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Accelerated Sulphate Attack Study on Cement – Metakaolin – Flyash Concretes

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Abstract*— Durability is that property of concrete which plays the prime role in governing the lifespan and serviceability of a structure with regard to its intended usage. Environmental conditions of the surroundings are the main criteria which decide the longevity and performance of concrete. For understanding the durability of concrete structures, analysis of the impact of chemical attacks may be crucial. As sulphate attacks are predominant chemical attacks on concrete structures, their study can interpret it when they are subjected to deterioration followed by damage. In this study, the effectiveness of ternary blends of OPC with metokaolin (MK) and flyash (FA) in sulphate resistance of concrete exposed to accelerated effect (i.e. by wetting and drying cycles) in 10% solution of sodium sulphate has been investigated. To assess the level of sulfate attack, the changes in strengths of concrete specimens and their weight change were measured after certain numbers of deterioration cycles. Cubes, prisms and cylinders of concrete were tested for compressive, flexural and splitting tensile strengths respectively whereas the weight changes (in percent) were measured for all the specimens. Combination of OPC with MK and FA has proved its effectiveness in improving the resistance against sulphate attack.

I. INTRODUCTION

Concrete usage is steadily growing.It has proved to be the most favoured building material for construction of simple roads to iconic structures. Concrete is said to be durable if it works well in the environmental conditions to which it is exposed, as well as in the conditions that it is expected to be exposed to during its service life. [1]. Durability is that property of concrete which plays prime role in deciding the lifespan and serviceability of a structure with regard to its intended usage .The resistance of a structure against weathering, chemical assault and abrasion as well as its ability to withstand other service conditions characterize it.

[2]. Environmental conditions of the surroundings are the main criteria which decide the longevity and performance of concrete .To understand durability of concrete structures, analysis of the impact of chemical attacks may be crucial. As sulphate attacks are predominant chemical attacks on concrete structures, their study can interpret it when they are subjected to deterioration followed by damage [3]. Concrete deterioration induced by sulphate attack can manifest itself as expansion, cracking, and loss of strength. The outer layer of the concrete is damaged first and gradually the damage reaches the inner layers causing complete damage**.** [4]-[7].

In the past few years, metakaolin the calcined form of kaolinite clay has gained substantial interest due to its filling effect and pozzolanicity to combine with lime to form cementitious compounds. [8]-[12] Effect of these characterstics of MK on different properties of cementitious composites like porosity, compressive and flexural strengths, permeability, creep and cracking due to shrinkage has been widely reported in the literature. [13]-[16]. Huge quantities of Flyash, a proven pozzolanic material, are readily and inexpensively available from thermal power plants all over the globe.

Some researchers have reported that certain combinations of Ordinary Portland Cement (OPC), MK and FA can provide concretes of high early strengths[17]-[18]. But, durability study on OPC, MK and FA concrete is necessary before recommending its use in actual structures. Sulphate attack is considered to be the most prominent effect, which reduces functional life span of concrete structures and this effect can be accelerated when the specimens are put through alternating cycles of wetting and drying. Alyami et. al [19] have carried out experimental study on cylindrical specimens under sodium sulphate solutions of 5% and 10% concentrations by imposing alternating wet and dry cycles of 8 hours wetting and 16 hours sun drying and also by 16 hours wetting and 8 hours sun drying. They concluded that 16 hours - 8 hours alternating wetting-sun drying cycles in 10% sodium sulphate solution give worse effects.

In this study, the effectiveness of concrete of ternary blends of OPC , MK and FA has been evaluated against its resistance to sulphate assault by subjecting the specimens to accelerated attack (i.e. by wetting for 16 hour and drying for 8 hour cycles) in 10% solution of sodium sulphate attack. To evaluate the level of sulphate attack the changes in strengths of concrete cubes for compressive strength, prisms for flexural strength and cylinders for splitting tensile strength and also their weight change(in percent) have been measured after certain number of reiterations of accelerated attack. [20]-[23].

II. EXPERIMENTAL PROGRAM

The experimental procedure has been designed to assess the durability of different concrete mixes under accelerated deteriorating environment. The materials, mixtures and the test procedures used to determine strengths are already reported in the previous study [18].Details of the same are briefly presented in the following sections:

A. Materials

Ordinary portland cement classified as OPC (43 grade) as per IS: 269 – 2015,has been used for all the mixtures [24]. Commercially available MK (particle size D50 of 6.5 µm, and fineness of 1342 m^2/kg determined by laser diffraction analyser), has the composition (by weight) of 52% SiO_2, 45% Al_2O_3, 0.7 % TiO_2, 0.7% Fe_2O_3, 0.9% CaO, traces of Na_2O along with K_2O and loss on ignition of 0.5%. The fly ash was collected from Rajghat Thermal Power Station, Delhi (particle diameter D50 of 10.2 µm and fineness of 1343 m^2/kg determined by laser diffraction analyser) has the composition (by weight) of 61.21% SiO_2, 30.07% Al_2O_3, 2.60% TiO_2, 4.17% Fe_2O_3, 0.1% CaO, some traces of Na_2O along with K_2O and loss on ignition of 1.40 % [25].

Good quality aggregates were procured from local market for this study. Crushed granite of 20 mm and down size and stone dust having particle size4.75 mm and below, have been used as coarse aggregate and fine aggregate respectively. Their properties were determined according to relevant IS Code[26].The coarse aggregate is specified as 20 mm nominal size whereas the fine aggregate belongs to the Grading zone I[27].The specific gravity and water absorption of the coarse aggregates were 2.91,0.57% and that of fine aggregates were 2.73, 0.80% respectively. A poly carboxylate ether (PCE) based super-plasticizer (SP) available from local vendor, was mixed in all the concrete mixtures.

B. Concrete Mixtures

A uniform water to binder ratio of 0.32 was adopted to prepare four concrete mixtures (Table 1). Out of these four mixes, one was control mix and the other three were ternary blends of OPC, MK and FA having 10, 13 and 16 percentages of metakaolin alongwith 15% fly ash in each mix. The quantities of MK and FA used to replace cement were calculated on weight basis.

C. Determination of Compressive Strength, Splitting Tensile Strength and Flexural Strength

Concrete cubes were tested according to the procedure mentioned in IS: 516[28]by means of a 3MN capacity compression testing machine. The splitting tensile strength tests have been performed in accordance with IS: 5816[29].Concrete prisms were tested For determination of flexural strength , loads were applied at both ends of the middle third portion of the prismatic beam as specified in IS:516. After water curing for 28 days the specimens were removed , allowed to drain and then tested after wiping with a soft cloth .The sets of three values thus obtained for each test were averaged to get the strengths of all the mix.

D. Scheme for Accelerated Sulphate Attack Testing by Alternate Wetting and Drying Cycles

For obtaining the experimental physical sulphate attack results in shorter duration, the artificial accelerated sulphate attack was designed as alternating wetting and drying in a 10% Na_2SO_4 solution.The wetting-drying cycles were set as alternate wetting and drying periods of 16 hours and 8 hours respectively. Some other researchers have also found this wetting- drying cycle quite severe[19],[30]. Also, the monthly average day time temperatures in this region as well as in some other regions of the globe lies in the range of 20^0C to 40^0C, which is sufficient for drying of the outer layer where the sulphate ion concentration is significant [31]. Thus, full wetting by submerging the specimens in the solution and sun drying of the specimens to maximum extent has been achieved by keeping them in the open environment for explained duration.

After the 28-day initial water curing, the specimens were transferred into 10% sodium sulphate solution for wetting-thereafter drying and such cycles were repeated at ambient temperatures. These specimens were tested for determination of three key strengths of concrete i.e. compressive strength, flexural strength and splitting tensile strength after 150 cycles,300 cycles and 500 cycles.The average of values obtained for the three specimens for each test after specified number of cycles , has been considered as the residual strength of the mix. Each specimen was brought in saturated surface dry condition and weighed on electronic balance before testing.

Table 1. Details of concrete mixtures

Mix Designation	water/binder ratio	OPC (kg/m^3)	MK %	MK (kg/m^3)	FA (%)	FA (kg/m^3)	Water (kg/m^3)	Fine Aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	SP (kg/m^3)
Control	0.32	466	00	00	00	00	144	643	1266	9.32
MK10	0.32	350	10	46	15	70	144	643	1266	9.32
MK13	0.32	336	13	60	15	70	144	643	1266	9.32
MK16	0.32	321	16	75	15	70	144	643	1266	9.32

III. RESULTS AND DISCUSSION

A. Loss of Compressive Strength

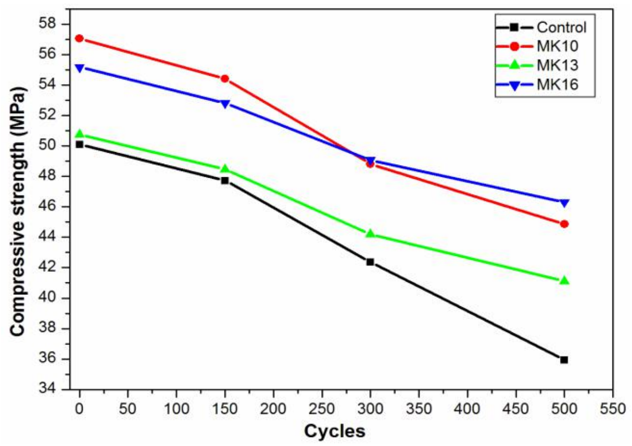

Fig.1 : Compressive strength at various exposure durations

Variations in compressive strength of concrete cubes after alternating wetting-drying in 10% Na_2SO_4solution are shown in figure1.The loss in compressive strength upto first 150 cycles is quite marginal. The percentage loss in control concrete keeps on increasing with increase in number of cycles, whereas in MK concrete it is not at that faster rate. The MK16 mix has been the best performer against sulphate attack by demonstrating the total loss after 500 cycles at only 16.1% as compared to the loss in control concrete at 28.3%.

B. Loss of Flexural Tensile Strength

As shown in figure 2, the total loss of flexural strength in all the mixes is of around 30%, among which 27.9% loss in MK 16 is the lowest. Other MK-FA mix have also performed better than the control mix in which the strength loss is 34.9%. Initially, up to 300 cycles the MK-FA mixes have shown only 12% loss as against 15% loss of strength in control mix. The residual flexural strengths in MK mixes are about 70% or more which is higher than the 65% residual strength of the control mix

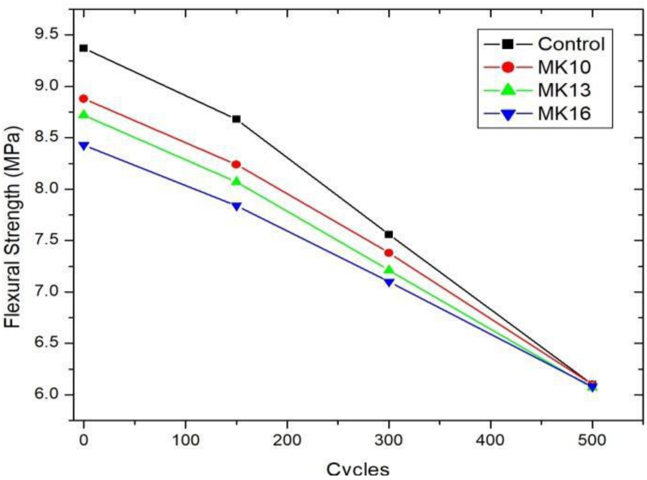

Fig.2 : Flexural tensile strength at various exposure durations

C. Loss of Splitting Tensile Strength

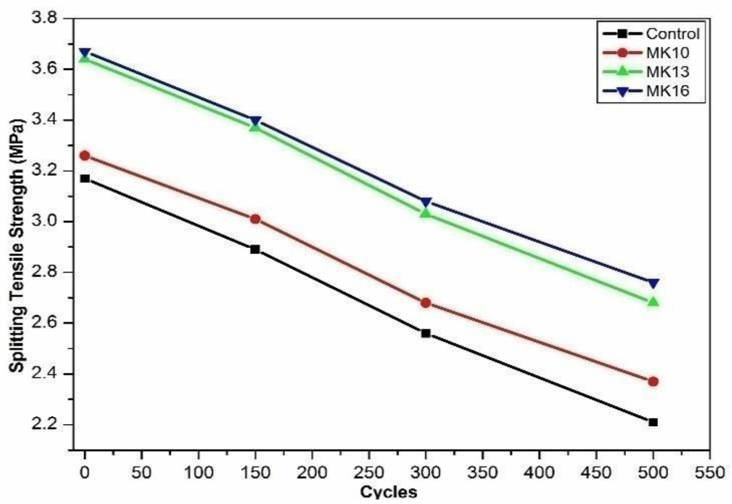

Fig. 3: Splitting tensile strength at various exposure durations

Figure 3 depicts loss of split tensile strength in all the mixes during first 150 cyclesis below 9%. In the next 150 cycles, the increase indeterioration in all the mixesis about 3%. The total loss after 500 cycles in MK16 is 24.8%, which is the least among all the mixes and this is also about 5% lesser than the loss in control mix. The MK concretes have been able to maintain about 70% residual strength after 500 cycles whereas for the control mix it is 63%.

D. Percentage weight loss

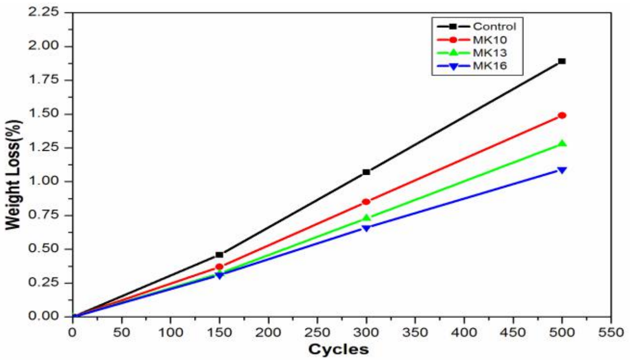

Fig.4: Percentage weight loss at various exposure durations

It is evident from figure 4 that initially the percentage weight loss in all the specimens is quite low. But, after 150 cycles the rate of deterioration keeps on increasing at a rapid rate. The control concrete has suffered highest weight loss of 1.9% after 500 cycles and the MK16 concrete has suffered the least(i.e.1.1 %).

IV. CONCLUSIONS

This study aims at examining the effectiveness of MK-FA blend OPC concrete for improving the resistance against sulphate attack. The specimens underwent accelerated sulphate attack caused by alternate wetting-drying cycles in sodium sulphate solution. The conclusions from this study are mentioned as under:

- Combination of OPC with MK and FA has proved its effectiveness in improving the resistance against sulphate attack in all wetting-drying cycles.
- Smaller loss of strengths, specially in concretes of higher percentages of MK has proved that MK-FA blend cement concrete is an effective supplementary cementitious material for resisting sulphate attack.
- Lower rate of percentage loss of strengths in MK concretes with increase in number of cycles indicates capability of MK concrete to extend service life of structures.

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