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EXPERIMENTAL INVESTIGATION OF CONCRETE WITH METAKAOLIN

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Abstract-* Metakaolin is specially produced by high quality kaolin using the art of thermal treatment technology yielding a highly reactive amorphous material with pozzolanic and latent hydraulic reactivity ideally suited for cementing applications especially for high performance concrete. It is a cementious material used as a mineral admixture to produce high strength concrete. Experimental work was carried out to investigate the strength and durability characteristics of concrete with metakaolin.The cement was replaced by 5%, 10%, and 15% of metakaolin and named as MK5, MK10, and MK15 respectively. The inclusion of metakaolin increased the compressive and flexural strength. The durability of concrete with metakaolin was also assessed by sulphate resistance and rapid chloride permeability test. Concrete containing metakaolin had less weight loss against sulphate attack and better resistance against chloride penetration compared to control mix.

***Keywords–* Metakaolin, Cement, Compressive Strength, Flexural Strength, Sodium Sulphate, Rapid Chloride Permeability**

I. INTRODUCTION

Concrete is the most widely used man made construction material in the world. It is obtained by mixing cement materials, water and aggregates, and sometimes admixtures in required proportions. Concrete is generally classified as a normal strength concrete, high strength concrete and ultra-high strength concrete etc. As per Indian standard a recommended method of mix design denotes the boundary of 35Mpa between Normal strength concrete and high strength concrete. But as per international forum, the high strength concrete label was applied to concrete having strength above 40MPa. Now it have been rose to 55MPa as per IS 456-2000.The strength, durability and other characteristics of a concrete depend upon the properties of its ingredients, on the proportion of mix, the method of compaction and other controls during placing, compaction and curing. Certain materials of mineral origin are also added to concrete to enhance their strength and durability properties of concrete materials such as metakalion and other byproduct like flyash and silica fumes which are generally very fine, may be finer than cement, when added to concrete in right proportion can improve the strength and durability of concrete.

Metakaolin is fine, natural white clay made by heating kaolin to particle structure making it a highly reactive, amorphous pozzolans. Metakaolin has the highest content of siliceous, so it is also called as High Reactivity Metakaolin(HRM). Metakaolin is produced by calcining purified kaolinite clay at a temperature ranging from 700^0 to 900^0c to drive of the chemically bound water and destroy the crystalline structure. Like other pozzolans metakaolin reacts with the calcium hydroxide (lime) byproducts produced during cement hydration. Metakaolin has pozzolanic properties bringing positive effect in resulting properties of concrete. Pozzolanic properties cause chemical reaction which increases strength, durability and other properties.In a mix metakaolin reduces the size of pores in cement paste and transform many finer particles into discontinuous pores. Therefore it decreases the permeability of concrete substantially, metakaolin increases compressive and flexural strengths.

For ordinary concrete: .Cement + water→ calcium silicate (cementious) + calcium hydroxide (non-cementious

For metakaolin added concrete: Cement + metakaolin + water→ calcium aluminate (cementious) + calcium alumina silicate (cementious)

II. MATERIALS AND MIX DESIGN

A. Materials

Ordinary Portland Cement of grade 43 having a specific gravity of 3.15 was used. Locally available sand of specific gravity 2.6 was used as fine aggregates. By sieve analysis the fine aggregates belonged to grading zone 1 as per IS: 383-1970 specification. Coarse aggregates of varying sizes were used. 50% of 20mm, 40% of 12mm and 10% of 6mm diameter aggregates was used and its specific gravity is 2.74. Ordinary potable water was used.

Metakaolin used was tested and had following properties.

The physical and chemical properties of metakaolin are given below in table 1 and 2 respectively.

TABLE I

PHYSICAL PROPERTIES OF METAKAOLIN

Si No	**Test**	**Result**
1	Specific Gravity	2.73
2	Normal Consistency	34%
3	Setting Time – Initial	230 minutes
4	Setting Time – Final	375 minutes
5	90 – Micron Sieve	94%

TABLE II

CHEMICAL PROPERTIES OF METAKAOLIN

1.	Silicon dioxide ($SiO_{2)}$	60-65
2.	Aluminium oxide ($Al_2O_{3)}$	30-34
3.	Iron oxide (Fe_2O_3)	1.00
4.	Calcium oxide (CaO)	0.2-0.8
5.	Magnesium oxide (MgO)	0.2-0.8
6.	Sodium oxide (Na_2O)	0.5-1.2
7.	Loss of ignition	< 1.4

B.Mix Design

Following the procedure from IS 10262-2009 the mix design for control mix, MK5, MK10 and MK15 is done. Cubes, beams and cylinders were prepared and tested. The maximum size of the coarse aggregate used was 20mm and the water cement ratio used was 0.5.Various tests such as compressive strength, flexural strength and durability test were carried out.

III EXPERIMENTAL INVESTIGATION

The casting of cube was done in iron moulds of size 100mmx100mmx100mm. These cubes were used for determining the compressive strength and for assessing its durability. Cylinder of dimension 200mmx100mm was casted for determining its permeability. For flexural strength determination beam of dimension 500mx100mmx100mm was casted. Compaction was done using rods and providing a minimum of 25 blows. Water was used for curing cubes, beams and cylinders.

A. *Testing of Specimen*

1) *Compressive Strength Test*

The compressive strength of cubes of different grades i.e. control mix M20, MK5, MK10 and MK15 for 7, 14 and 28 days were tested. The testing was done using universal testing machine of load capacity 1000kN.

Fig. 1 Compressive Strength Test

2) *Flexural Strength Test*

The flexural strength of beam of different grade i.e. control mix M20, MK5, MK10 and MK15 were determined using universal testing machine of load capacity 1000KN.

Fig. 2 Flexural Strength Test

3) *Durability Test*

Durability tests such as rapid chloride permeability test and sodium sulphate resistance test were done.

i) Rapid Chloride Permeability Test (RCPT)

RCPT is a technique to nondestructively measure the chloride permeability of in-place concrete. The test method involves a 100 mm diameter cylinder sample from the concrete being tested. A 50 mm specimen is cut from the sample and is placed in the test device. The left-hand side (–) of the test cell is filled with a 3% NaCl solution. The right-hand side (+) of the test cell is filled with 0.3N NaOH solution. The system is then connected and a 60-volt potential is applied for 6 hours. Readings are taken every 30 minutes. At the end of 6 hours the sample is removed from the cell and the amount of coulombs passed through the specimen is calculated. The RCPT apparatus with the sample is given is given in figure 3.

Fig. 3 Rapid Chloride Permeability Test

ii) Sodium Sulphate Resistance Test

After completion of 28 days curing, the cubes were immersed in a barrel of distilled water containing 5% of Na2SO4 solution for a period of 14 days and were taken out. They were dried and their weight was taken and their compressive strength was determined. The loss of weight and compressive strength were compared. The specimen immersed in Na2SO4 solution is given below in figure 4.

Fig. 4 Sulphate Resistance Test

IV RESULTS AND DISCUSSION

The physical properties such as specific gravity of cement, sand, coarse aggregates and metakaolin are determined. The specific gravity of cement, sand, coarse aggregates and metakaolin was found to be 3.15, 2.6, 2.74 and 2.73 respectively. Particle size distribution of fine aggregates was studied using sieve analysis and the sand was conformed to be in zone I. The calculated values were used in the mix design and mix proportion of the ingredients is calculated.

A) Compressive Strength Test

The comparison of the experiment result for compressive strength at 7, 14 and 28 days is given in table III and it is further represented in graph i.e. figure 5.

TABLE III. COMPARISON OF COMPRESSIVE STRENGTH

Curing period	**Control mix (M20) in N/mm^2**	**MK5 in N/mm^2**	**MK10 in N/mm^2**	**MK15 in N/mm^2**
7 days	14.4	16.75	20.25	18
14 days	18.8	21.5	23.25	25
28 days	20.5	25.5	29.5	26.5

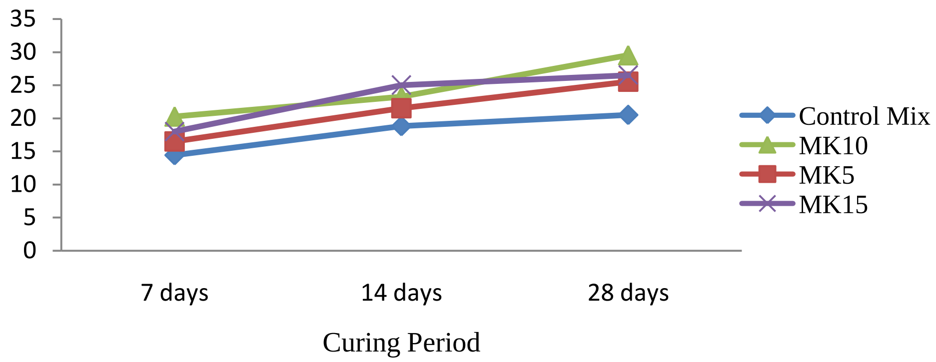

Fig .5 Comparison of Compressive Strength

B) Flexural Strength Test

The flexural strength of beams of different grade control mix i.e. M20, MK5, MK10 and MK15 was tested using Universal Testing Machine. The table IV given below shows the flexural strength of beams of different grades and same is represented in graph in figure 6.

TABLE IV COMPARISON OF FLEXURAL STRENGTH

Grades of concrete	**Flexural strength in N/mm^2**
M20	7.9
MK5	8.6
MK10	9
MK15	8.2

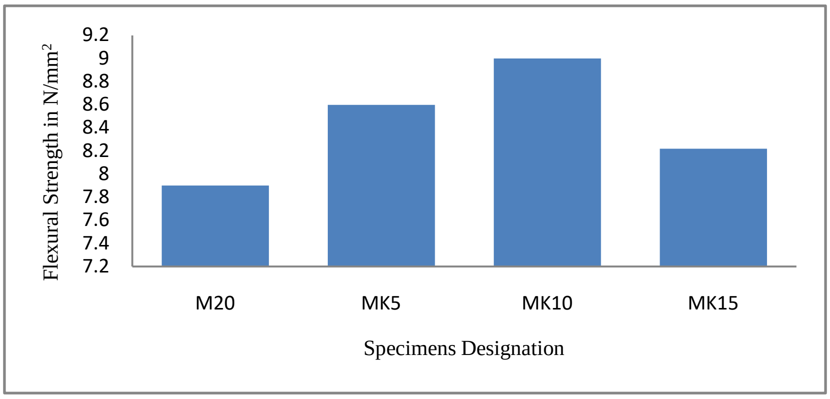

Fig. 6 Comparison of Flexural Strength

C. *Rapid Chloride Permeability Test*

Chloride ion permeability was determined based on charge passed as per ASTM C1202. The charge passing in each cylinder of different grade per half an hour for a period of six hours is noted. Here the passing of charge is more in control mix and less in specimens containing metakaolin, thus concrete containing metakaolin has less permeability. The charge passing is measured in coulombs and is given below in table V and same is represented in graph in figure 7.

TABLE V CHARGE PASSING IN SPECIMEN

Time period	Charge passing in coulombs in different grades of cylinders			
	M20	MK5	MK10	MK15
12.30pm	47.3	43.5	40	34.66
1pm	50.3	47	43	36.33
1.30pm	51	47	44.33	38.33
2pm	52.3	47	46	39.33
2.30pm	52.6	47.5	46.66	40
3pm	53.3	47.5	47	40.66
3.30pm	54.3	48	47.33	40.66
4pm	56	48	47.33	41
4.30pm	57.3	49	47.33	41.66
5pm	59.3	49.5	47.66	41.66
5.30pm	61	51	48.33	41.66
6pm	62.6	52.5	49.33	41.66
6.30pm	63.3	52.5	50	42.33

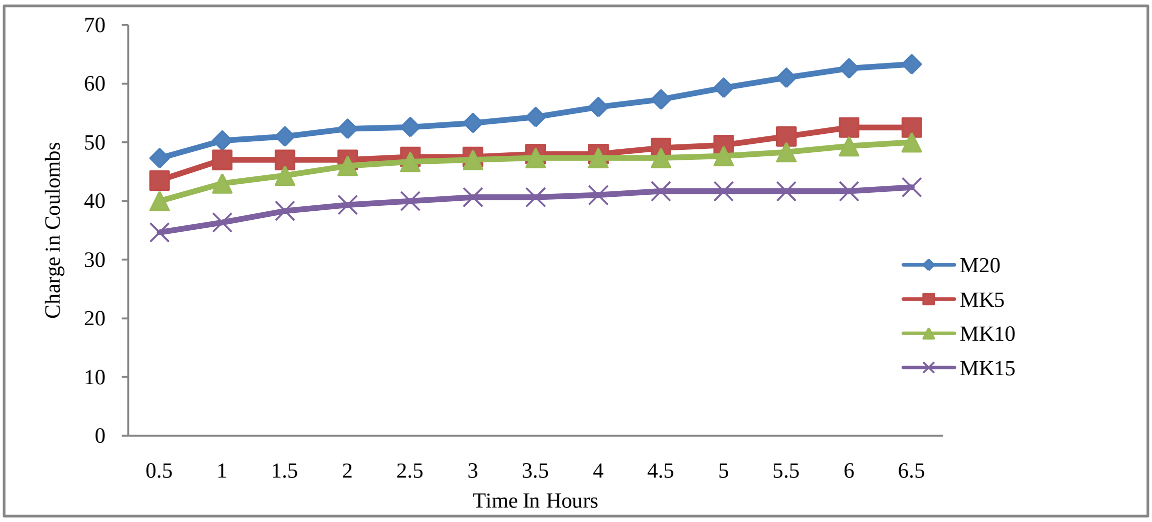

Fig.7 Chloride Permeability Test

D. *Sodium Sulphate Resistance Test*

The weight of the cubes before and after immersion were found and compared. The comparison is shown below in table VI and same is represented in graph in figure 8.

TABLE VI COMPARISON OF WEIGHT LOSS

Specimen Designation	**Weight(in kg) before attack**	**Weight (in kg) after attack**	**Loss of weight (in %)**
M20	2.4	2.3	4.2
MK5	2.55	2.46	3.52
MK10	2.56	2.48	3.12
MK15	2.58	2.52	2.32

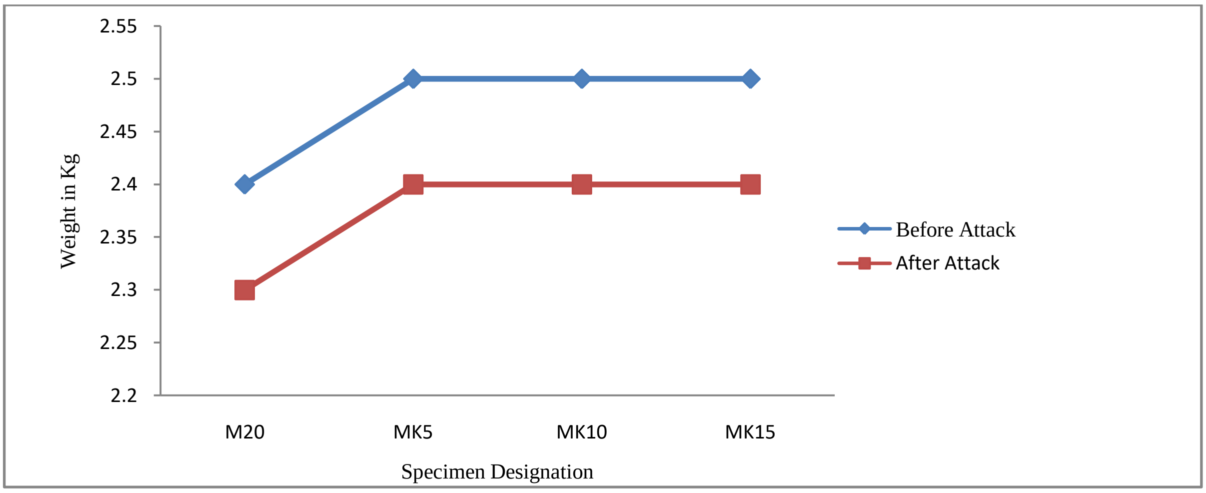

Figure. 8 Comparison of Weight Loss.

The loss of compressive strength before and after immersion in sodium sulphate were found and compared. It is further given below in table VII and the same is represented in figure 9.

TABLE VII COMPARISON OF COMPRESSIVE STRENGTH

Specimen Designation	Compressive Strength Before Attack in N/mm^2	Compressive Strength After Attack in N/mm^2	Loss of Compressive Strength in %
M20	20.5	16	21.95
MK5	25.5	22.75	10
MK10	29.5	23.5	20.3
MK15	26.5	24	9.4

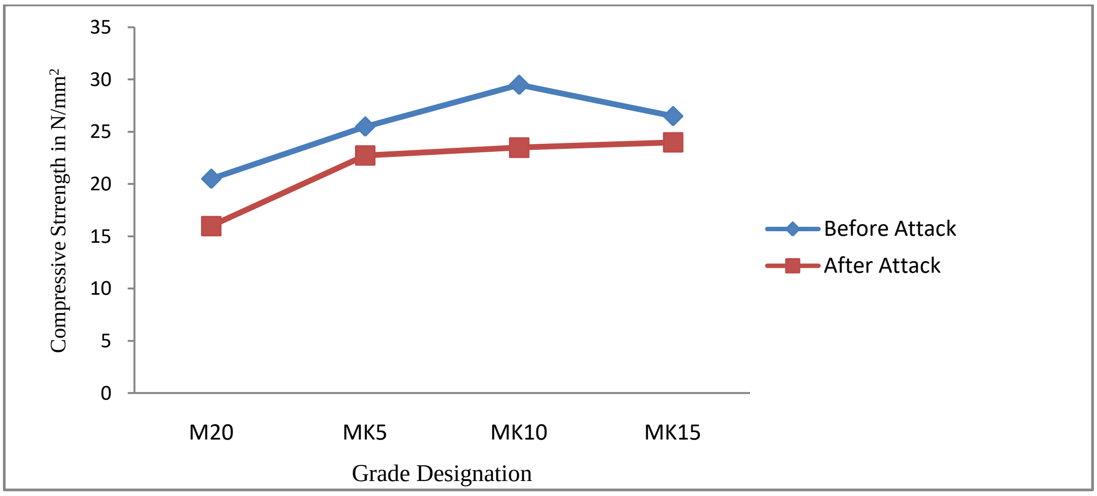

Figure. 9 Comparison of Compressive Strength

V. CONCLUSIONS

The following conclusions were made from the experiment:

1. The compressive strength of MK5, MK10 and MK15 for 28 days was higher by 24%, 44% and 29% respectively than the control mix M20 and the optimum percentage replacement of MK is found to be 10%.

3. The flexural strength of the concrete increased with increase in percentage of metakaolin. The flexural strength of MK5, MK10 and MK15 increased by 8.8%, 14% and 5% with respect to control mix.

3. MK is more effective in reducing Coulombs (increasing resistance to chloride penetration) at early ages. Addition of MK has a significant effect on the chloride permeability, from the detailed investigations, 15% of MK is found to be the optimum percentage. MK15 has the lowest permeability, it decreased by 38% than the control mix.

4. Sulphate resistance of concrete also increased with the addition of metakolin. The weight loss and compressive strength loss is maximum in control mix and it decreased by 4.2% and 21.95% respectively. On the other hand weight loss and compressive strength loss is minimum in MK15 and it decreased by 2.3% and 9.4%.

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