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Behaviour of High-Performance Concrete using Metakaolin and Flyash

Swapnil Kansay[1], Dr. Anita Khanna[2]

[1] P.G student, [2] Faculty
Punjab Engineering College, Chandigarh

Abstract
Concrete is a versatile construction material. For more durable and strong structures, the concrete showing high performance is required. High performance concrete (HPC) is nothing new but a concrete which performs acceptable in adverse conditions. To make concrete perform acceptable, pozzolans are added as replacement to cement in concrete. Metakaolin (MK) and Flyash (FA) are such pozzolanas added to the concrete to achieve the required performance. This present study investigates the characteristics strength and durability of the HPC containing MK at various proportions of 0%, 5%, 7.5% and 10% and other mixes with 10% FA along with the above proportions of MK. In this study low water/binder ratio of 0.29 is used and hence, a high range water reducing admixture is used for enhancing the workability of the concrete. The compressive strength, splitting tensile and flexural strength test were done at 7, 28 and 56 days from the starting of curing period. The end results obtained from the compressive strength, splitting tensile strength, flexural strength and durability test like acid resistance test were compared with different levels of mineral admixtures used to get the optimum proportion of metakaolin and flyash for the desirable performance of the concrete.

Keywords: High Performance Concrete, Admixtures, Metakaolin, Flyash, Compressive strength, Tensile strength, Flexural test, Durability test, Acids resistance.

1. Introduction

It is an undeniable fact that cement is the most widely used construction building material in the today's world and will remain so for decades to come. The popularity of cement is due to the fact that raw material is abundantly available, excellent strength along with durability, low manufacturing and maintenance costs, versatility in forming various shapes and unlimited structural applications combined with steel reinforcement. However, there are concerns regarding environment both in terms of damage from raw material extraction and Carbon dioxide emissions during cement production. These factors led to the idea of reducing cement consumption and intensifying the research into the possibility of enhancing strength and durability through the use of mineral admixtures. Other factors that contributed to the thought are the increase in number of cases where concrete structures are deteriorating in hostile environment. Therefore, in recent years, High Performance Concrete (HPC) along with pozzolana has been widely used not only for its increased compressive strength, improved durability and economic benefits but also for causing less impact on environment. The term pozzolana includes all siliceous/aluminous materials which in fine state along with water react with Calcium Hydroxide (CH) to create compounds having cementitious properties. This simple definition includes waste materials like Silica fumes (SF), fly ash (FA) and rice husk ash. One possible natural pozzolan source is calcined clay. The use of calcined clay as Metakaolin (MK) in the form of pozzolan in concrete has gained quite an interest in recent years. In the long term, there are valid reasons to increase the use of these Supplementary Cementitious Materials (SCM) due to the fact that they are easy on environment and the volume of these industrial by-products having pozzolanic features created is quite high then their commercial use.

2. Experimental details

2.1 Materials

The selection of materials has to be ascertained for purpose of achieving the desired performance of the concrete.
Cement: It is the basic binding material in concrete. The main property of cement is to fill up voids existing between the fine aggregates and make the concrete impermeable. The cement used was UltraTech PPC cement conforming to IS1489 (Part 1):2015 was used in this study. It was locally sourced and was fresh and free from any lumps. Specific gravity= 2.92
Water: Water is used as a binding agent for the concrete mix. Potable water is normally considered satisfactory for mixing and curing of concrete. In the current study accordingly potable water available in the material testing laboratory was used for making concrete. It was free from any detrimental contaminants and was of good potable quality.
Coarse aggregates: Coarse aggregate is the strongest and least porous component of the concrete. It occupies substantial volume of the concrete and gives concrete its dimensional stability. The coarse aggregates used in the present study, obtained locally were of 10mm and 20mm sizes. The aggregates were thoroughly washed to remove dirt, dust and then dried to surface dry condition. Specific gravity= 2.74

Fine aggregates: Fine aggregate principally fills the voids within the coarse aggregate. It is responsible for giving cohesiveness to the concrete mix and has direct bearing on the workability and rheological aspects. IS 383 has divided the fine aggregate into four grading zones (Grade I to IV) depending on the particle size distribution. The grading zones become gradually finer from grading zone I to grading zone IV. In this experimental program fine aggregates lying in grading zone II were collected from the local supplier. Specific gravity= 2.65

Mineral admixture: Admixtures are added in concrete to improve the quality of concrete. Mineral admixtures which possess certain characteristics through which they influence the properties of concrete differently. Moreover, effect on strength parameters and durability factors remained the primary focus of these mineral admixtures. Two types of admixtures are used in this study metakaolin and flyash.

The way these pozzolans work are, they react with the CH produced by the the concrete and convert it to more calcium hydrate silicates gel. The CH produced by the concrete makes it less durable. So as pozzolans uses up the CH, more CSH gel is produced, making concrete stronger.

Table 1 Properties of metakaolin

Appearance	Pinkish colored free flowing powder
Amorphous Content	>70%
BET Surface Area (m^2 / gm)	≤9
Bulk Density (Kg / M^3)	350 to 380
Specific Gravity	2.6

Table 2: Properties of Flyash

Sr. No.	Characteristics	Values
1.	Colour	Light grey
2.	Specific gravity	2.4
3.	Class	F

Superplasticizer: Chemical admixtures namely high range water reducers are used as superplasticizers. These polymers are used as dispersants to improve the flow characteristics of suspensions such as in concrete applications by avoiding the particle aggregation. Adding the HRWRA to the concrete reduces the water- binder ratio, also not reducing the workability of the concrete, thus enabling the production of high-performance concrete. This increases the strength of concrete as decreasing the water/cement ratio significantly improves the strength, thus drastically improving the performance of the hardened paste.

AURAMIX300 superplasticizer was used and sourced from a dealer in Panchkula. The superplasticizer complied with IS 9103-1999(2007). It also complies with ASTM C 494 Type F & Type G, with specific gravity of 2.6.

2.2 Mix proportions

Guidelines given in IS 10262: 2019 were used to develop the mix design. Concrete mixes were designed to attain M 60 grade concrete to study the strength parameters. The w/b ratio of 0.29 and 0.264 was adopted, and metakaolin content to replace cement were varied as 0%, 5%, 7.5% and 10% by weight of cement for the first three mixes and metakaolin content varied as 5%, 7.5% and 10% by weight of cementitious material with constant replacement of cement by 10% flyash for the other three mixes. A concrete mixer machine was used for mixing the dry as well as wet concrete and was mixed for sufficient time till a uniform mix was achieved.

Table 3 Description of mixes for metakaolin and flyash based concrete

Mix	MK %	Flyash %
Reference mix	0	0
MK1	5	0
MK2	7.5	0
MK3	10	0
MKF1	5	10
MKF2	7.5	10
MKF3	10	10

3. Experimental Results

3.1 Compressive strength: The cubes of dimensions 150 x 150 x 150mm were casted under standard laboratory conditions and were tested after a curing period of 7, 28 and 56 days. The time was calculated from the time when water was added to the dry ingredients. Load was applied continuously at the rate of 5.8kN per second until the failure of the specimen takes place.

Table 4 Compressive strength of concrete mixes with and without mineral admixtures

Specimen	MK%	Flyash%	Avg. compressive strength (MPa)		
			7 day	28 day	56 day
Reference mix	0	0	21.48	45.82	50.67
MK1	5	0	27.37	51.38	59.60
MK2	7.5	0	35.52	54.71	61.50
MK3	10	0	30.33	53.38	58.12
MKF1	5	10	26.04	51.71	60.30
MKF2	7.5	10	34.26	59.24	62.78
MKF3	10	10	31.86	51.31	57

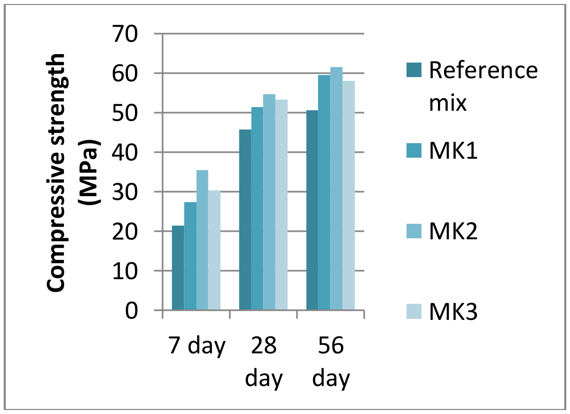

Figure 1Influence of metakaolin on compressive strength

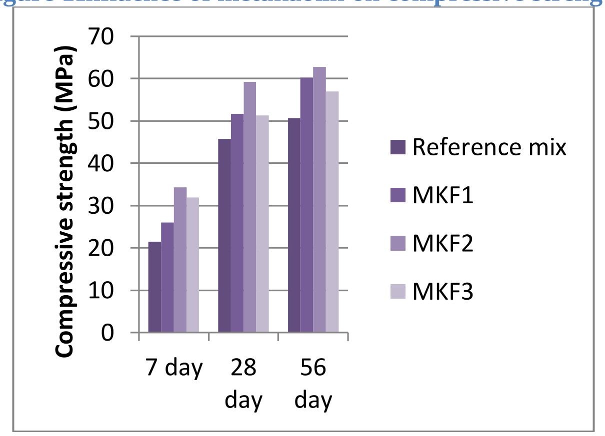

Figure 2Influence of metakaolin and flyash on compressive strength

3.2 Splitting tensile strength: Splitting tensile strength tests were carried out at the age of 28 days for the concrete cylinder specimens of size 150 mm diameter and 300 mm length, using compression testing machine as per IS:5816-1999.

Table 5 Splitting tensile strength of concrete mixes at 28 days

Mix	MK %	FA %	Tensile strength (MPa)
MK1	5	0	4.1
MK2	7.5	0	4.14
MK3	10	0	4.12
MKF1	5	10	4.17
MKF2	7.5	10	4.5
MKF3	10	10	4.23

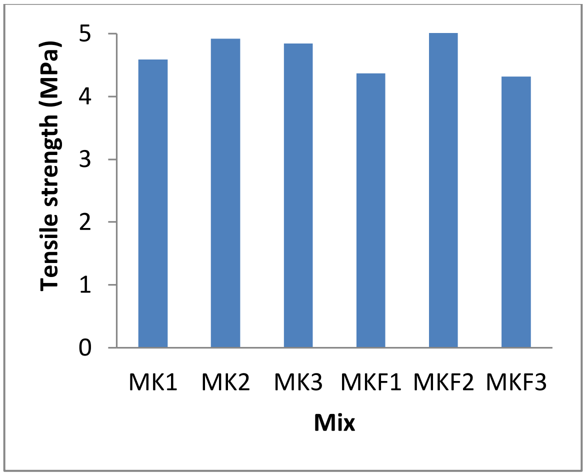

Figure 3Splitting tensile strength of concrete mixes

3.3 Flexural strength: Flexural strength tests were carried out at the age of 28 days for the 150 mm x 150 mm x 900 mm prism specimen using 1000 kN capacity flexural strength testing machine by subjecting the specimen to four point bending to determine the flexural strength as per IS: 516-1959.

Table 6 Flexural strength of concrete mixes at 28 days

Mix	MK %	FA %	Flexural Strength (MPa)
MK1	5	0	4.59
MK2	7.5	0	4.92
MK3	10	0	4.84
MKF1	5	10	4.37
MKF2	7.5	10	5.07
MKF3	10	10	4.32

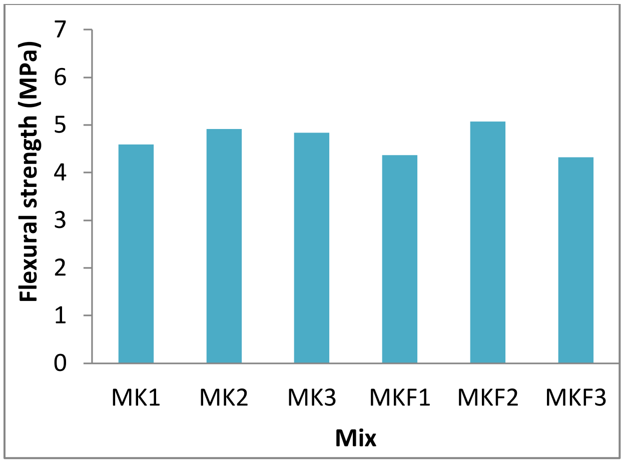

Figure 4Flexural strength of concrete mixes

3.4 Acid resistance test: The acid resistance tests were carried out on 150 mm size cube specimens at the age of 28 days curing. The cube specimens were weighed and immersed in water diluted with one percent by weight of sulphuric acid for 30 days continuously. Then the specimens were taken out from the acid diluted water, the surfaces of the cubes were cleaned with water and were left to dry. Then the weights of the specimens were found out and the average percentages of loss of weight were calculated.

Table 7 Weight loss in cubes with different levels of admixtures

Mix	MK (%)	FA (%)	Dry weight (kg)	Weight after immersed in acid (kg)	Weight loss (%)
MK1	5	0	7.893	7.602	3.68
MK2	7.5	0	7.937	7.709	2.87
MK3	10	0	7.871	7.562	3.91
MKF1	5	10	7.980	7.715	3.32
MKF2	7.5	10	8.040	7.827	2.64
MKF3	10	10	7.930	7.669	3.29

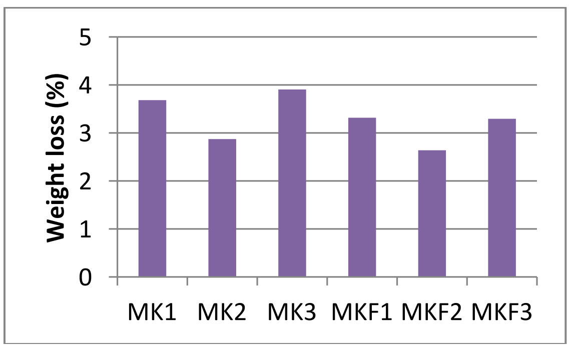

Figure 5Influence of metakaolin and flyash on acid resistance

4. Conclusion

- Concrete mix MK2 came out to having the highest compressive strength in mixes without flyash.
- In mixes having flyash, highest compressive strength was observed for the mix MKF2.
- This is due to the fact that, on the pozzolanic reaction, the MK and FA react with calcium hydroxide and produce more C-S-H gel. This gel is the source of strength of hardened concrete as it is the binder which binds the aggregate together.
- It was also observed that the maximum splitting tensile strength was obtained for mix MK2 and MKF2.
- Beyond 7.5% MK, strength decreases.
- Similar result was observed for the flexural strength test, as MK2 and MKF2 showed the highest result.
- From the result of acid resistance test, it was seen that mixes without flyash showed weight loss between 2.87% to 3.91%, while the mixes with flyash showed less weight loss between 2.64% to 3.32%.

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