,
- Higher economy in terms of time and money.

MATERIALS USED ARE DETAILED BELOW

Cement: In HPC, since cement is the main cementitious material, the ultimate performance of the concrete, both in plastic and hardened state, will depend upon the cement characteristics and its interactions with other constituents. Cement is a binder, a substance used for construction that sets, hardens and adheres to other materials, binding them together.

Coarse aggregate: Coarse aggregate is the strongest and least porous component of the concrete. It occupies substantial volume of the concrete and gives concrete its dimensional stability. Crushed hard stone and gravel are the common materials used as coarse aggregates for structural concrete.

Fine aggregate: Fine aggregate principally fills the voids within the coarse aggregate. It is responsible for giving cohesiveness to the concrete mix and has direct bearing on the workability and rheological aspects. The sum of percentage of all types of deleterious substances in fine aggregate should not exceed 5%. Natural river sand is the

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 3, Issue 4, April 2018

most commonly used fine aggregate, River Sand is usually obtained from River Beds and Banks.

Water: Water is the ingredient responsible of the hydration reactions. The IS 456-2000 has stipulated stringent limits for various constituents in water to be used for making concrete. Water should be tested periodically for organic and inorganic matter, sulphates, chloride and suspended matter. The values should fall within permissible limits prescribed.

Mineral admixtures: Admixtures are added in concrete to improve the quality of concrete. Mineral admixtures which possess certain characteristics through which they influence the properties of concrete differently. Moreover, effect of mineral admixtures on the durability and on the mechanical properties of concrete remained a focus of interest. Nevertheless, effect of mineral admixtures on the properties of fresh concrete is very important as these properties may affect the durability and mechanical properties of concrete.
METAKAOLIN: Calcinations of clay mineral (kaolin) at moderately-high temperature. Metakaolin is a highly pozzolanic and reactive material. Metakaolin improves most mechanical and durability properties of concrete. Metakaolin is a processed amorphous silica material and it is obtained from calcinations of kaolin to a temperature between 600 and 850°C (1112 to 1562°F). Kaolin is naturally occurring material; the chemical and mineralogical compositions are highly dependent on the rock from which it is formed. Due to its high surface area and high reactivity, relatively small addition rates of MK produce relatively large increases in strength, impermeability and durability while its light color gives it an aesthetic advantage. In addition, the optimum replacements with respect to strength and durability were determined by varying the amount of MK as partial cement replacement. The various advantages are given below:

- Increased resistance to chemical attack.
- Increased durability.
- Enhanced workability and finishing of concrete.
- Reduced shrinkage, due to "particle packing" making concrete denser.
- Improved color by lightening the color of concrete making it possible to tint lighter integral color.
- Increased compressive and flexural strengths.

Chemical admixtures: Super plasticizers constitute a relatively new category and improved version of plasticizer, the use of which was developed in Japan and Germany during 1960 and 1970 respectively. They are chemically different from normal plasticizers. Use of super plasticizers permits the reduction of water to the extent up to 15% in case of plasticizers.

MIX PROPORTIONS

Cement = 400
Water = 112
Fine aggregate = 678
Coarse aggregate = 1249
Metakaolin = 40
Chemical admixture = 7
Water – cement ratio = 0.3
MIX RATIO = 1: 1.69: 3.12

EXPERIMENTAL PROGRAMME

FRESH CONCRETE TEST: Concrete is tested to ensure that the material that was specified and bought is the same material delivered to the job site.

Slump cone test: The slump test is a mean of assessing the consistency of fresh concrete. It is performed to the workability of fresh made concrete, and therefore the ease with which concrete flows. slump cone test results are shown in Table 1.

Table 1 Slump cone test values

S.No	Description detail	Slump value in (mm)	Slump obtained
1	Conventional concrete	15	TRUE SLUMP
2	Metakolin 10%	5	TRUE SLUMP
3	Metakolin 20%	5	TRUE SLUMP
4	Metakolin 30%	3	TRUE SLUMP
5	Metakolin 40%	4	TRUE SLUMP
6	Metakolin 50%	5	TRUE SLUMP

Flow table test: The flow table test of cement mortar is done only to calculate the amount of water required for gauging for conducting strength of masonry cement and for dying shrinkage test of cement. it also gives us some idea on the workability of cement mortar. The flow table test results are shown in Table 2.

Table 2 Flow table test values

S.No	Description detail	Flow percentage
1	Conventional concrete	32%
2	Metakolin 30%	20%

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 3, Issue 4, April 2018

HARDENED CONCRETE: The sections describe the properties with reference to IS: 1343-1980. The strength of concrete is required to calculate the strength of members. For prestressed concrete applications, high strength concrete is required for the following reasons.

Compressive strength test: The compressive strength of concrete is given in terms of the characteristic compressive strength of 150mm size cubes tested at 7and 28 days (fck). Test for compressive strength carried either in cube or cylinder. Various standard codes recommend concrete cylinder or concrete cube as the standard specimen for the test. Compressive strength of concrete at 07 days should be in the range of 60 to 75% of its characteristic compressive strength as shown in table 3.

Table 3 Compressive strength of cubes for 7 days

Identification mark	Age of cubes (days)	Wt of cubes (kg)	Dimensions of cube (mm×mm×mm)	Failure load (kN)	Compressive strength (N/mm²)
Conventional **P_0**	7	8.38	150×150×150	1098	48.8
Metakolin 10% **P_1**	7	8.52	150×150×150	1140	50.6
Metakolin 20% **P_2**	7	8.44	150×150×150	1179	52.3
Metakolin 30% **P_3**	7	8.46	150×150×150	1239	55.1
Metakolin 40% **P_4**	7	8.34	150×150×150	1244	55.3
Metakolin 50% **P_5**	7	8.40	150×150×150	873	38.8

Thus the results of compressive strength test after 28 days and use this strength as the base for our design and evaluation. Compressive strength of concrete at 28 days should be in the range of 75 to 99% of its characteristic compressive strength as shown in table 4.

Table 4 Compressive strength of cubes for 28 days

Identification mark	Age of cubes (days)	Wt of cubes (kg)	Dimensions of cube (mm×mm×mm)	Failure load (kN)	Compressive strength (N/mm²)
Conventional **P_0**	28	8.48	150×150×150	1098	71.1
Metakolin 10% **P_1**	28	8.56	150×150×150	1140	73.2
Metakolin 20% **P_2**	28	8.51	150×150×150	1179	74.5
Metakolin 30% **P_3**	28	8.55	150×150×150	1239	75.6
Metakolin 40% **P_4**	28	8.44	150×150×150	1244	75.1
Metakolin 50% **P_5**	28	8.49	150×150×150	873	62.9

Split tensile test: It is a standard test, to determine the tensile strength of concrete in an indirect way. This test could be performed in accordance with IS: 5816-1970. A standard test cylinder of concrete specimen (300mm×150mm diameter) is placed horizontally between the loading surfaces of compression testing machine. The splitting tensile strength of concrete that varies between 1/7to 1/12of the cube compressive strength as shown in Table 5.

Table 5 Split tensile test of cylinder for 28 days

Identification mark	Age of cylinder (days)	Dimensions of cylinder (mm×mm×mm)	Failure load (kN)	Compressive strength (N/mm²)
Conventional **C_0**	28	150×300×150	156	2.20
Metakolin 10% **C_1**	28	150×300×150	172	2.43
Metakolin 20% **C_2**	28	150×300×150	197	2.78
Metakolin 30% **C_3**	28	150×300×150	215	3.04
Metakolin 40% **C_4**	28	150×300×150	208.4	2.91
Metakolin 50% **C_5**	28	150×300×150	183	2.62

RESULTS AND DISCUSSION

Effect of variation of metakaolin on compressive strength: The compressive strength of concrete is one of the utmost important and valuable properties of concrete. Compressive Strength of high performance concrete containing Meta kaolin of Conventional, 10%, 20%, 30%, 40% and 50% as shown in Figure 1.1. On comparing the result of compressive strength of cubes after 7days, the peak value obtained in the 40% , Similarly for 28 days the peak value

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 3, Issue 4, April 2018

obtained in 30% replacement of metakaolin as shown in figure 1.2.

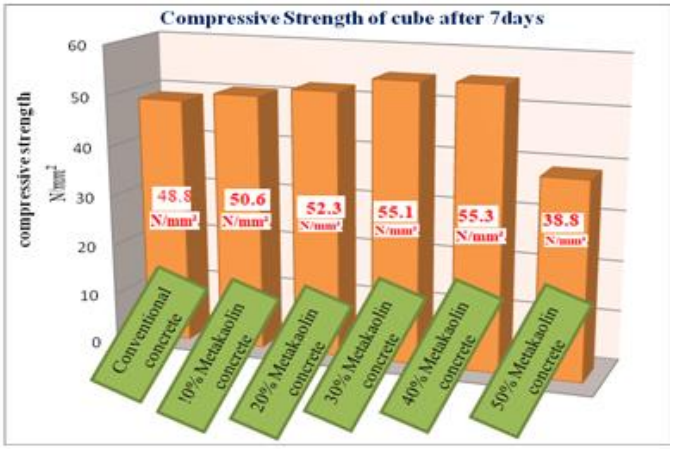

Figure 1 .1 Graph between Compressive Strength of concrete for M60 vs. % of metakaolin [7DAYS]

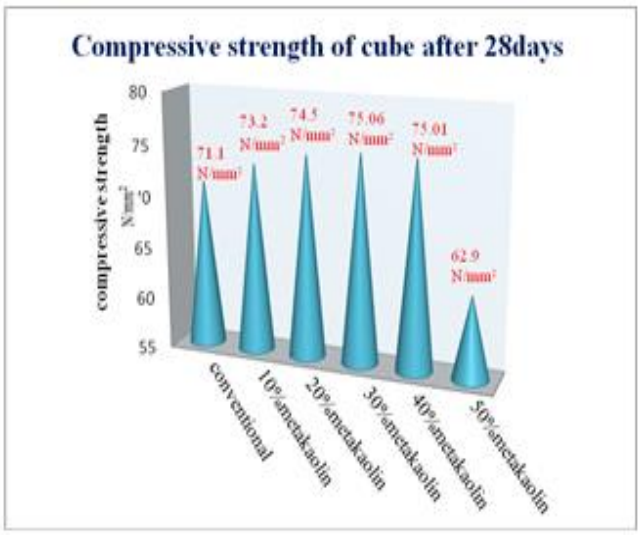

Figure 1.2 Graph between Compressive Strength of concrete for M60 vs. % of metakaolin [28DAYS]

Effect of variation of metakaolin on split tensile strength:

The test was carried out to obtain split tensile strength of M60 grade concrete. The split tensile strength of concrete is tested for 28 days for Conventional, 10%, 20%, 30%, 40% and 50% replacement of metakaolin and the values are presented in Table and also graphs were plotted bellow in Figure 1.3. On comparing the result of compressive strength of cubes after 28days, the peak value obtained in the 30% replacement of metakaolin.

Figure 1.3 Graph between Split Tensile Strength of concrete for M60 vs. % of metakaolin

Durability of concrete:

Durability is defined as the capability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties. It normally refers to the duration or life span of trouble-free performance. Different concretes require different degrees of durability depending on the exposure environment and properties desired. The test on both the solutions was conducted for 1 week. From this weight loss of cubes is calculated.

Weight loss = weight of cube after normal curing – weight of cube after taken form acid.

Acid Test and alkaline test: In order to access the weight loss concrete is exposed to chemical media. For acid test hydrochloric acid and concentrated sulphuric acid was prepared by mixing 5% of solution with one liter of water. As per ASTM G20-8. After normal curing (28days) cubes were taken out and weight of cube was noted. Than weighted cubes was immersed in the prepared Sulphuric acid and hydrochloric acid for 7days. After curing the cubes were taken out from the acid.

H_2SO_4 reaction on concrete:

Sulphuric acid attack causes extensive formation of gypsum in the regions close to the surfaces, and tends to cause disintegrating mechanical stresses which ultimately lead to spalling and exposure of the fresh surface. And the Reaction of H2SO4 with 30% of Metakaolin concrete gives less value compare with conventional, as shown in figure 1.4 .

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
Vol 3, Issue 4, April 2018

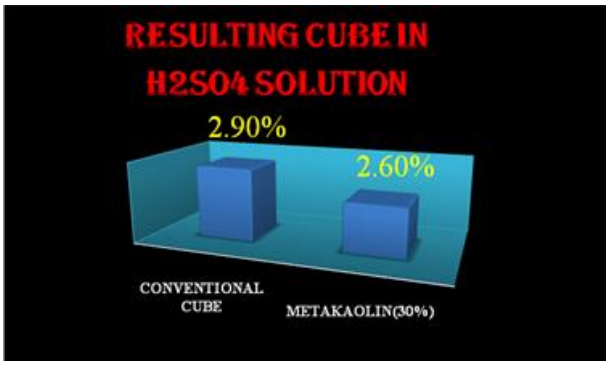

Figure 1.4 Comparison result of H_2SO_4 Solution

Reaction of HCl:

Concrete is susceptible to acid attack because of its alkaline nature. The components of the cement paste break down during contacts with acids. A more aggressive and destructive case of acid attack occurs when concrete is exposed to hydrochloric acid.

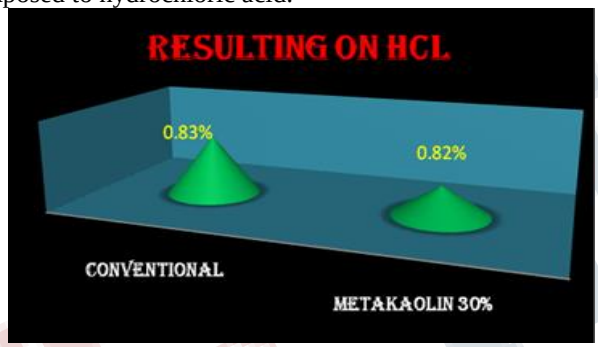

Figure 1.5 Comparison result of HCl Solution

Reaction of NaOH:

Test results indicate that concentration variation of sodium hydroxide had least effect on the fresh properties of SCGC. With the increase in sodium hydroxide concentration, the workability of fresh concrete was slightly reduced. And the Reaction of NaOH with 30% of Metakaolin concrete gives less value compare with conventional, as shown in figure 1.6.

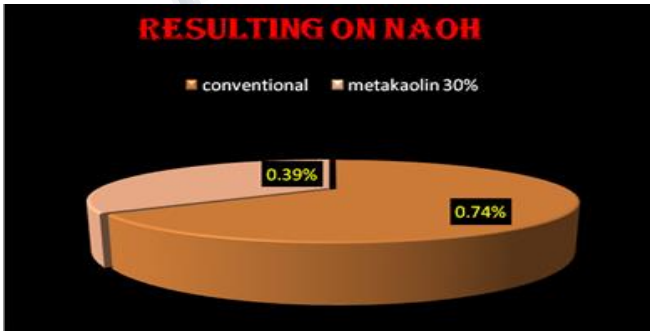

Figure 1.6 Comparison result of H2SO4 Solution

NON DESTRUCTIVES TESTING

Rebound hammer: Rebound hammer test is done to find out the compressive strength of concrete by using rebound hammer as per IS: 13311 (Part 2) – 1992.Commonly adopted equipment for measuring the surface hardness. The hammer impacts against the concrete and spring control mass rebounds, taking the rider with it along the guide scale. By pushing a button, the rider can be held in position to allow the reading to be taken. The rebound hammer results that the 30% metakaolin replacement with cement gets the higher quality of the concrete than other propositions as shown in Table 6.

Table 6 Test Result of Rebound Hammer

TYPE OF CONCRETE	REBOUND NUMBER
Conventional $\mathbf{P_0}$	35
Metakaolin 10% $\mathbf{P_1}$	36
Metakaolin 20% $\mathbf{P_2}$	37
Metakaolin 30% $\mathbf{P_3}$	42
Metakaolin 40% $\mathbf{P_4}$	39
Metakaolin 50% $\mathbf{P_5}$	38

Ultrasound pulse velocity: Ultrasonic pulse velocity testing method, which involves measurement of the time of travel of electronically generated mechanical pulse through the concrete. UPV consists of measuring the time of an ultrasonic pulse, passing through the specimen to be tested. The pulse generator circuit consists of electronic circuit for generating pulses and a transducer for transforming this electronic pulse into mechanical energy having vibration frequencies in the range of 15 to 50 KHZ. The Ultrasonic pulse velocity results that the 30% metakaolin replacement with cement gets the higher quality of the concrete than other propositions as shown in Table 7.

Table7 Result of Ultrasonic Pulse Velocity

TYPES OF CONCRETE	TIME TRAVELLING(μ)	VELOCITY VALUE (KM/SEC)
Conventional $\mathbf{P_0}$	21.4μ	4.20
Metakaolin 10% $\mathbf{P_1}$	20.5μ	4.43
Metakaolin 20% $\mathbf{P_2}$	21.6μ	4.63
Metakaolin 30% $\mathbf{P_3}$	23.5μ	4.88
Metakaolin 40% $\mathbf{P_4}$	22.2μ	4.67
Metakaolin 50% $\mathbf{P_5}$	20.1 μ	3.99

ISSN (Online) 2456 -1304

International Journal of Science, Engineering and Management (IJSEM)
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SUMMARY AND CONCLUSION

The following conclusions are drawn from the study on metakaolin concrete and they are applicable for the range of parameters and materials used in this study. Metakaolin can be used in the parital replacement of cement. It is observed that there is a strength increase with addition Metakaolin of 30% of M60 grade concrete and beyond which there appears to be no specific enhancement in strength.

- The compressive strength of 30% replacement with Metakaolin in M60 grade concrete is 11.38% higher than conventional concrete.
- The split tensile strength of 30% replacement with Metakaolin in M60 grade concrete is 27.4% lower than conventional concrete.
- The weight loss due to acid attack (H2SO4) of 30% replacement with Metakaolin in M60 grade concrete were 2.6% and it is less when compare with the conventional concrete.
- The weight loss due to acid attack (HCl) of 30% replacement of Metakaolin in M60 grade concrete were 0.82% and it is less when compare with the conventional concrete.
- The acid attack is due to presence of high calcium content in the cement, because calcium is the high reactive element in the Periodic table.
- The weight loss due to alkaline attack (NaOH) of 30% replacement of Metakaolin in M60 grade concrete were 0.39% and it is less when compare with the conventional concrete.
- The Non Destructive testing (REBOUND HAMMER) and (ULTRASOUND PULSE VELOCITY) on the cubes that results the 30% replacement of Metakaolin in M60 grade concrete has the high quality of concrete when compared to other proportions.

Thus, it concluded that the 30% replacement of Metakaolin in M60 grade concrete reaches optimum level. However, more research studies are being made on the Metakaolin is necessary for the practical application as Admixtures.

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