RESEARCH ARTICLE OPEN ACCESS

Effect of Mineral Admixtures on Durability Properties of High Performance Concrete

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ABSTRACT
Concrete is the most commonly used construction material. The premature deterioration of concrete structures in aggressive environments has led to the development of high performance concrete (HPC). The production of HPC involves appropriate selection and proportioning of the constituents to produce a composite mainly characterised by its low porosity and fine pore structure. These, in turn improve the resistance of concrete to the penetration of harmful substances such as chloride and sulphate ions, carbon dioxide, water and oxygen, and hence enhance durability performance. The improved pore structure of HPC is mainly achieved by the use of chemical and mineral admixtures. In the present study the effect of mineral admixtures on the durability properties of HPC is investigated. A control mix without any mineral admixtures having a compressive strength was designed of 60MPa and two other mixes are prepared one by replacing cement by 10% metakaoline and other by replacing cement with 10% metakaoline + 30% fly ash respectively The workability tests were carried out on the fresh mix. Durability properties were determined by conducting sulphate attack test, acid attack test and rapid chloride permeability test.
Keywords – deterioration, high performance concrete, mineral admixtures

I. Introduction

High-performance concrete is defined as concrete that meets special performance and uniformity requirements that cannot always be achieved routinely by using conventional materials and normal mixing, placing, and curing practices. Thus, a high-performance concrete is a concrete in which certain characteristics are developed for a particular application and environment. For example, concrete that provides substantially improved durability under severe service conditions, extraordinary properties at earlier ages, or substantially enhanced mechanical properties are potential HPCs. These concretes may contain materials such as fly ash, silica fume, ground granulated slags, natural pozzolan, fibers, chemical admixtures, and other materials, individually or in various combinations.

From a structural design standpoint, high-performance concrete allows more slender structural elements with greater rigidity (higher modulus of elasticity) for smaller deflection, less creep, and a high MPa/$ ratio. Unfortunately, very few material building codes have provisions for high-performance concrete at present.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. The rate at which the hardened cement paste is deteriorated due to the exposure to harmful chemicals depends mainly on the concentration of the chemicals in water, the time of exposure and the chemical resistance of concrete. Extensive investigations have been carried out on the use of fly ash and silica fume in concrete during the past two decades and have consequently led to their widespread application in the construction industry. Many national standards also exist which determine the degree of attack, and this primarily on the basis of the concentration of the aggressive substances. However, the chemical resistance of high-performance concrete using metakaoline, fly ash and superplasticizers are issues which have not yet received sufficient attention from the research community. In the present study the effect of various mineral admixtures on the durability properties of HPC is being investigated.

II. Materials

Portland cement of 53 grade manufactured by Krishna nagar Company confirming to IS 12269 was used in this investigation. The specific gravity of the cement was 3.01. The initial and final setting times were found as 70 minutes and 240 minutes respectively. Locally available river sand passing through 4.75 mm IS. Sieve was used. The specific gravity of the sand is found to be 2.47.Crushed granite aggregate available from local sources has been used. To obtain a reasonably good grading, 50% of the aggregate passing through 25mm I.S.sieve and retained on 20mm I.S.sieve and 50% of the aggregate passing through 20 mm I.S.sieve and retained on 12 mm I.S.sieve was used in the production of HPC. In the production of M60 grade concrete, 20mm maximum size coarse aggregate has been used. The specific gravity of coarse aggregate is 2.76. Potable fresh water available from local sources was used for mixing and curing of both HPC mixes and M60 grade concrete. To improve the workability of the HPC mixes, a high range water-reducing agent Auromix has been used in the present work. The mineral admixture metakaoline is obtained from English indian clay limited company at Trivandrum. The specific gravity of Metakaolin is 2.6. The Metakaolin is in conformity with the general requirements of pozzolana..FA was supplied by National Power from Drax Power Station and conformed to BS 3892: Part 1

III. Concrete mixes

The constituents of the OPC mix were proportioned to achieve maximum packing of the particles and thus minimum porosity The composition of the OPC mix was 1:1.63:2.6 by weight of cement: sand: gravel, with a cement content of 450 kg/m3.For the MK and FA concrete mixes, 10% and 30% by weight of the OPC were replaced by MK and FA, respectively. A high superplasticiser dosage was used, and the amount of mixing water was decided on the basis of equal workability. The w/b ratio was 0.303for all the 3 mixes concrete mixes. The workability of the concrete mixes ranged between 180 and 190 mm as obtained by the slump test, BS 1881: Part 102 [9].

IV. Test specimens

Standard moulds were used for casting 150mm cube specimen. which includes cubes of size 150mm x 150mm x 150mm, discs of size 100mmdia x50mm thick were cast. For durability study specimens were kept in respective solutions till the test ages are reached. These specimens were tested for different mechanical properties and durability properties. Mixing was done in a laboratory type pan mixer. Pan mixers with revolving star of blades were used. While preparation of HPC aggregates, cement and mineral admixtures were mixed in the revolving pan. After proper mixing, mixture of water and plasticizer was added. The mixing was continued until a uniform mix was obtained. The concrete was then placed into the moulds which were properly oiled. After placing of concrete in moulds proper compaction was given. Specimens were demoulded after 24 hours of casting and were kept in a curing tank for water curing.

V. Experimental Details

5.1 Durability properties of hardened concrete

5.1.1Sulphuric Acid Attack Test

The compressive strength of HPC mix with mineral admixtures was then compared with HPC mix without mineral admixtures exposed to acid environment. 150mm concrete cube specimens were tested based on modified ASTM C 267-01 test method. After 28 days of water curing, the concrete specimens were exposed to 3% sulphuric acid solution for 56 days and 90 days, and the surface colour change and surface deterioration were studied. The 3% sulphuric acid solution was prepared by diluting 98% concentrated sulphuric acid with water.

5.1.2 Sulphate attack test

This test proposes to assess the sulphate attack on concrete specimen by determining the deterioration of compressive strength of 150 mm concrete cube specimens. The concrete specimens, after 28 days of water curing, were exposed to sodium sulphate solution for 56 days and 90 days. A 20000 ppm sulphate solution was prepared by dissolving 52 gm of $MgSO_4.7H_2O$ in one litre of water. The test was conducted based on ASTM C 452-02 test method.

5.2.3 Rapid Chloride Permeability Test (RCPT)

This test covers laboratory evaluation of the electrical conductance of concrete samples to provide a rapid indication of their resistance to chloride ion penetration. In this method 60 V dc was applied across the opposite faces of 150 mm diameter × 50 mm thick concrete specimens. One of the faces was exposed to 3% NaCl solution and the other face was exposed to 0.3M NaOH solution. The duration of experiment was kept as 6 hours. The current between the electrodes was monitored at 30 min interval of time. The total charge passed through the specimen indicates the chloride permeability of concrete. Total current passed through the specimen in coulombs is calculated using the following equation

$$Q = 900\ (I_0 + 2I_{30} + 2I_{60} + \ldots\ldots.. + 2I_{330} + I_{360})$$

Where I_0, I_{30}.... etc are current passed through the specimens in 0, 30… minutes respectively. Depending on the charge passed, ASTM C 1202-97 has graded the chloride permeability of concrete from negligible to high as given in Table 1. Fig 1 shows the schematic diagram of RCPT set up. Fig 2 shows the test setup for RCPT.

Table1 Chloride permeability based on charge passed

Charge Passed (Coulombs)	Chloride Permeability
> 4,000	High
2,000 – 4,000	High
1,000 – 2,000	High
100 – 1,000	Very Low
<100	Negligible

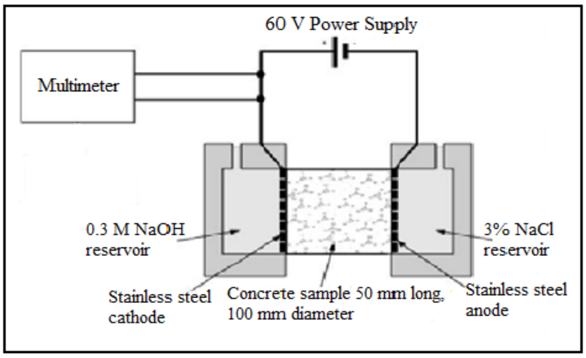

Fig.1 Schematic diagram of RCPT set-up

Fig.2 Test setup for rapid chloride permeability test

VI. Test Results and Discussions

6.1 Workability of fresh concrete

At present standard methods are not available to measure the workability of HPC. Slump test was done to measure the workability of HPC. The workability of various mixes was assessed as per the IS 1199:1959 specification. Table 2 shows the values of slump for various mixes of HPC.

Table 2 Workability details of various HPC mixes

Mix Type	Degree of workability	Slump (cm)
HPCL	High	19
HPM	High	12
HPMF	High	18

The minimum workability for HPM mix may be due to the extremely small particles of metakaoline which can result in higher water demand thereby reducing workability. HPMF mix has high workability compared to HPM which may be due to the spherical shape and glassy surface of fly ash particles which permit greater workability.

6.2 Sulphuric Acid Attack Test

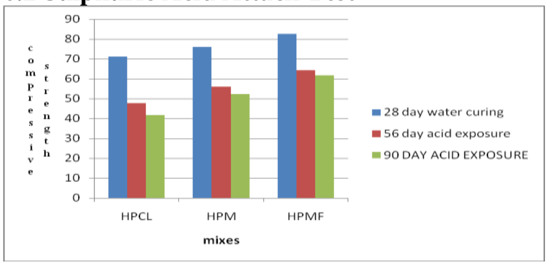

Fig.7 Effect of acid attack on various HPC mixes

From the figure it is clear that compared to all other mixes the strength loss is maximum for the HPCL mix. By comparing the compressive strength after acid exposure it can be seen that the rate of strength loss was minimum for HPMF mix followed by HPM mix and HPCL. The minimum rate of strength loss for HPMF mix may be due to its higher percentage of cement replacement. From the experimental investigation it is clear that the percentage of mass loss is maximum for the HPCL mix compared to all other mix. The mass loss percentage was minimum for HPMF mix for 28 day water curing. For all HPC mix with mineral admixtures the mass loss was less compared to HPCL mix.

6.3 Sulphate Attack Test

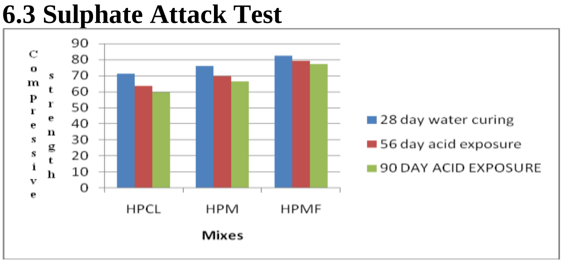

Fig.8 Effect of sulphate attack on various HPC mixes

From the figure it is clear that compared to all other mixes the strength loss is maximum for the HPCL mix.Comparing the strength corresponding to 56 day sulphate exposure the rate of strength loss was found to be minimum for HPMF mix. By the addition of mineral admixtures the sulphate resistance of HPC mix was improved.

6.4 Rapid Chloride Permeability Test

From figure it is clear that HPCL mix has the lowest chloride penetration resistance compared to all other mix HPMF mix has highest chloride penetration resistance. The higher resistance of HPMF mix may be due to their higher percentage of cement replacement.For all the three mixes the chloride permeability is very low. The results obtained clearly indicate that by the addition of mineral admixtures resistance to chloride penetration can be increased.

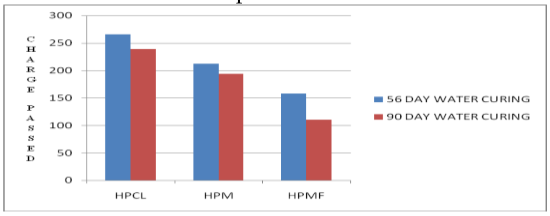

Fig.9 RCPT results for various HPC mixes

VII. Conclusions

The principal conclusions of the present investigation are:

- By the addition of fly ash the workability of the mix was improved but addition of metakaoline resulted in lower workability.
- In both the curing conditions, mineral admixture incorporated concrete shows better resistance against the acid attack. By comparing the compressive strength at 56 day and 90 day acid exposure the rate of strength loss was minimum for HPMF mix followed by HPM mix and HPCL mix respectively for both curing condition.
- By the addition of mineral admixtures the percentage mass loss was decreased. The mass loss percentage due to acid attack was minimum for HPMF mix for 28 day water curing.
- In the case of sulphate attack test the strength loss percentage was reduced by the addition of mineral admixtures. Comparing the strength corresponding to 56 and 90 day sulphate exposure the rate of strength loss was found to be minimum for HPMF mix for both curing condition.
- For mixes with mineral admixtures, chloride penetration was less compared to HPCL mix. Chloride penetration was minimum for HPMF mix for both curing condition due to its higher percentage of cement replacement.
- The results from rapid chloride permeability test have shown that the chloride penetration resistance was increased by addition of mineral admixture for both 56 and 90 day water curing. HPMF mix has highest chloride penetration resistance followed by HPM mix and HPCL mix.
- Based on the diffusion coefficient values and chloride permeability level according to ASTM C1202-97, all concrete mixes have very low permeability but the durability properties was enhanced by the addition of mineral admixtures compared to control mix

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