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Study on the Effect of Supplementary Cementing Materials on the Durability Properties of M70 Grade High-performance Concrete with Superplasticizer

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ABSTRACT

High-performance concrete (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 the high strength and HPC mix design. The addition of SCMs to concrete reduces the heat of hydration and extends the service life in structures by improving both long-term durability and strength. The concrete durability crisis which started to attract public attention forced the engineers to think about the performance of concrete. Proper mix design and careful construction using the best available materials and technologies are necessary to achieve quality concrete structures. In this investigation, the SCMs used are fly ash, silica fume, and metakaolin, which are recommended by IS: 456-2000 to enhance the durability of concrete. This study discusses the role of supplementing cementing materials as partial replacement for cement in concrete in reducing greenhouse gas emissions. In this investigation, an attempt was made to study the behavior of HPC of M70 grade specimens curing with acids such as hydrochloric acid, alkaline solution such as NaOH and sulfate solution $MgSO_4$ and Na_2SO_4. The durability properties were evaluated by conducting acid attack test, alkaline attack test, and sulfate attack tests. One of the important changes is the introduction of micro technology for concrete with ultrafine and various other micro sized and fine cementitious materials. It is now possible to achieve excellent particle packing and thereby comply with the demands for performance in concrete both in fresh and in the hardened state.

Key words: *High-performance concrete, Durability, Acid attack test, Alkaline attack test, Sulfate attack test.*

1. INTRODUCTION

Another advantage of using supplementary cementing materials (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 (FA) and silica fume (SF) is becoming more common because they improve concrete durability and strength, especially where high early age curing temperatures occur. High replacement levels of FA are uncommon, however, because of resistance to change by the cement industry and because of concerns about the early-age strength and the quality of concretes produced with high cement replacement levels.

High-performance concrete (HPC) will extend the service life of structures in severe environments; there has been a gradual acceptance of HPC. HPC is characterized by a low water/cementitious materials ratio (generally >0.35, high dosages of superplasticizer and the incorporation of SCMs. Established a testing regime to optimize the strengths and durability characteristics of a wide range of HPC 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 75-100 years. One of the prime methods of optimizing the mixtures was to implement supplemental cementitious materials, at their most advantageous levels. FA, slag cement, and microsilica all proved to be highly effective in creating more durable concrete design mixtures [1].

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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_2SO_4 solution, and the pH (4) was maintained constant throughout. The solution was replaced at regular intervals to maintain constant concentration throughout the test period. The mass of specimens was measured at regular intervals up to 90 days, and the mass losses were determined [2]. An experimental study on the effect of FA and SF on the properties of concrete subjected to acidic attack and sulfate attack. Changes in physical and chemical properties in the mortars with different replacements by FA and SF when immersed in 2% H_2SO_4, 10% Na_2SO_4, and 10% $MgSO_4$ solutions for 3 years were investigated [3].

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 the order of hazard harmful to concrete as they react with hydrated cement paste leading to expansion, cracking, spalling, and loss of strength [4].

1.1. Research Significance

Presently, the Indian practice for mix design is based on IS: 456 which emphasis only on certain prescriptive specifications, namely, limits on minimum cement content, maximum water-cement ratio, and minimum grade of concrete for different exposures. However, no performance specifications are imposed for quality checking. Acceptance of concrete based on the specifications of strength, minimum water-cement ratio, and amount of cementitious content should go out of practice keeping in mind the stringent durability requirements. Furthermore the present exposure classifications of IS: 456 do not correctly address many of the durability issues especially for severe exposure. What is important in future concrete mix design is to ensure certain minimum performance requirements to be satisfied with regard to durability (performance approach). Simple durability tests that can be conducted on concrete in the laboratory are the acid, alkaline, and sulfate attack tests. Keeping this in mind, this study is planned with varying cement and SCMs contents and to achieve M70 grade of concrete based on IS practice. This study serves as a tool for selecting suitable combinations of SCMs depending on what type of cementing materials are available in the site to achieve good resistance against these tests.

2. MATERIALS AND METHODOLOGY

2.1. Cement

Ordinary Portland Cement (OPC), 53 grade conforming to IS: 12269-1987 was used [5].

2.2. Aggregates

Crushed granite rock 20 mm and downsize and river sand were used as coarse and fine aggregates. The fineness modulus is 3.12 and 7.19 for fine and coarse aggregate, respectively. The specific gravity of fine and coarse aggregates are 2.62 and 2.74, respectively [6].

2.3. Water

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

2.4. SCMs

2.4.1. FA

FA supplied by M/s Ennore Thermal Power Station, Tamil Nadu, India, is used.

2.4.2. SF

SF used in the study was obtained from Elkem Laboratory, Mumbai.

2.4.3. Metakaolin (MK)

The MK was obtained from M/s. 20 Microns Limited, Baroda, India.

2.5. Chemical Admixture

VARAPLAST PC 100, an HPC superplasticizer based on modified polycarboxylic ether supplied from M/S Akarsh Specialities, Chennai, is used. In all mixes about 0.25-0.75 kg of SP per 50 kg, cementitious materials are used to get an average workability of about 25-50 mm slump. However in higher grades, namely, M60 and beyond, the dosage of superplasticizer is suitably adjusted based on trials to get the desired workability.

2.6. Mix Proportion

In this work, the mix proportion for HPC mix of M70 was carried out according to IS: 10262-2009 [7] recommendations. The mix proportions are presented in Table 1. The tests were carried out as per IS: 516-1959 [8]. The 150 mm cube specimens of various concrete mixtures were cast to test compressive strength. The cube specimens after de-molding were stored in curing tanks, and on removal of cubes from water, the compressive strength was conducted at 7, 28, and 90 days. The test results were compared with individual percentage replacements (Binary System) and combinations of admixtures (Ternary System) for M70 Mix.

2.7. 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 with pH of about 2 at 5% weight of water was added to water, in which the concrete cubes were stored. The pH 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.

2.8. 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 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 and tested for compressive strength. The resistance of concrete to alkaline attack was found by % loss of weight of specimen and % loss of compressive strength on immersion of concrete cubes in alkaline water.

2.9. Sulfate Attack Test

The resistance of concrete to sulfate attacks was studied by determining the loss of compressive strength or variation in compressive strength of concrete cubes immersed in sulfate water having 5% of sodium sulfate (Na_2SO_4) and 5% of magnesium sulfate ($MgSO_4$) by weight of water and those which are not immersed in sulfate water. The concrete cubes of 150 mm size after 28 days of water curing and dried for 1 day were immersed in 5% Na_2SO_4 and 5% $MgSO_4$ added water for 90 days. The concentration of sulfate water was maintained throughout the period. After 90 days immersion period, the concrete cubes were removed from the sulfate 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 sulfate resistance of concrete [9].

3. RESULTS AND DISCUSSIONS

Before conducting the compressive strength tests on concrete cubes after immersion in different solutions prepared for acid, alkaline, and sulfate tests for finding out the durability properties, the percentage weight loss when compared to the control mix concrete cubes are calculated. The effect of SCMs on partial replacement of cement concrete (M70) with superplasticizer is presented in Table 2 and Figure 1. From Table 2 and Figure 1, it is clearly recognized that the percentage loss in weight due to acid attack on concrete cubes prepared by 25% replacement of OPC

Table 1: Mix proportion for M70 grade of concrete in kg/m^3.

Grade of concrete	Cement	SCM	Fine aggregate	Coarse aggregate	Water
M70	482	120	715	1012	153
	1		1.19	1.68	0.26

SCMs=Supplementary cementing materials

Table 2: Effect of SCMs replacement on cement concrete (M70) with Superplasticizer on percentage weight loss.

Grade of concrete	Cement+ admixture	Percentage loss in weight after 90 days immersion in different solutions		
		Acid solution	Alkaline solution	Sulfate solution
M70	100% OPC+SP	1.30	1.00	1.15
	25% FA+SP	3.80	1.50	2.65
	20% FA+10% SF+SP	2.40	2.10	2.25
	20% FA+10% MK+SP	2.23	1.80	2.015

SCMs=Supplementary cementing materials, FA=Fly ash, SF=Silica fume, OPC=Ordinary Portland Cement, SP=Super pozz, MK=Metakaolin

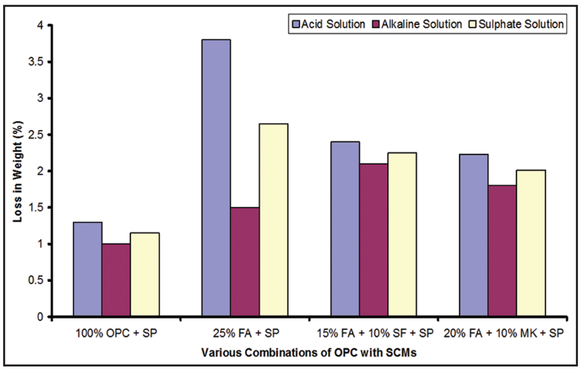

Figure 1: Effect of supplementary cementing materials replacement on cement concrete (M70) with superplasticizer on percentage weight loss.

by FA is 3.8% and 20% FA, 10% SF and 20% FA, 10% MK replacement are 2.4% and 2.23% when OPC with superplasticizer a weight loss of 1.3% is observed.

In the similar style, a decreasing trend in the weight loss is observed in the case of alkaline attack which is in the order of 1.5% in the concrete cubes prepared by partial replacement of OPC by 25% FA and 2.1%, 1.8% in the concrete cubes prepared by partial replacement of OPC by 20% FA, 10% SF and 20% FA, 10% MK when OPC with superplasticizer a weight loss of 1.0% is observed. Similar trend of decreasing weight loss is presented after sulfate attack also by the concrete cubes prepared by partial replacement of OPC by 25% FA is 2.65% and 2.25%, 2.015% in the concrete cubes prepared by partial replacement of OPC by 20% FA, 10% SF and 20% FA, 10% MK when OPC with superplasticizer a weight loss of 1.15% is observed. From the above-mentioned results, it can be clear that the concrete cubes are losing their weights after immersion in different acid, alkaline, and sulfate solutions, which reveal their capacity of resistance. It can be noticed from the graphical representation that the concrete cubes are showing much resistance to alkaline attack followed by sulfate attack and finally showing less resistance against acid attack. The effect of FA, SF, and metakaolin on different durability tests such as acid test, alkaline test, and sulfate test after 90 days immersion in the respective samples along with percentage loss in compressive strength are presented in Table 3.

Based on the results presented in Table 3 and Figure 2, the concrete cubes prepared by OPC showed a percentage loss of 22, 23, and 11.9 for acid, alkaline, and sulfate resistance attack tests, respectively, which depict that the concrete cubes showed greater resistance to alkaline than sulfate than acid attacks. Similar is the trend followed by the concrete cubes prepared by the replacement by 25% FA and 20% FA, 10% SF and 20% FA, 10% MK with the presence superplasticizer. For the samples prepared by 25% FA and 20% FA, 10% SF and 20% FA, 10% MK replacement the percentage loss in compressive strengths started declining which in turn implies that greater resistance offering characteristic is appeared with the FA, SF, and MK replacement against acid, alkaline, and sulfate attacks.

- In M70 grade of concrete as the water-cement ratios of 0.26 is insufficient to provide the good workability, superplasticizer is necessary for the development of HPC.
- It is observed that the percentage loss in weight due to acid attack on concrete cubes prepared by 25% replacement of OPC by FA is 3.8% and 20% FA, 10% SF and 20% FA, 10% MK replacement are 2.4 and 2.23% when OPC with superplasticizer a weight loss of 1.3% is observed.
- Based on the results, the concrete cubes prepared by OPC showed a percentage loss of 22, 23, and 11.9 for acid, alkaline, and sulfate resistance attack tests, respectively, which depict that the concrete cubes showed greater resistance to alkaline than sulfate than acid attacks.
- The samples prepared by 25% FA and 20% FA, 10% SF and 20% FA, 10% MK replacement the percentage loss in compressive strengths started declining which in turn implies that greater resistance offering characteristic is appeared with the FA, SF, and metakaolin replacement against acid, alkaline, and sulfate attacks.
- This investigation has revealed that the SCMs such as FA, SF, and metakaolin in different combinations, depending on what is available in practice, which is otherwise hazardous to the environment, may be profitably used as partial replacement to cement. Due to this, economical and durable concrete mixes exhibiting better resistance to these tests. Proper utilization of these industrial wastes in the manner discussed enhances the protection of the environment to a large extent. An optimum consumption of these

Table 3: Durability properties of cement concrete cubes (M70) at different ages made with partial replacement of SCMs with superplasticizer in OPC.

Grade of concrete	Cement+ admixture	Percentage loss in strength after 90 days immersion in different solutions		
		Acid solution	Alkaline solution	Sulfate solution
M70	100% OPC+SP	22.00	23.00	11.90
	25% FA+SP	24.00	26.80	11.85
	20% FA+10% SF+SP	15.50	17.20	11.70
	20% FA+10% MK+SP	15.14	19.20	11.65

SCMs=Supplementary cementing materials, FA=Fly ash, SF=Silica fume, OPC=Ordinary Portland Cement, SP=Super pozz, MK=Metakaolin

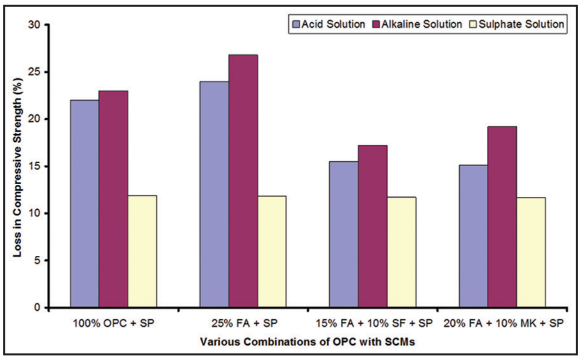

Figure 2: Durability properties of cement concrete cubes (M70) at different ages made with partial replacement of supplementary cementing materials with superplasticizer in Ordinary Portland Cement.

materials can be identified without scarifying the quality of concrete to make them suitable as "green building materials" and which eventually leads to "sustainable development" and growth of cement industry.

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Bibliographical Sketch

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