EXPERIMENTAL EVALUATION OF THE DURABILITY PROPERTIES OF HIGH PERFORMANCE CONCRETE USING ADMIXTURES

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ABSTRACT

High Performance Concrete (HPC) is a complex system of materials that perform most effectively when placed in severely aggressive environments. Optimum strength and high durability are the two main characteristics of HPC mixtures. The Concrete Durability Crisis which started to attract public attention forced the engineers to think about the performance of the concrete. If the concept involves an end product approach to ensure performance as specified, it is known as High Performance Concrete (HPC). Recently, many efforts are carried out to create the HPC for maximizing the compressive strength as well as durability. In the new millennium, concrete incorporating self-curing agents will represent a new trend in the concrete construction. Curing of concrete plays a major role in developing the concrete microstructure and pore structure, and hence improves its durability and performance. Due to the high alkalinity of concrete it has always been susceptible to acid attack. This paper presents results on the durability related properties of M70 grade of HPC specimens curing with acids such as HCL, Alkaline such as NaOH and sulphate solution MgSO4 and Na2SO4.

The HPC has become an object of intensive research due to its growing use in the construction practice. In the last decade the use of Supplementary Cementing Materials (SCMs) has become an integral part of high strength and high performance concrete mix design. The addition of SCM to concrete reduces the heat of hydration and extends the service life in structures by improving both long term durability and strength. Some of the commonly used SCMs are Flyash, Silica fume and Metakaoline.
Key Words: High Performance Concrete (HPC), Supplementary Cementing Materials (SCMs), Flyash, Silica Fume, Metakaoline.

INTRODUCTION

High Performance Concrete (HPC) is that which is designed to give optimized performance characteristics for the given set of materials, usage and exposure conditions, consistent with requirement of cost, service life and durability. The Ordinary Portland Cement is one of the main ingredients used for the production of concrete and has no alternative in the construction industry. Unfortunately, production OPC involves emission of large amounts of Carbon dioxide (CO2) gas into the atmosphere, a major contributor for Green House Effect and the Global Warming. Hence, it is inevitable either to search for another material or partly replace it by SCM which should lead to global sustainable development and lowest possible environmental impact. Another advantage of using SCMs is increase in durability of concrete which consequently results increase in resource use efficiency of ingredients of concrete which are depleting at very fast rate. Long term performance of structure has become vital to the economies of all nations. The use of fly ash and silica fume is becoming more common because they improve concrete durability and strength, especially where high early age curing temperatures occur.

Acid Resistant Concrete

In general, the concrete is damaged by action of acids. The degradation mechanism involves dissolution of soluble constituents of cement destroying its crystalline structure. The major factor contributing to destruction of concrete is the permeability and the concentration of the acids. Portland cements are more vulnerable of attacks on account of high calcium hydroxide release during hydration of calcium silicate. It should be noted that the Binder is damaged after acid attack. The chemical reaction can be expressed as follows:

1. Formation of Calcium Hydroxide

\[ C_2S_i \cdot C_2S + H_2O \rightarrow CSH + Ca(OH)_2 \]

2. Reaction of Calcium Hydroxide

\[ Ca(OH)_2 + \text{'acid'} \rightarrow Ca^2(\text{solution}) \]

It is also an established fact that concretes made with pozzolans like Blast Furnace slag in which Calcium Oxide is combined in a less soluble form for a greater degree of resistance. Therefore the initial step for producing an acid resistant concrete is formulation of Acid Resistant Binder. The testing for Acid Resistance of the Binder should be conducted by immersing the mortar and concrete specimen in water containing sulphuric acid of 2.5 pH over a period of some days. The acid containing water is continuously changed to arrest the lowering of salt concentration which in turn would provide the protection to the surface of the specimen. In order to avoid the building of protection on the test specimen, they are cleaned weekly. The loss of weight of the test specimen can be measured as well as degree of deterioration should be optically assessed [1].
Sulphate Attack

Most sulphate solutions (e.g. Sodium, Magnesium) in soils, groundwater and sea water can react with Calcium Hydroxide and Calcium Aluminate in concrete to form calcium sulphate and calcium sulfo-aluminate hydrate. The increased volume of the compounds formed lead to the breakdown of the concrete structure, while, in some cases, decomposition of the matrix can occur. The intensity and rate of sulphate attack depends on a number of factors, such as the cation associated with the sulphate, its concentration and the continuity of supply to concrete.

Test with various SCMs indicate that as a result of the dilution of the reactive components of the cement (Aluminate phases) and densifying effects associated with these SCMs, reductions in expansion and damage due to sulphate attack may be achieved.

The definition of high performance concrete element is that which is designed to give optimized performance characteristics for a given set of load, usage and exposure conditions, consistent with requirement of cost, service life and durability [2].

[3] Established a testing regime to optimize the strengths and durability characteristics of a wide range of high-performance concrete mixes. The intent of the selected designs was to present multiple solutions for creating a highly durable and effective structural material that would be implemented on Pennsylvania bridge decks, with a life expectancy of 75 to 100 years. One of the prime methods of optimizing the mixtures was to implement supplemental cementitious materials, at their most advantageous levels. Fly ash, slag cement, and microsilica all proved to be highly effective in creating more durable concrete design mixtures.

The chemical resistance of the concretes was studied through chemical attack by immersing them in an acid solution. After 90 days period of curing the specimens were removed from the curing tank and their surfaces were cleaned with a soft nylon brush to remove weak reaction products and loose materials from the specimen. The initial weights were measured and the specimens were identified with numbered plastic tokens that were tied around them. The specimens were immersed in 3% H$_2$SO$_4$ solution and the pH was maintained constant throughout. The solution was replaced at regular intervals to maintain constant concentration throughout the test period. The mass of specimens were measured at regular intervals up to 90 days, and the mass losses were determined [4].

An experimental study on the effect of fly ash and silica fume on the properties of concrete subjected to acidic attack and sulphate attack. Changes in physical and chemical properties in the mortars with different replacements by fly ash and silica fume when immersed in 2% H$_2$SO$_4$, 10% Na$_2$SO$_4$ and 10% MgSO$_4$ solutions for 3 years were investigated [5].

One of the main causes of deterioration in concrete structures is the corrosion of concrete due to its exposure to harmful chemicals that may be found in nature such as in some ground waters, industrial effluents and sea waters. The most aggressive chemicals that affect the long term durability of concrete structures are the chlorides and sulfates. The chloride dissolved in waters increase the rate of leaching of portlandite and thus increases the porosity of concrete, and leads to loss of stiffness and strength. Calcium, sodium, magnesium, and ammonium sulfates are in increasing order of hazard harmful to concrete as they react with hydrated cement paste leading to expansion, cracking, spalling and loss of strength [6].
MATERIALS USED IN THE PRESENT STUDY

Cement

Ordinary Portland cement Zuari-53 grade conforming to IS: 12269-1987 [7] were used in concrete. The physical properties of the cement are listed in Table 1.

### Table 1. Physical Properties of Zuari-53 Grade Cement

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Properties</th>
<th>Values</th>
<th>3 days</th>
<th>7 days</th>
<th>28days</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specific gravity</td>
<td>3.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Normal consistency</td>
<td>32%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Initial setting time</td>
<td>60 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Final setting time</td>
<td>320 min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Compressive strength (Mpa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Aggregates

A crushed granite rock with a maximum size of 20mm and 12mm with specific gravity of 2.60 was used as a coarse aggregate. Natural sand from Swarnamukhi River in Srikalahasthi with specific gravity of 2.60 was used as fine aggregate conforming to zone- II of IS 383-1970 [8]. The individual aggregates were blended to get the desired combined grading.

Water

Potable water was used for mixing and curing of concrete cubes.

Supplementary Cementing Materials

Flyash

Fly ash was obtained directly from the M/s Ennore Thermal Power Station, Tamilnadu, India. The physicochemical analysis of sample was presented in Table 2.

### Table 2. Physicochemical properties of Flyash sample.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Specific Gravity</th>
<th>Specific Surface area (m2/g)</th>
<th>Moisture Content (%)</th>
<th>Wet density (gram/cc)</th>
<th>Turbidity (NTU)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flyash</td>
<td>2.20</td>
<td>1.24</td>
<td>0.20</td>
<td>1.75</td>
<td>459</td>
<td>7.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical Composition, Elements (weight %)</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>Fe2O3</th>
<th>CaO</th>
<th>K2O</th>
<th>TiO2</th>
<th>Na2O3</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56.77</td>
<td>31.83</td>
<td>2.82</td>
<td>0.78</td>
<td>1.96</td>
<td>2.77</td>
<td>0.68</td>
<td>2.39</td>
</tr>
</tbody>
</table>

Silica Fume

The silica fume used in the experimentation was obtained from Elkem Laboratory, Navi Mumbai. The chemical composition of Silica Fume is shown in Table 3.

### Table 3. Chemical composition of Silica Fume.

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>Silica (SiO2)</th>
<th>Alumina (Al2O3)</th>
<th>Iron Oxide (Fe2O3)</th>
<th>Alkalies as (Na2O + K2O)</th>
<th>Calcium Oxide (CaO)</th>
<th>Magnesium Oxide (MgO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>89.00</td>
<td>0.50</td>
<td>2.50</td>
<td>1.20</td>
<td>0.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Metakaoline

The Metakaoline was obtained from M/s. 20 Microns Limited, Baroda, India. The chemical composition of Metakaoline is shown in Table 4.

Table 4. Chemical composition of Metakaoline

<table>
<thead>
<tr>
<th>Chemical Composition</th>
<th>SiO\textsubscript{2}</th>
<th>Al\textsubscript{2}O\textsubscript{3}</th>
<th>Fe\textsubscript{2}O\textsubscript{3}</th>
<th>TiO\textsubscript{2}</th>
<th>CaO</th>
<th>MgO</th>
<th>SO\textsubscript{3}</th>
<th>Na\textsubscript{2}O</th>
<th>K\textsubscript{2}O</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Percentage</td>
<td>52 to 54%</td>
<td>42 to 44%</td>
<td>&lt; 1 to1.4%</td>
<td>&lt; 3.0%</td>
<td>&lt; 0.1%</td>
<td>&lt; 0.1%</td>
<td>&lt; 0.05%</td>
<td>&lt; 0.4%</td>
<td>&lt; 1.0%</td>
<td></td>
</tr>
</tbody>
</table>

Super Plasticizer

VARAPLAST PC100: A high performance concrete superplasticizer based on modified polycarboxilic ether, supplied from M/s Akash specialities, Chennai.

RESULTS AND DISCUSSION

In the present work, the mix proportion for HPC mix of M\textsubscript{70} was carried out according to IS: 10262-2009 [9] recommendations. The mix proportions are presented in Tables 5. The tests were carried out as per IS: 516-1959 [10]. The 150 mm cube specimens of various concrete mixtures were cast to test compressive strength. The cube specimens after demoulding were stored in curing tanks and on removal of cubes from water the compressive strength were conducted at 7 days, 28 days and 90 days. The test results were compared with individual percentage replacements (Binary System) and combinations of admixtures (Ternary System) for M\textsubscript{70} Mix.

Table 5. Mix Proportion for M\textsubscript{70} Concrete.

<table>
<thead>
<tr>
<th>Composition in Kg/m\textsuperscript{3}</th>
<th>Cement</th>
<th>Fine aggregate</th>
<th>Coarse aggregate (20mm 20% &amp; 12.5mm 80%)</th>
<th>water</th>
<th>Secondary Cementing Materials</th>
<th>Superplasticizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>482</td>
<td>715</td>
<td>1012</td>
<td>2.099</td>
<td>0.317</td>
<td>0.248</td>
<td>0.0199</td>
</tr>
</tbody>
</table>

ACID ATTACK TEST

The concrete cube specimens of various concrete mixtures of size 150 mm were cast and after 28 days of water curing, the specimens were removed from the curing tank and allowed to dry for one day. The weights of concrete cube specimen were taken. The acid attack test on concrete cube was conducted by immersing the cubes in the acid water for 90 days after 28 days of curing. Hydrochloric acid (HCL) with p\textsubscript{H} of about 2 at 5% weight of water was added to water in which the concrete cubes were stored. The p\textsubscript{H} was maintained throughout the period of 90 days. After 90 days of immersion, the concrete cubes were taken out of acid water. Then, the specimens were tested for compressive strength. The resistance of concrete to acid attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in acid water. Figure 1 represents the Percentage loss in Weight of M\textsubscript{70} due to Acidity respectively and Figure 2 represents the Percentage loss in Strength of M\textsubscript{70} due to Acidity respectively.
ALKALINE ATTACK TEST

To determine the resistance of various concrete mixtures to alkaline attack, the residual compressive strength of concrete mixtures of cubes immersed in alkaline water having 5% of sodium hydroxide (NaOH) by weight of water was found. The concrete cubes which were cured in water for 28 days were removed from the curing tank and allowed to dry for one day. The weights of concrete cube specimen were taken. Then the cubes were immersed in alkaline water continuously for 90 days. The alkalinity of water was maintained same throughout the test period. After 90 days of immersion, the concrete cubes were taken out of alkaline water. Then, the specimens were tested for compressive strength. The resistance of concrete to alkaline attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersion of concrete cubes in alkaline water. Figure 3 represents the Percentage loss in Weight of M70 due to Alkalinity respectively and Figure 4 represents the Percentage loss in Strength of M70 due to Alkalinity respectively.
SULPHATE ATTACK TEST

The resistance of concrete to sulphate attacks was studied by determining the loss of compressive strength or variation in compressive strength of concrete cubes immersed in sulphate water having 5% of sodium sulphate (Na$_2$SO$_4$) and 5% of magnesium sulphate (MgSO$_4$) by weight of water and those which are not immersed in sulphate water. The concrete cubes of 150mm size after 28days of water curing and dried for one day were immersed in 5% Na$_2$SO$_4$ and 5% MgSO$_4$ added water for 90days. The concentration of sulphate water was maintained throughout the period. After 90days immersion period, the concrete cubes were removed from the sulphate waters and after wiping out the water and girt from the surface of cubes tested for compressive strength following the procedure prescribed in IS: 516-1959. This type of accelerated test of finding out the loss of compressive strength for assessing sulphate resistance of concrete [11]. Figure 5 represents the Percentage loss in strength of M$_{70}$ due to Sulphate.
CONCLUSIONS

1. In HSC mix design as water/cement ratio adopted is low, super plasticizers are necessary to maintain required workability. As the percentage of mineral admixtures is increased in the mix, the percentage of super plasticizer should also be increased, for thorough mixing and for obtaining the desired strength.

2. In M70 grade concrete as the water-cement ratios of 0.317 was insufficient to provide the good workability; hence super plasticizer was necessary for M70 mix.

3. It is observed from the results the maximum percentage loss in weight and percentage reduction in compressive strength due to Acids for M70 grade concrete are 2.23%, 15.14% with replacement of 20% Flyash and 10% Metakaoline and the minimum percentage loss in weight and strength are 1.4%, 15.5% with replacement of 15% Flyash and 10% Silica Fume. There is considerable increase in loss of weight and strength only with Flyash replacement.

4. Present investigation shows that the maximum percentage loss in weight and percentage reduction in compressive strength due to Alkalinity for M70 grade concrete are 3.30%, 19.20% with replacement of 20% Flyash and 10% Metakaoline and the minimum percentage loss in weight and strength are 2.10%, 17.20% with replacement of 20% Flyash and 10% Silica Fume. There is considerable reduction in loss of weight and strength only with Flyash replacement.

5. It is identified that the maximum percentage reduction in compressive strength due to Sulphates of M70 grade concrete is 11.70% with replacement of 20% Flyash and 10% Silica Fume and the minimum percentage reduction in strength is 11.65% with 20% Flyash and 10% Metakaoline. There is considerable increase in loss of strength only with Flyash replacement.
REFERENCES


