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# Strength and Durability Properties of High Performance Concrete incorporating High Reactivity Metakaolin

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**ABSTRACT**

Concrete is probably the most extensively used construction material in the world. The addition of mineral admixture in cement has dramatically increased along with the development of concrete industry, due to the consideration of cost saving, energy saving, environmental protection and conservation of resources. However, environmental concerns both in terms of damage caused by the extraction of raw material and carbon dioxide emission during cement manufacture have brought pressures to reduce cement consumption by the use of supplementary materials. High Performance Concrete (HPC) is the latest development in concrete. It has become more popular these days and is being used in many prestigious projects. Mineral admixtures such as fly ash, rice husk ash, metakaolin, silica fume etc are more commonly used in the development of HPC mixes. Addition of such materials has indicated the improvements in the strength and durability properties of concrete. The utilization of calcined clay, in the form of high reactivity metakaolin (HRM) in concrete has received considerable attention in recent years.

The present paper deals with the study of properties namely workability, compressive strength and durability of M60 grade HPC mixes incorporating different percentages of high reactivity metakaolin by weight of cement along with some suitable super plasticizer. The results of the study indicate that the workability and strength properties of HPC mixes improved by incorporating HRM up to a desirable content of 7.5% by weight of cement. HPC mixes have also indicated better resistance to the attacks of chemicals such as chlorides and sulfates when the HPC mixes were exposed to theses chemical for 180 days period.

**Keywords:** Compressive strength, Durability, High Performance Concrete, High reactivity metakaolin, Mineral Admixtures.

## 1. Introduction

Concrete is probably the most extensively used construction material in the world. However, when the high range water reducer or super plasticizer was invented and began to be used to decrease the water/cement (w/c) or water/binder (w/b) ratios rather than being exclusively used as fluid modifiers for normal-strength concretes, it was found that in addition to improvement in strength, concretes with very low w/c or w/b ratios also demonstrated other improved characteristics, such as higher fluidity, higher elastic modulus, higher flexural strength, lower permeability, improved abrasion resistance, and better durability. This fact led to the development of HPC. HPC is the latest development in concrete. It has become more popular these days and is being used in many prestigious projects such as Nuclear power projects, flyovers, multistoried buildings etc. [1]

Since 1990s, HPC has become very popular in construction works. At present, the use of HPC has spread throughout the world. In 1993, the American Concrete Institute (ACI) published a broad definition for HPC and is defined as the concrete which meets special performance and uniformity requirements that cannot always be achieved by using only the conventional materials and mixing, placing and curing practices. The performance requirements may involve enhancements of placement and compaction without segregation, long-term mechanical properties, early age strength, toughness, volume stability, or service life in severe environments. [2]

The addition of mineral admixture in cement has dramatically increased along with the development of concrete industry, due to the consideration of cost saving, energy saving, environmental protection and conservation of resources. However, environmental concerns both in terms of damage caused by the extraction of raw material and carbon dioxide emission during cement manufacture have brought pressures to reduce cement consumption by the use of supplementary materials. [3]

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. [4] 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 byproduct 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. [5] However, information to understand the behavior of this mineral additive in HPC is insufficient. Some of the recent information is discussed in this paper highlighting the role of high reactivity metakaolin in high strength high performance concrete.

Keeping all these things in view, an attempt has been made in the present paper to study various properties namely workability, compressive strength and durability of M60 grade HPC mixes incorporating different percentages of metakaolin by weight of cement along with some suitable super plasticizer. The results of the study indicate that the workability and strength properties of HPC mixes improved by incorporating HRM up to a desirable content of 7.5% by weight of cement. HPC mixes have also indicated better resistance to the attack of chemicals such as chlorides and sulfates when the HPC mixes were exposed to theses chemical for 180 days period.

## 2. Experimental Investigations

### 2.1 Materials:

The materials used in making HPC mixes along with their various properties have been given in Table 1.

Table 1: Properties of Materials Used In Making HPC Mixes

| Materials | Sp. Gravity | Fineness Modulus | Grade/ Type | Comp Strength | Source |
|---|---|---|---|---|---|
| Cement | 3.15 | - | 53 OPC | 54 MPa | Ultratech Cement |
| Fine Aggregate | 2.70 | 3.2 | Zone I | - | Krishna River, Local spot |
| Coarse Aggregate | 2.78 | 7.125 | 60%-20mm 40%-12.5mm | 22.20 % | Locally available |
| High reactivity metakaolin | 2.50 | - | - | - | 20 microns India Ltd, Mumbai |
| Super-plasticizer | 1.09 | - | 'GLENIUM B233' (Polycarboxylic ether polymer) | - | BASF Chemical Company Ltd., Mumbai |

### 2.2 Mix design of HPC:

The mix design of HPC was done by using the guidelines of IS Code method (IS10262-2009). The design stipulations and the data considered for mix design HPC has been presented below. [6]

Characteristic Strength, fck (MPa): 60

Max. Size of Course Aggregate: 20mm (Crushed)

[Fraction I-60%, 20mm-12.5mm]

[Fraction II-60%, 12.5mm-10mm]

Degree of Quality Control : Good

Type of Exposure : Severe

Degree of Workability : 100mm (slump)

Target Mean Strength ($f_{ck}$), MPa:

$$f_{ck} + 1.65 \text{ x } S = 60+1.65\text{x}5 = 68.25$$

Where,

$f_{ck}$ =characteristic compressive strength at 28 days,

S = standard deviation

### 2.3 Mix Proportions:

Mix proportion of M60 grade HPC mix was obtained by making certain modifications in the mix proportion arrived at using the guidelines of IS Code method. The mix proportion was obtained without considering any addition or replacement of mineral admixture (i.e. high reactivity metakaolin).

After several trials, a cement content of 475 kg/m$^3$ and water-binder ratio of 0.31 were finalized based on 28 days compressive strength gain of HPC mix and desired workability properties (slump & flow). Thus, for making HPC mixes a cement content of 475 kg/m$^3$ and a water-binder ratio of 0.31 were used along with optimum content of high reactivity metakaolin as mineral admixture. After carrying out several preliminary mix trials, the optimum contents of high reactivity metakaolin at 7.5% and a super plasticizer dose at 0.73%, both by weight of cement, were found to give desired workability and strength properties. The water-binder ratio was calculated by dividing the weight of mixing water by combined weight of cement and high reactivity metakaolin. The final mix proportion was arrived at by altering the ratio of fine aggregate to coarse aggregate and is expressed as parts of water: cement: fine aggregate: coarse aggregate as given by 0.31: 1:1.63: 2.33.

**2.4 Preparation of HPC Mix**

The required quantities of all the ingredients were taken by weigh batching, with appropriate coarse aggregate fractions and mineral admixtures. Mixing of the ingredients was done in a pan mixer as per the standard procedure. A reference mix was prepared using a water-binder ratio of 0.31 and suitable super plasticizer content (by weight of cement) in order to get desired workability.

The workability of the concrete was studied by conducting slump and flow tests as per the standard procedure (IS: 1199–1959) (Figure 1 and Figure 2). Standard cube specimens of 150mm x 150mm x 150mm size were cast using the procedure described in IS Code (IS: 516–1959) and were immediately covered with plastic sheet and kept there for 24 hours and then released in water tank for 28 days curing.

All the HPC mixes were prepared using the same mix proportion, water-binder ratio and super plasticizer dose and considered for study of workability, strength and durability properties of HPC mixes. The details of workability properties of the mixes prepared with their quality are given in the Table 2.

Figure1 slump test

Figure2 flow test

**2.5 Testing of specimens:**

After 28 days curing period, the specimens were taken outside the curing tank and were tested under a compression testing machine of 2000KN capacity for compressive strength. For durability performance of HPC in chloride and sulfate environment after initial curing of 28 days, the specimens are kept immersed in 3.5% NaCl and 5% $MgSO_4$ solution for a period of 180 days.[7] The crushing loads were noted and the average compressive strength of three specimens is determined. The compressive strength values of specimens subjected to different durability conditions has been presented in Table 2.

Figure3 compression testing machine (200tcapacity)

Figure4 testing of specimen

## 3. Results and Discussion:

Generally, high reactivity metakaolin is proven to be a reactive pozzolan. The strength enhancement is probably due to a combination of the filler effect and accelerated cement hydration. This is particularly significant in the interfacial zone regions where they produce more efficient packing at the cement paste-aggregate particle interface, reducing the amount of bleeding and produce a denser, more homogeneous, initial transition zone microstructure and also a narrower transition zone. Addition of high reactivity metakaolin results an increase in the strength of concrete possibly due to an improved transition zone. High reactivity metakaolin rapidly removes calcium hydroxide from the system and accelerates the ordinary Portland cement (OPC) hydration. It result in enhanced early strength with no detrimental effect to the long term strength and greatly improves the resistance to the transportation of water and diffusion of harmful ions. [8]

The compressive strength of all the mixes except 5%, 7.5%, 10% addition is lower than the control mix. This is generally caused by the “dilution effect”. As the addition ratios exceed 10%, the amount of high reactivity metakaolin is in excess to react with calcium hydroxide. These extra high reactivity metakaolin produce an immediate dilution effect such that the water-binder ratio is reduced. Concrete strength is reduced in approximate proportion to the degree of addition. As the results, the 15% addition endures the most critical strength loss. However, only concrete with 5%, 7.5% & 10% addition exhibits higher strength than the control mix at 28 days. The additions over 10% cause the concrete to have excess of high reactivity metakaolin to react with the hydrated calcium hydroxide and thus reduce the compressive strength of the concrete.

Compared to the findings of other studies, it appears that the results of this study do not cohere with some of the studies, although there are some studies agree the optimum high reactivity metakaolin addition is around 7.5%. These variations are not surprising as the products of hydration and pozzolanic activity depend on the Portland cement composition, the purity of the high reactivity metakaolin and the water-binder ratio. In this study, the high reactivity metakaolin samples have silica and alumina content of 81%. It is considered that the high reactivity metakaolin has a high purity and high kaolinite content. As a result, 7.5% addition is sufficient to reduce the calcium hydroxide to the minimum level and attains the highest compressive strength in 28 days.

Table 2 Details of HPC mix (M60) exposed to durability conditions

| Sr. No. | % HRM addition | Slump in mm | Compressive strength in $N/mm^2$ |
|---|---|---|---|
| I) 28 days Strength | | | |
| 1 | Control mix | 110 | 63.70 |
| 2 | 5 | 115 | 66.96 |
| 3 | 7.5 | 60 | 69.04 |
| 4 | 10 | 60 | 65.48 |
| 5 | 12.5 | 70 | 63.26 |
| 6 | 15 | 40 | 60.74 |
| II) Exposure to Chloride attack | | | |
| 1 | Control mix | 160 | 60.59 |
| 2 | 5 | 85 | 64.30 |
| 3 | 7.5 | 70 | 66.37 |
| 4 | 10 | 65 | 62.96 |
| 5 | 12.5 | 45 | 60.89 |
| 6 | 15 | 50 | 59.56 |
| III) Exposure to Sulfate attack | | | |
| 1 | Control mix | 140 | 57.78 |
| 2 | 5 | 100 | 61.63 |
| 3 | 7.5 | 110 | 64.89 |
| 4 | 10 | 50 | 61.63 |
| 5 | 12.5 | 45 | 58.81 |
| 6 | 15 | 30 | 56.00 |

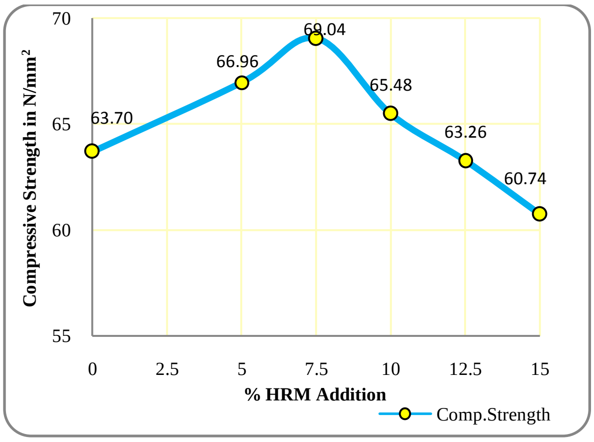


Figure5 compressive strength at 28 days

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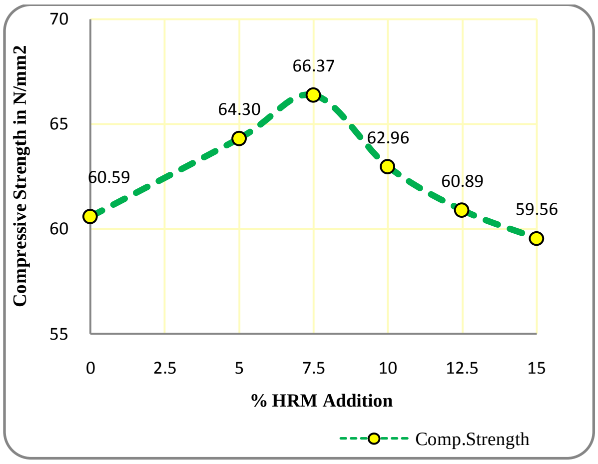


Figure6 compressive strength after chloride attack

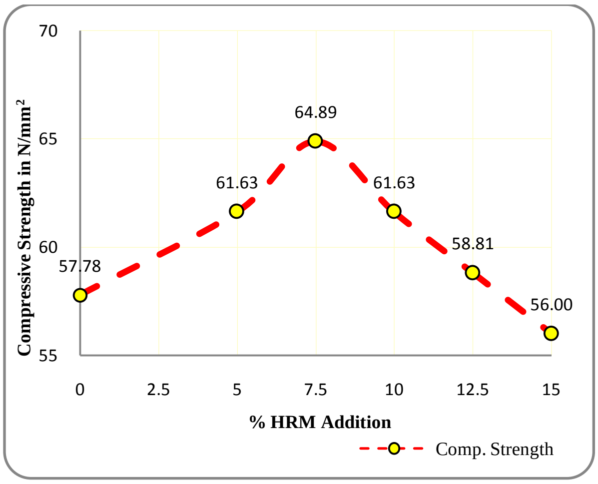


Figure7 compressive strength after sulfate attack

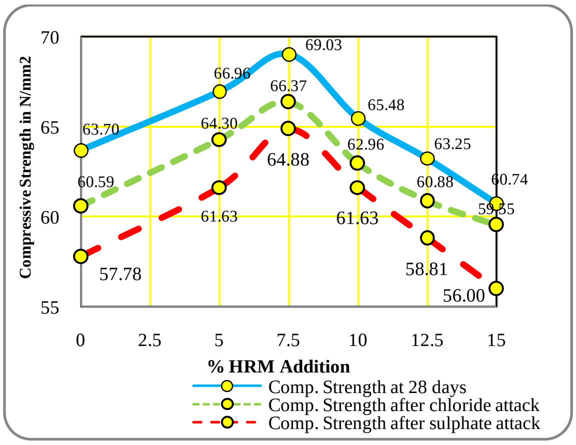


Figure 8 comparison of compressive strength

## 4. Conclusions:

The compressive strength of concrete increases with increase in HRM content up to 7.5%. Thereafter there is slight decline in strength for 10%, 12% and 15% due excess amount of HRM which reduces the w/b ratio and delay pozzolanic activity. The higher strength in case of 7.5% addition is due to sufficient amount of HRM available to react with calcium hydroxide which accelerates hydration of cement and forms C-S-H gel.

- The 7.5% addition of high reactivity metakaolin in cement is the optimum percentage enhancing the compressive strength at 28 days by 7.73% when compared with the control mix specimen.
- The 7.5% addition of high reactivity metakaolin in cement is enhanced the resistance to chloride attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 3.85% as compared with the reduction of strength of control mix specimen is by 4.88%.
- The 7.5% addition of high reactivity metakaolin in cement is also enhanced the resistance to sulfate attack. The compressive strength of concrete incorporated with 7.5% HRM is reduced only by 6.01% as compared with the reduction of strength of control mix specimen by 9.29%.

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