Effect Of Replacement Of Cement By Metakalion On The Properties Of High Performance Concrete Subjected To Hydrochloric Acid Attack

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ABSTRACT

This paper presents an experimental investigation on the effect of partial replacement of cement by metakalion by various percentages viz 0%, 10%, 20%, and 30% on the properties of high performance concrete, when it is subjected to hydrochloric acid attack. An aggregate binder ratio of 2 and different water binder ratios viz 0.3, 0.35, 0.40 and 0.45 was used in this investigation. Concrete specimens of size 150 x 150 x 150 mm were casted to find residual compressive strength and specimens of size 100 x 100 x 100mm were casted to find percentage weight loss; both the sizes of specimens were casted and cured as per IS specification. After 28 days water curing, the concrete specimens were kept immersed in 5% concentrated hydrochloric acid solution for 30, 60 and 90 days for observation. Before immersion, they were weighed accurately and after required days of immersion and observation, the specimens were removed from hydrochloric acid media, weighed accurately and tested for their compressive strength; weight loss and hardness of concrete were studied. The various results which indicate the effect of replacement of cement by metakalion on HPC are presented in this paper to draw useful conclusions. The results were compared with reference mix. Test results indicate that use of replacement cement by metakalion in HPC has improved performance of concrete up to 10%

KEYWORDS: Metakaolin, High Performance Concrete, Hydrochloric acid attack, Residual compressive strength, Weight loss

1.0 INTRODUCTION

Conventional concrete in India is often produced with four components namely, a) cement and b) Water, together they act as binder. c) The crushed or uncrushed stone and d) natural sand or stone dust. In addition to the above ingredients one or two additional chemicals are also added to the recipe of concrete in order to enhance some properties. Certain materials of mineral origin are also added to concrete to enhance their strength and durability properties of concrete materials such as flyash, silicafume, metakalion 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 drastically and high strength and high performance concrete is obtained in this manner. So modern concrete can have more four ingredients mentioned earlier and like many other composites, property of concrete can be suitably tailored for specific construction related performance [2]

The High Performance Concrete is concrete which ensures long-time durability in structures exposed to aggressive environments. Durability of concrete is its ability to resist weathering action, chemical attack, abrasion and all other deterioration processes. Weathering includes environmental effects such as exposure to cycles of wetting and drying, heating and cooling, as also freezing and thawing. Chemical deterioration process includes acid attack, expansive chemical attack due to moisture and chloride ingress [5]

Mineral admixtures such as fly ash, rice husk ash, metakaolin, silica fume etc are more commonly used in the development of HPC mixes. They help in obtaining both higher performance and economy. These materials increase the long term performance of the HPC through reduced permeability resulting in improved durability. Addition of such materials has indicated the improvements in the strength and durability properties of HPC. High reactivity metakaolin, which is a relatively newer material in the concrete industry, is effective in increasing the compressive strength, reducing the sulfate attack and improving air-void network. Unlike fly ash, slag, or silica fume, this material is not a by-product but is manufactured from high-purity kaolin clay by calcination at temperature range of 650 to 800°C. The material, ground to an average particle size of 1.5 to 2.5 μm, is white in color. However, information to understand the behaviour of this mineral additive in HPC is insufficient [4]

High-Reactivity Metakaolin (HRM) as mineral admixture in dry dense form conforming to ASTM C 618 class N Pozzolana. Metakaolin differs from other supplementary Cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for specific purpose under controlled conditions. 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). During the cement hydration process, water reacts with Portland cement and forms calcium-silicate hydrate (CSH). The by-product of this reaction is the formation of calcium hydroxide (lime). This lime has weak link in concrete, and hence reduces the effect of the CSH. When Metakaolin is added in the hydration process, it reacts with the free lime to form additional CSH material, thereby making the concrete stronger and more durable [3]

Metakaolin differs from other supplementary cementitious materials (SCMs), like fly ash, silica fume, and slag, in that it is not a by-product of an industrial process; it is manufactured for a specific purpose under carefully controlled conditions. Metakaolin is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. This heat treatment or calcination, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications. When used as a partial replacement for Portland cement, metakaolin may improve both the mechanical properties and the durability of concrete [1]

2.0 EXPERIMENTAL PROGRAMME

The main aim of this experimentation is to study the effect of partial replacement of cement by metakalion on the properties of high performance concrete, when it is subjected to hydrochloric acid attack. To study this effect the following parameters were considered in this experimentation:
Aggregate-binder ratio (A/B ratio): 2.0
Water-binder ratio (W/B ratio): 0.3, 0.35, 0.4, 0.45
Percentage replacement of cement by Metakaolin: 0, 10, 20, 30

3.0 MATERIALS USED

Cement: Ordinary Portland Cement-53 grade was used having a specific gravity of 3.15 and it satisfies the requirements of IS: 12269-1987 specifications. The physical properties of tested cement are given in Table 3.1

Table 3.1: Physical properties Ordinary Portland Cement-53 grade

Properties	Results	Permissible limit as per IS: 12269-1987
Fineness	30.0 m^2/N	Should not be more than 22.5 m^2/N
Normal consistency	33	-
Specific gravity	3.06	-
Setting Time a. Initial b. Final		Should not be less than 30 Min Should not be more than 600 Min
Compressive strength of mortar cubes for a. 3days. b. 7days. c. 28 days	34.0 N/mm^2 44.8 N/mm^2 59.0 N/mm^2	Should not be less than 27 N/mm^2 Should not be less than 37 N/mm^2 Should not be less than 53 N/mm^2

Coarse aggregates: The crushed granite aggregate were collected from the local quarry. The coarse aggregate was used in the experimentation were of 20mm and down size aggregate and tested as per IS: 2386-1963 (I, II and III) specifications. Physical and mechanical properties of tested coarse aggregates are given in Table 3.2

Table 3.2: Physical and Mechanical properties of coarse aggregate

Properties	Results	Permissible limit as per IS: 2386-1963
Impact value	15.50 %	Should not be more than 30% used for concrete
Crushing value	21.43%	Should not be more than 30% for surface course and 45% other than wearing course
Specific gravity	2.75	In between range 2.6-2.8
Moisture content	0.7%	-
Fineness modulus	6.73	-

Fine aggregates: Locally available Pandameru river sand was used as fine aggregate. The sand used was having fineness modulus 3.77 and confirmed to grading zone-II as per IS: 383-1970 specification. Physical properties of tested fine aggregate are given in Table 3.3

Table 3.3: Physical properties of fine aggregate

Properties	Results	Permissible limit as per IS: 383-1970
Organic impurities	Colourless	Colour less /Straw Colour/Dark Colour
Silt content	0.7%	Should not be more than 6
Specific gravity	2.68	Should be between the limit 2.6-2.7
Bulking of sand	16%	Bulking of sand 16% Should not be more than 40%
Moisture content	0.65%	-
Fineness Modulus	3.77	-
Grading	Zone-II	-
Bulk density a. Loose b. Compacted	 14.67kN/m^3 16.04 kN/m^3	-

Metakaolin: The mineral admixture Metakaolin was obtained from the 20 MICRON LIMITED company at Vadodara in Gujarat. The Metakaolin was in conformity with the general requirements of pozzolana. Properties of Metakaolin are given in below Table 3.4

Table 3.4: Properties of Metakaolin

Property	Results
Specific Gravity	2.54
Accelerated pozzolanic active index, % of control	89
Residue on 45μ sieve, %	1.31
Chemical analysis, %	
Loss on ignition	0.70
Silica (SiO_2)	52.24
Iron oxide (Fe_2O_3)	0.60
Aluminium (Al_2O_3)	43.18
Calcium oxide (CaO)	1.03
Magnesium Oxide (MgO)	0.61

Water: Ordinary potable water free from organic content, turbidity and salts was used for mixing and for curing throughout the investigation.

Superplasticizer: To impart the additional desired properties, a superplasticizer (Conplast SP-337) was used. Dosage of super plasticizer was added 2.5% by weight of cement.

Chemical: Hydrochloric acid (Hcl) was used to conduct durability test

4.0 EXPERIMENTAL PROCEDURE

Concrete testing specimens of required number were casted and cured for 28days for an aggregate binder ratio of 2, which is correspond to M20 grade of concrete with different water binder ratios viz 0.3, 0.35, 0.40, and 0.45 and replacement of cement by Metakaolin for various percentages viz 0, 10, 20, and 30.

Concrete specimens of size 150 x 150 x 150 mm were casted to find residual compressive strength and size of 100m x 100mm x 100mm were casted to find percentage weight loss after 30, 60 and 90 days of hydrochloric acid immersion.

Water cured specimens for 28 days were taken out and allowed to dry under shade and then the same concrete specimens were kept immersed in 5% concentrated hydrochloric acid solution for 30, 60 and 90 days for durability observation. The curing media was replaced with fresh solution at the end of every week to maintain the same concentration (i.e.5%).

Durability test was conducted initially the normal weights of cubes were taken and observed the deteriorating effect after 30, 60 and 90 days by taking weights again accurately after washing the specimens in running water. The weight loss due to hydrochloric acid immersion was noted. Compressive strength test conducted as per IS: 516-1959 specifications. Final results are tabulated in comparison with reference mix.

5.0 EXPERIMENTAL RESULTS

The following Table No.5.1.1 gives the residual compressive strength test results of HPC when it is subjected to hydrochloric acid attack with respect to reference mix.

5.1 COMPRESSIVE STRENGTH TEST RESULTS

The following Table No.5.1.1 gives the residual compressive strength test results of HPC when it is subjected to hydrochloric acid attack with respect to reference mix.

Table 5.1.1: Percentage decrease in compressive strength test results of HPC for 0.3 W/B ratio

% replace-ment of cement by Metakaolin	28 days compr-essive strength (ref.mix)	30 days compr-essive strength	% decrease in compr-essive strength	60 days compr-essive strength	% decrease in compr-essive strength	90 days compr-essive strength	% decrease in compr-essive strength
0	83.42	76.75	7.99	71.73	14.01	65.91	20.99
10	94.22	87.64	6.98	84.31	10.52	78.22	16.98
20	82.13	76.86	6.41	74.31	09.52	68.98	16.01
30	79.33	74.53	6.05	72.53	08.57	67.38	15.06

Table 5.1.2: Percentage decrease in compressive strength test results of HPC for 0.35 W/B ratio

% replace-ment of cement by Metakaolin	28 days compr-essive strength (ref.mix)	30 days compr-essive strength	% decrease in compr-essive strength	60 days compr-essive strength	% decrease in compr-essive strength	90 days compr-essive strength	% decrease in compr-essive strength
0	81.02	74.53	8.01	69.69	13.98	64.00	21.00
10	92.75	86.27	6.98	83.02	10.49	76.98	17.00
20	80.00	74.80	6.50	72.40	9.50	67.20	16.00
30	75.11	70.62	5.97	68.71	8.52	63.87	14.96

Table 5.1. 3: Percentage decrease in compressive strength test results of HPC for 0.40 W/B ratio

% replace-ment of cement by Metakaolin	28 days compr-essive Strength (ref.mix)	30 days compr-essive strength	% decrease in compr-essive strength	60 days compr-essive strength	% decrease in Compr-essive strength	90 days compr-essive strength	% decrease in compr-essive strength
0	80.22	73.82	7.97	68.98	14.01	63.38	20.99
10	87.64	81.51	6.99	78.44	10.49	72.76	16.97
20	76.31	71.33	6.52	69.07	9.48	64.09	16.01
30	71.29	67.02	5.98	65.24	8.48	60.58	15.02

Table 5.1.4: Percentage decrease in compressive strength test results of HPC for 0.45 W/B ratio

% replace-ment of cement by Metakaolin	28 days compr-essive strength (ref.mix)	30 days compr-essive strength	% decrease in compr-essive strength	60 days compr-essive strength	% decrease in compr-essive strength	90 days compr-essive strength	% decrease in compr-essive strength
0	75.95	69.87	8.00	65.33	13.98	60.00	21.00
10	86.00	80.00	6.97	76.89	10.48	71.38	17.00
20	74.31	69.47	6.51	67.24	9.51	62.40	16.02
30	70.00	65.82	5.97	64.04	8.51	59.51	14.98

5.2 The following Table No.5.2.1 gives the percentage weight loss test results of HPC when it is subjected to hydrochloric acid attack.

Table 5.2.1: Percentage weight loss test results of HPC

% replacement of cement by Metakaolin	W/B	30 Days	60 Days	90 Days
		% weight loss	% weight loss	% weight loss
0	0.3	6.1	7.15	8.26
	0.35	6.4	7.47	8.62
	0.4	6.72	7.86	9.04

	0.45	6.99	8.18	9.44
10	0.3	4.22	5.08	5.75
	0.35	4.77	5.31	6.02
	0.4	4.68	5.42	6.38
	0.45	4.87	5.71	6.60
20	0.3	4.68	5.24	6.11
	0.35	4.71	5.51	6.32
	0.4	4.89	5.75	6.64
	0.45	5.09	6.03	6.92
30	0.3	6.12	7.20	8.32
	0.35	6.42	7.53	8.76
	0.4	6.74	7.76	9.12
	0.45	7.31	8.24	9.52

6.0 OBSERVATIONS AND DISCUSSIONS

1. It has been observed that the compressive strength of Metakaolin based HPC decreases with the increase in W/B ratio. As the W/B ratio increases from 0.3 to 0.45, the decrease in compressive strength was found 8 to 21% for plain HPC, for HPC with 10% Metakaolin was 9.24% to 14.47%, for HPC with 20% was 4.874% to 1.258% and for HPC with 30% Metakaolin was 4.902% to 11.13%
2. It has been observed that the maximum compressive strength was obtained for mixes containing 10% metakaolin. This is true for all W/B ratios. As the percentage replacement increases beyond 10%, the 28 days compressive strength of HPC started decreasing when compared to plain HPC. Similar results are observed for all water binder ratios.
3. It has been observed that the residual compressive strength decreases with increase in W/B ratio for all percentage replacements of cement by Metakaolin. This may be due to porous transition zone at higher water contents for 30days immersion. Similarly the same trend has been observed for 60 and 90 days of acid immersion.
4. It has been observed that the addition of Metakaolin has improved the resistance of HPC mixes to acid attack. This is evident by higher residual compressive strength of metakaolin based HPC mixes when compared to plain HPC mixes.
5. It has been observed that maximum residual compressive strength is obtained at 10% replacement cement by metakaolin. The mixes containing 20% & 30% metakaolin have shown, better resistance to acid attack compare to plain mixes.
6. It has been observed that the the residual compressive strength decreases with the age of acid immersion. Maximum loss of compressive strength is noticed at 90 days of acid immersion. This may be due to more & more formation of ettringite with the increase in age of acid immersion. Same trend is observed for all percentage replacement of cement by Metakaolin.
7. It has been observed that with the addition of Metakaolin the percentage decrease in compressive strength decreases. Maximum percentage decrease in compressive strength is observed for plain HPC mixes without Metakaolin.
8. It has been observed that from the results percentage decrease in compressive strength decreases rapidly from 0% to 10% replacement and from then onwards it decreases very gradually. Hence it can be concluded that optimum results are obtained at 10% replacement of cement by Metakaolin.
9. It has been observed that with the percentage weight loss due to acid attack increases with the increasing W/B ratio. This may be due to the porous transition zone at higher W/B ratios giving scope for more ettringite formation leading to severe decay of concrete.
10. It has been observed that from the results the percentage weight loss is least for HPC mixes containing 10% metakaolin. Even mixes containing 20% metakaolin behaved well under acid attack when compared to plain HPC mixes. The percentage weight loss at 30% replacement is almost coinciding with that of plain HPC mixes.
11. It has been observed that the influence of percentage replacement of cement by Metakaolin on percentage weight loss due to acid attack presented in tables. It is evident from these results that with the addition of metakaolin the percentage weight loss decreased upto 10% metakaolin and increased beyond 10% metakaolin. However even at 20% replacement, the percentage weight loss is less compare to plain HPC. Thus it can be concluded that, 10% metakaolin HPC mixes resisted acid attack better than other mixes.

7.0 CONCLUSIONS

1. It can be concluded that the compressive strengths of HPC mixes decreases with increasing water binder ratio.

2. It can be concluded that the residual Compressive strength after 30, 60 and 90 days of acid immersion decreases with increasing water binder ratio. This may be due to porous transition zone leading to the formation of ettringite at higher water levels.
3. It can be concluded that the addition of metakaolin increases the resistance to acid attack of HPC. Optimum results obtained were at 10% replacement of cement by metakaolin.
4. It can be concluded that the residual compressive strength of HPC decreases with increasing age of acid immersion.
5. It can be concluded that the percentage decrease in compressive strength decrease rapidly upto 10% replacement cement by metakaolin as from then onwards it decreases gradually.
6. It can be concluded that the percentage weight loss due to acid attack increase with the increasing W/B ratio.
7. It can be concluded that for 10% metakaolin based HPC, the weight loss due to acid attack is minimum

ACKNOWLEDGEMENT

The authors would like to thank Dr. H. Sudarsana Rao and Dr.Vaishali. G. Ghorpade, JNTUA College of Engineering, Anantapur for giving their constant encouragement and valuable guidance. The authors also indebted to Vice-Chancellor, Christ University, Fr. Benny Thomas, Director and Dr. Iven Jose, Associate Dean, Christ University Faculty of Engineering, Bangalore for their encouragement

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