HIGH EARLY STRENGTHS IN CONCRETE WITH FLY ASH AND METAKAOLIN

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Abstract

The present study investigates different replacement percentages of metakaolin (MK) in ternary blends of ordinary portland cement (OPC), fly ash (FA) and MK for achieving high early strengths in cement concrete. OPC is replaced by 10%, 13% and 16 % MK while 15% FA is uniformly used in all the mixtures. The tests for compressive strength, splitting tensile strength and flexural strength at 7 days and 28 days periods reveal that 7 days strengths at par with the control concrete can be achieved in OPC-FA mix by MK addition. The mix with 10% MK gives highest 7 days compressive strength.

Keywords: Early strength, fly ash, metakaolin

1. INTRODUCTION

Cement concrete, due to easy availability of its constituents, mouldability and durability has been the most widely used construction material for a long time. However, the production of Portland cement is a highly energy consuming process. It involves emission of greenhouse gases which makes an environmental issue. Significant utilisation of natural resources as raw material for cement compels us to think for its alternative. Use of industrial by-products as cement replacing materials makes the concrete more economical and environment friendly. Fly ash (FA), a by-product of thermal electricity generation plants is very cheap and abundantly available material, which otherwise is a pollutant, has been advantageously blended with Portland cement. FA normally provides some strength enhancement at extended ages. However, early strengths of mortar and concrete are substantially reduced when cement is partially replaced by it [1-4]. High early strength is desirable in construction for increasing speed, efficient utilisation of formwork and protection of concrete specially in cold weather, during its initial vulnerable period [5].

In recent years, metakaolin (MK) has been studied because of its high pozzolanic properties [6–9]. Unlike other pozzolans, it is a primary product not a secondary product or by-product. It is formed by the dehydroxylation of kaolin upon heating in the temperature range of 650–750°C [10-11]. Metakaolin on reaction with $Ca(OH)_2$, produces C–S–H gel at ambient temperature and also produces alumina containing phases like C_4AH_{13}, C_2ASH_8, and C_3AH_6[12-13]. Metakaolin is increasingly being used to produce high strength and high-performance concretes with improved durability. Several researchers have studied its performance for enhancement of compressive strength in binary and ternary blends. Poon et al. [14] have reported that concrete achieved maximum strength at 10% MK when used as cement replacement. Similar results have also been reported by some other researchers [15-17].

The present study aims to determine the optimum proportion of OPC, FA and MK in concrete, which should have 7 days compressive strength at par with the control concrete, so that by replacing some quantity of cement, an economical and eco-friendly concrete could be produced.

2. EXPERIMENTAL PROGRAM

After careful analysis of the results of previous studies, present experimental program was designed to produce a concrete mix having 7 days strength at par with the control concrete. The materials used and the experimental procedures are described in the following sections.

2.1. Materials

The following materials were used.

The cement used in all mixtures was normal OPC (43 grade) conforming to IS: 269 [18]. The fly ash obtained from Rajghat Thermal Power Station, Delhi and commercially available MK were used as mineral additives. Chemical composition of cement, MK and FA [19] along with physical properties of these materials are shown in Tables 1 and 2, respectively. The particle size analyses of fly ash and metakaolin carried out on Laser diffraction analyzer are shown in Figures1 (a) and 1 (b) respectively, while their particle size summaries are given in Table 3. Good quality aggregate have been procured for this investigation. Crushed granite with maximum size of 20 mm and down along with stone dust of maximum size 4.75 mm were used as coarse and fine aggregate, respectively. The properties of the aggregate were determined in accordance with IS 2386[20]. The coarse aggregate is of 20 mm nominal size while the fine aggregate falls in the grading zone I as per the sieve analyses results, which are given in Tables 4 and 5, respectively. The specific gravities and water absorption of coarse and fine aggregates were found to be 2.91,0.57% and 2.73, 0.80%, respectively. Commercially available poly carboxylate ether (PCE)-based super-plasticiser (SP) was used in all the concrete mixtures.

Table 1: Chemical composition of cement, metakaolin and fly ash

CHEMICAL COMPOSITION	CEMENT (%)	METAKAOLIN (%)	FLY ASH (%)
Silica (SiO_2)	21.30	50-52	61.21
Alumina (Al_2O_3)	5.00	40-45	30.07
Ferric oxide (Fe_2O_3)	4.10	0.70 Max	4.17
Calcium oxide (CaO)	60.20	0.90 Max	0.10
Magnesium oxide (MgO)	0.89	0.30 Max	0.40
Titanium oxide (TiO_2)	--	0.70Max	2.60
Sodium oxide (Na_2O)	0.13	0.10 Max	0.01
Potassium oxide (K_2O)	0.43	0.30 Max	0.02
Sulphuric anhydride (SO_3)	2.73	--	0.01
Loss on ignition (LOI)	2.04	0.20-0.50	1.40

Table 2: Physical properties of cement, metakaolin and fly ash

PROPERTY	CEMENT	METAKAOLIN	FLY ASH
Specific gravity	3.13	2.65	2.19
Fineness (m^2/kg)	309 (Blaine)*	1342(LD)**	1343(LD)**

*By Blaine permeability apparatus, **By laser diffraction (LD) analyser

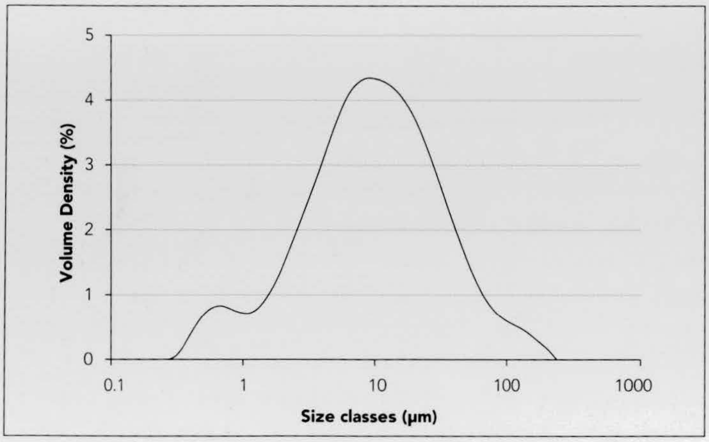

Figure 1(a): Particle size distribution of fly ash.

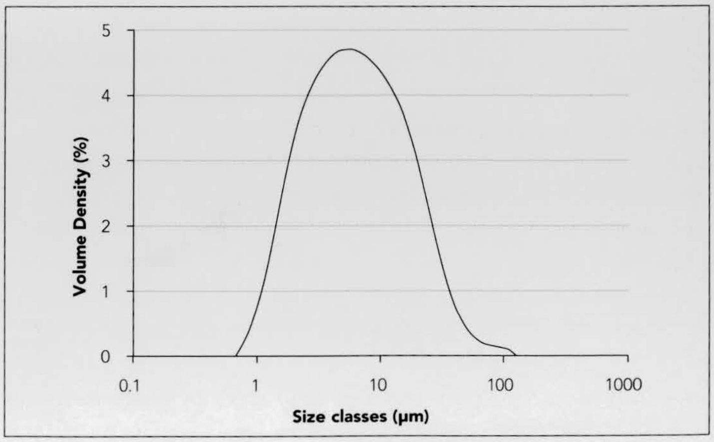

Figure 1(b): Particle size distribution of metakaolin.

Table 3: Particle size summary of fly ash and metakaolin

MATERIAL	D [3,2] (μM)	D [4,3] (μM)	DX [10] (μM)	DX [50] (μM)	DX [90] (μM)
Fly ash	4.47	19.4	1.99	10.2	44.4
Metakaolin	4.47	10.5	1.96	6.5	23.3

Table 4: Details of sieve analysis of coarse aggregate

IS SIEVE DESIGNATION	WEIGHT RETAINED (G)	WEIGHT RETAINED (%)	CUMULATIVE WEIGHT RETAINED (%)	WEIGHT PASSING (%)	% RANGE FOR 20 MM NOMINAL SIZE AS PER IS:383 [21]
40 mm	0	0	0	100	100
20 mm	92	1.84	1.84	98.16	95-100
16 mm	838	16.76	18.60	81.40	--
12.5 mm	1599	31.98	50.58	49.42	--
10 mm	1158	23.16	73.74	26.26	25-55
4.75 mm	1307	26.14	99.88	0.12	0-10

2.2. Concrete Mixtures

Four concrete mixes were prepared with constant water to binder ratio of 0.32. They were one control mix and three FA-MK mixes having 15% fly ash with 10, 13 and 16% metakaolin. MK and FA were used as a replacement of cement on weight to weight basis. The details of the concrete mixtures are given in Table 6.

Table 5: Details of sieve analysis of fine aggregate

IS SIEVE DESIGNATION	WEIGHT RETAINED (G)	WEIGHT RETAINED (%)	CUMULATIVE WEIGHT RETAINED (%)	WEIGHT PASSING (%)	RANGE FOR ZONE I FINE AGGREGATE AS PER IS :383 [21] (%)
10 mm	0	0	0	100	100
4.75 mm	32.5	1.65	1.65	98.35	90-100
2.36 mm	485	24.71	26.36	73.64	60-95
1.18 mm	547	27.86	54.22	45.78	30-70
600 μm	415.4	21.16	75.38	24.62	15-34
300 μm	290	14.77	90.15	9.85	5 -20
150 μm	193.6	9.85	100.0	0.15	0-10

Table 6: Details of concrete mixtures

MIX DESIGNATION	WATER/ BINDER RATIO	OPC (KG/M³)	MK (%)	MK (KG/M³)	FA (%)	FA (KG/M³)	WATER (KG/M³)	FINE AGGREGATE (KG/M³)	COARSE AGGREGATE (KG/M³)	SP (KG/M³)
Control	0.32	466	00	00	00	00	149	643	1266	9.32
MK10	0.32	350	10	46	15	70	149	643	1266	9.32
MK13	0.32	336	13	60	15	70	149	643	1266	9.32
MK16	0.32	321	16	75	15	70	149	643	1266	9.32

2.3. Specimen Preparation and Curing

The concrete mixtures were prepared in the laboratory by hand mixing. The OPC, FA and MK were intimately mixed and then the entire quantity was mixed dry. Subsequently, three-quarters of the water was added, followed by the SP and the remaining water while mixing continued. For compression test cubes of 150 mm x 150 mm x 150 mm were cast in steel moulds and compacted on a vibrating table. The cubes were removed from the moulds after 24 hours of casting, and allowed to cure in water at ambient temperature. For splitting tensile strength test, cylinders of 150 mm diameter and 300 mm high and prisms of 150 mm x 150 mm x 700 mm were used for flexural strength test. The casting and curing methods were the same as adopted for cubes.

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

Compressive strength of concretes was determined as per IS 516 [22] by means of a 3000 kN capacity compression testing machine. The splitting tensile tests were performed in accordance with IS 5816:1999 [23]. For determination of flexural strength, loads were applied at each 1/3rd span of the prism as mentioned in IS:516 for which the arrangement is shown in Figure 2. Strength developments of the mixtures for all the tests were determined at the completion of 7 days and 28 days of water curing. The strengths were computed from average of the results of three specimens for each test.

3. RESULTS AND DISCUSSION

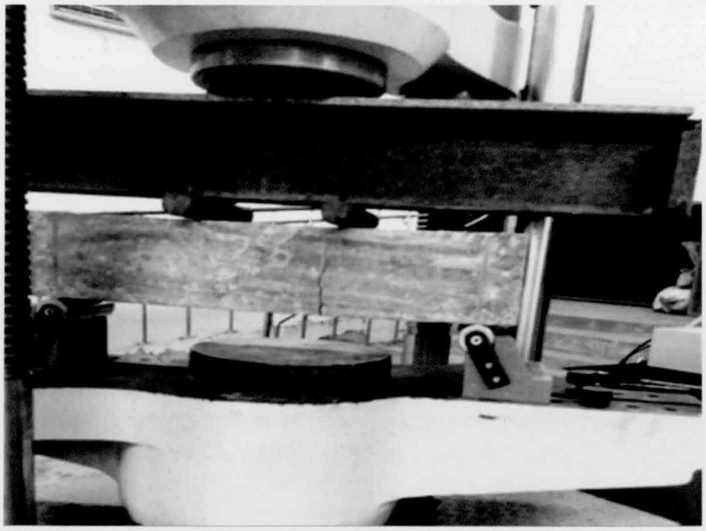

Figure 2: Flexural strength test arrangement.

3.1. Compressive Strength Results

The results of compressive strength, as shown in Figures 3 clearly reveal that only MK10 mix could achieve strength more than the control mix at 7 days while MK10 and MK16 both performed better than the control mix at 28 days. These results indicate that 10% is the optimum percentage of metakaolin, which can suitably compensate the slow reactivity of fly ash in the initial period. Both MK13 and MK16 failed to perform better than the control mix probably due to dilution effect. The 28 day strength of MK10 is also the highest among the four mixes.

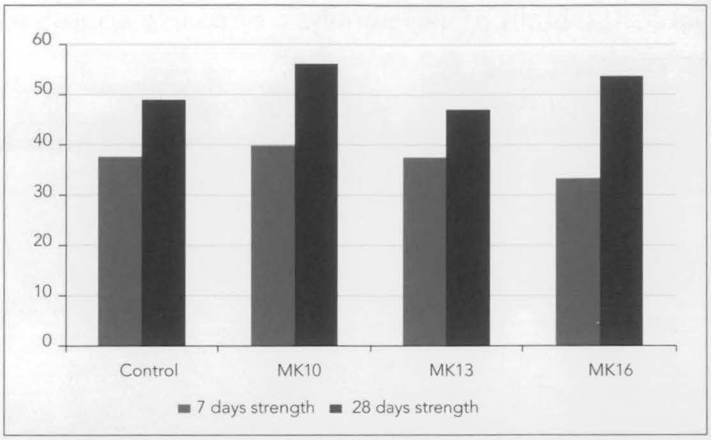

Figure 3: Compressive strength in MPa.

3.2. Flexural Tensile Strength Results

Flexural tensile strength is a measure of the tensile strength of the concrete, which gives an idea about the resistance of an unreinforced beam or slab against bending. Flexural tests are extremely sensitive to specimen preparation, handling and curing procedure, hence utmost care was taken during the entire process of casting, curing and testing. The results of 7 days and 28 days tests (Figure 4) reveal that the performance of MK10 mix is better than the other two mixes and is almost equal to the control mix.

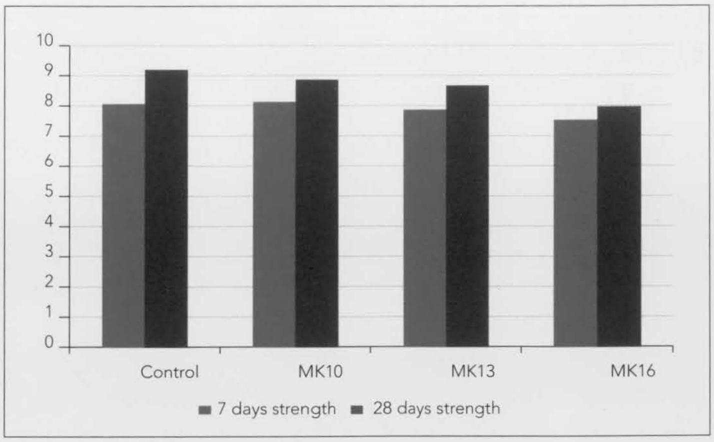

Figure 4: Flexural strength in MPa.

3.3. Splitting Tensile Strength Results

This is an indirect measure of the tensile strength of concrete. As it is difficult to apply direct tensile stresses to concrete, the cylinder of concrete specimen was placed horizontally between the loading surfaces of the compression testing machine and load was applied diametrically and uniformly along its length. As per the test results shown in Figure 5, the performance of MK13 is the best among all mixes at 7days as well as at 28 days. However, the strength of MK10 is also comparable with that of control mix. The flexural tensile strength for all the mixtures are much higher than their corresponding splitting tensile strength because it was measured at the extreme fibers only whereas the splitting tensile strength depends on failure of almost full diameter.

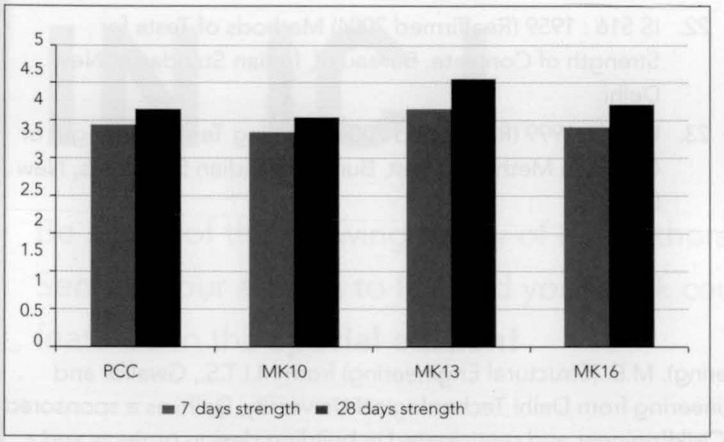

Figure 5: Splitting tensile strength in MPa.

4. CONCLUSIONS

The following conclusions are drawn from the current study.

(a) The optimum percentage of metakaolin in a ternary blend cement, considering early strength and economy, with OPC and fly ash to achieve high early (7 days) strength is 10%. This mix has given the highest compressive strength among all replacement levels, which is comparable to control mix.

(b) The mix (MK10) has also exhibited 28-day compressive strength better than any other mix including control mix.

(c) Flexural tensile strength results have also followed the same trend to that of compressive strength test results, showing the highest values at 10% replacement. However, the splitting tensile strength was highest for MK13 mix while MK10 strength may be comparable i.e. within sample variation tolerance.

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