Study on Strength Characteristics of High Strength Concrete using Mineral Admixtures

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Abstract **- High strength concrete (HSC) may be defined as concrete with specific characteristic cube strength between 60 and 100 N/mm2. In this experimental investigation, a brief review is made on high strength concrete by using mineral and chemical admixtures. Mineral admixtures, namely, fly ash and metakaolin were used. Superplasticizer (chemical admixture), namely, conplast SP 430 is also used in order to achieve good workability under lower water-cement ratio for high strength concrete of M60 grade. Mechanical properties of the admixed concrete is determined by replacing metakaolin (5%, 10%, 15%, 20%) and flyash (15%, 30%, 45%, 60%) in both binary combination and taking an optimum strength from both individual replacements to form a terinary combination to find a optimum strength at the age of 7 days and 28 days. Compressive strengths of all these mineral admixtures are compared at their individual replacements and combinations of various percentages to found out the optimum percentage replacements to achieve maximum strength. The beams were casted for control mix and obtained optimum mix and were tested to determine the Load – Deflection characteristics, peak load, first crack load, Crack and failure pattern were observed. Finally on influence of replacement of mineral admixtures on the fresh and hardened concrete, strength and durability aspects are reported and discussed and compare with the control mix.**

Keywords: **High strength concrete; Fly ash; Metakaolin; Super plasticizer; Compressive strength; Crack pattern.**

I. Introduction

Concrete is defined as "high- strength concrete" solely on the basis of its compressive strength measured at a given age. In the 1970's, any concrete mixtures that showed 40MPa or more compressive strength at 28-days were designed as high-strength concrete. Later, 60-100MPa concrete mixtures were commercially developed and used in the construction of high-rise buildings and long-span bridges in many parts of the world [1]. The primary reason for selecting HSC is to produce a more economical product, provide a feasible technical solution, or a combination of both.

The main applications for HSC in-situ concrete construction are in offshore structures, columns for tall buildings, long-span bridges and other highway structures [2-3]. The methods and technology for producing high strength concrete are not substantially different from those required for normal strength concrete. The target water/cement ratio should be in the range 0.30–0.35 or even lower [4]. HSC can be produced with all of the cements and cement replacements (additions). A wide range of aggregates can be used though crushed rock aggregates (of suitably high crushing value) are preferable.

For producing normal strength concrete, it is well recognised that the use of supplementary cementitious materials (SCM), such as silica fume (SF), ground granulated glass blast-furnace slag (GGBS) and fly ash (FA), are necessary. These materials, when used as mineral admixtures in HPC, can improve either or both the strength and durability properties of concrete [5]. Concretes with these cementitious materials are used extensively throughout the world. Some of the major users are power, gas, oil and nuclear industries. The applications of such concretes are increasing with the passage of time due to their superior structural performance, environmental friendliness and low impact on energy utilization [6].

II. Materials Used

A. Cement

The cement used during the experiments is Ordinary Portland Cement of Grade 53 conforming to IS 12269:1987. The specific gravity is 3.10; the initial is35 minutes. The normal consistency being 30% and the particle size range lies between 31µm to 7.5µm.

B. Fine Aggregate

River sand was used as fine aggregate. Indian standard specification in IS: 2386 (Part III) of 1963 gives various procedure to find out the specific gravity of different sizes of aggregates. The bulk density of 1700kg/m^3 with fineness modulus of sand was 2.81 with a specific gravity of 2.65.

C. Coarse Aggregate

The ideal CA should be clean, cubical, angular, 100% crushed aggregate with a minimum of flat and elongated particles (ACI 363R, 1992).Crushed granite of size ranging 20mm – 10mm was used as coarse aggregate and bulk density of 1500kg/m^3 with fineness modulus of 6.48 with specific gravity of 2.74.

D. Water

Water conforming to the requirements of BIS: 456-2000 is found to be suitable for making concrete. It is generally stated that water fit for drinking is fit for making concrete. For the present investigations, Potable drinking water was used for mixing of concrete and curing.

E. Super Plasticizer

For the present investigation, a super plasticizer by the name CONPLAST SP430 has been used for obtaining workable concrete at low w/c ratio having a specific gravity of 1.18. CONPLAST SP430 complies with BIS: 9103-1999 and BS: 5075-part3 and ASTM C494.Super plasticizer molecules and cement grains are oppositely charged and hence repel each other. This increases the mobility and hence makes the concrete flow. Super plasticizers enable savings in cement for a given strength and ideal for pumping concrete, casting heavily reinforced concrete members, and the precast elements of concrete [8].

F. Metakaolin

Kaolin can satisfy the world demand for filler, paper and ceramic industries. Kaolin converts to a pozzolan material named metakaolin (MK) after suitable thermal treatment [7]. MK can be used in mortar and concrete to improve their properties. In addition, MK can be used as a source of cementing materials in alkali activation or geo polymer[10]. This part presents a comprehensive overview of the previous works carried out on kaolin history, MK sources, production and composition. Kaolin and paper sludge are the main sources of metakaolin (MK).

Metakaolin is white, amorphous, highly reactive aluminium silicate pozzolan forming stabile hydrates after mixing with lime stone in water and providing mortar with hydraulic properties. Heating up of clay with kaolinite $Al_2O_3.2SiO_2.2H_2O$ as the basic mineral component to the temperature of 500 °C - 600°C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form metakaolinite.

Figure 1. Physical Appearance of Metakaolin

Table 1. Chemical Properties of Metakaolin

Name of the compound	(%)
Sio_2	51.53%
AL_2o_3	42-44%
Tio_2	<2.2.%
SO_4	<3.0%
Cao	<0.5%
Mgo	<0.20%

2. 7 Fly ash

Fly ash is a byproduct from burning pulverized coal in electric power generating plants. During combustion, mineral impurities in the coal (clay, feldspar, quartz, and shale) fuse in suspension and float out of the combustion chamber with the exhaust gases [11]. Two types of fly ash are commonly used in concrete: Class C and Class F. Class C are often high-calcium fly ashes with carbon content less than 2%; whereas, Class F are generally low-calcium fly ashes with carbon contents less than 5% but sometimes as high as 10%. In general, Class C ashes are produced from burning sub-bituminous or lignite coals and Class F ashes bituminous or anthracite coals. Performance properties between Class C and F ashes vary depending on the chemical and physical properties of the ash and how the ash interacts with cement in the concrete.

Table 2. Chemical Composition of Fly Ash

Component	Bituminous	Sub bituminous	Lignite
SiO_2 (%)	20-60	40-60	15-45
AL_2O_3 (%)	5-35	20-30	20-25
Fe_2O_3 (%)	10-40	4-10	4-15
Cao (%)	1-12	5-30	15-40
Loss of ignition (%)	0-15	0-3	0-5

Figure 2. Physical Appearance of Fly ash

III. Mix Proportion

Various mix proportions of fly ash and metakaolin was carried out to determine the optimum strength and individual replacements. Four mixes of fly ash (F1-15%, F2-30%, F3-45%, F4-60%) and 4 mixes of metakaolin (MK1-5%, MK2-10%, MK3-15%,MK4 -20%) of w/c 0.3 was carried out.

To examine the consequence of addition of metakaolin and flyashterinary combination as partial replacement of cement is also carried out to find the compression strength and flexural strength .Chemical admixture is added to all the mixes to increase the workability.

Based on the test results of compressive strength of cube, 100mm × 150mm × 1200mm size beam specimens were casted for optimum mix proportion to get M60 grade of concrete. Concrete were placed in the well lubricated mould and compacted and the specimens were left at room temperature for 24hrs and were placed in curing tank till their testing ages.

Table 3. Individual Replacement of Metakaolin in Cement

Mix	Cement (%)	Metakaolin (%)	Fine Aggregate (%)	Coarse Aggregate (%)	W/C Ratio
1	95	5	100	100	0.3
2.	90	10	100	100	0.3
3.	85	15	100	100	0.3
4.	80	20	100	100	0.3

Table 4. Individual Replacement of Fly Ash in Cement

Mix	Cement (%)	Fly ash (%)	Fine Aggregate (%)	Coarse Aggregate (%)	Water Cement Ratio
1	85	15	100	100	0.3
2.	70	30	100	100	0.3
3.	55	45	100	100	0.3
4.	40	60	100	100	0.3

Table 5. Mix Proportions

<table>
<tr><th>S. No</th><th>Description</th><th colspan="2">Mix combination</th><th rowspan="2">w/c</th><th rowspan="2">No. of Speci mens</th><th rowspan="2">Total specime ns</th></tr>
<tr><td rowspan="5">1.</td><td rowspan="5">Compressive strength 150mm×150mm×150mm of cube size</td><td>Metak olin</td><td>Fly ash</td></tr>
<tr><td>5%</td><td>15%</td><td>0.3</td><td>6</td><td rowspan="4">24</td></tr>
<tr><td>10%</td><td>30%</td><td>0.3</td><td>6</td></tr>
<tr><td>15%</td><td>45%</td><td>0.3</td><td>6</td></tr>
<tr><td>20%</td><td>60%</td><td>0.3</td><td>6</td></tr>
<tr><td rowspan="5">2.</td><td rowspan="5">Sorptivity (Water Absorption) 100mm diameter and 50mm height of cylinders</td><td>Metak olin</td><td>Fly ash</td><td>W/C</td><td>No. of Speci mens</td><td rowspan="5">16</td></tr>
<tr><td>5%</td><td>15%</td><td>0.3</td><td>4</td></tr>
<tr><td>10%</td><td>30%</td><td>0.3</td><td>4</td></tr>
<tr><td>15%</td><td>45%</td><td>0.3</td><td>4</td></tr>
<tr><td>20%</td><td>60%</td><td>0.3</td><td>4</td></tr>
<tr><td>3.</td><td>Bending strength</td><td colspan="2">Control mix, MK-10 , FH-30 and C+MK+FH</td><td>0.3</td><td>4</td><td>4</td></tr>
</table>

IV. Results and Discussion

A. Compressive strength

The cube compressive strength results for various ages with different combinations are presented in figure 3, figure 4 and figure 5. Increase in the age of concrete increase in strength. At the age of 28 days, the control concrete yield 61Mpa.From the test results higher compressive strength for concrete was observed for mix MK-10% and F-30% with 0.8% of super plasticizer at all ages of 7and 28 days. As a result, individual replacements of metakaolin 10% and fly ash 30% give their maximum strength and finally terinary combination of (MK+FY+C) shows the results as 36Mpa at 7 days and 60.5Mpa at 28 days.

The compressive strength development is due to the pozzolanic reaction and filler effects of FY and MK. On the pozzolanic reaction, the FY and MK 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. MK combines with the calcium hydroxide to produce additional cementing compounds, the material responsible for holding concrete together.

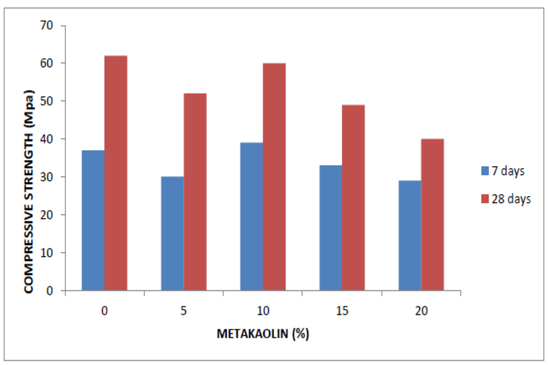

Figure 3. Compressive Strength Test of Metakaolin

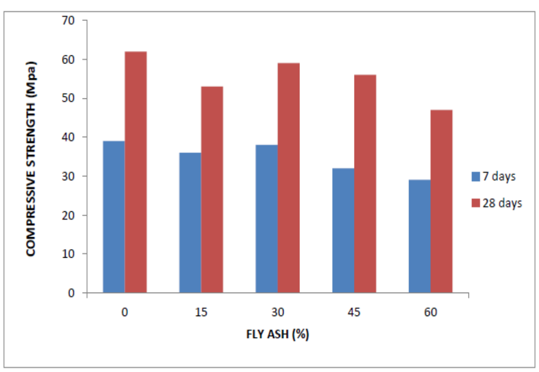

Figure 4. Compressive Strength of Fly Ash

Hence, less calcium hydroxide and more cementing compounds results in stronger concrete. It has been observed during test on controlled specimens that the cracks are developed around coarse aggregates. However, in concrete with SF and MK, the interfacial zone becomes stronger, more homogeneous and dense. Hence, the cracks usually traverse the aggregates.

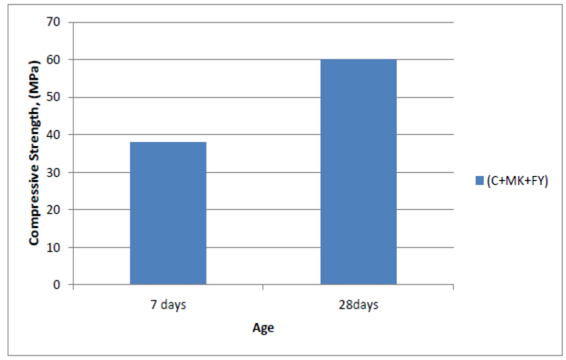

Figure 5. Compressive Strength of Terinary Combination of (C+MK+FY)

V. Flexural Behaviour

To find the flexural behaviour, tests were carried on 100 mm x 150 mm x 1200 mm beam prototypes at the age of 28 days using 1000kN capacity flexural strength testing machine. The test setup includes two point loading using a single point loading system by which the loads are transferred equally to the two points using a spreader beam and two rollers. Dial gauges are placed in the bottom of the beam at the mid-point to find the deflection. Demacs are placed on the surface of the beam to find the surface strain which is placed at a distance of 100mm from one another.

The strains at these points are found using a mechanical strain gauge. The crack patterns are noted on both sides of the beams at particular intervals. The gauge length between the loading points is 333.33mm and 100mm are left on both sides of the beam at the supports.

VI. First Crack Load

The first crack load for beams cast with metakaolin, fly ash and C+MK +FA is shown in Table 8. Replacement of mineral admixture gives high strength so it resist load maximum up to 34kN,35kN,37kN and after that loads, it start a first crack and continues till it attain a peak load.

Under concentrated loading system, diagonal cracks are usually the first cracks to be observed in the clear shear span of the deep beam. It is observed from the investigation that under two-point loading diagonal cracks is the first crack to be developed in relatively deeper beams and flexural cracks are the first crack to be developed in the shallower beams. The crack pattern and the mode of failure of all the test beams were almost similar despite the variations in web reinforcement arrangement.

Table 8 Initial and peak load

	Control Mix	Metakaolin	Fly ash	(C+MK+FA)
Initial Crack Load (kN)	40	34	35	37
Peak Load (kN)	70	58	60	61

The ultimate load or Peak load for beams of control mix is 70kN, Metakaolin is 58kN, Fly ash is 60kN and C+MK+FA is 61kN are given in Table 8.

VII. LOAD-DEFLECTION BEHAVIOUR

A beam is a one dimensional (normally horizontal) flexural member which provides support to the slab and vertical walls. In a normal beam (simply supported) two zones generally arise, compression zone at top and tension zone at bottom. As concrete is weak in tension, steel is introduced in the tension zone to take the tension, but as strength of concrete is ignored in tension zone with respect to compression zone. So logically no concrete is required in tension side.

At every load increment, it was noted that metakaolin, fly ash and combination of cement + metakaolin + fly ash has equal deflection values. This shows the replacement of cement by MK and FY leads to ductile behaviour. Optimum mix is more deflected when compared to the admixed beam. Alike deflection was observed under loads in beams cast with control specimen and optimum specimens. Maximum deflections for different mixes were given in Table 6.5, Table 6.6, Table 6.7, Table 6.8. The ultimate moment capacities for the beam are considerably improved with the addition of metakaolin and fly ash.

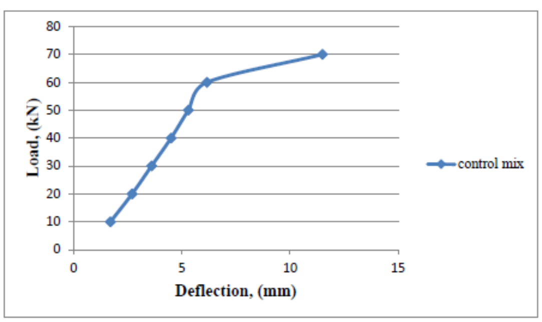

Figure 7. Load-Deflection Behaviour of Control Mix

Optimum mix is more deflected when compared to the admixed beam. Alike deflection was observed under loads in beams cast with control specimen and optimum specimens.

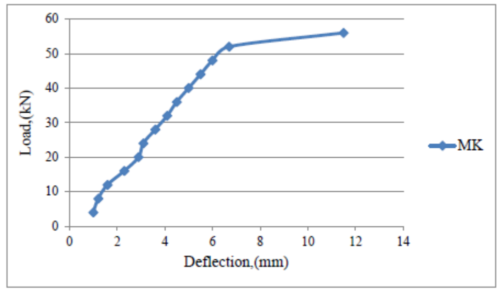

Figure 8. Load-Deflection Behaviour of Metakaolin

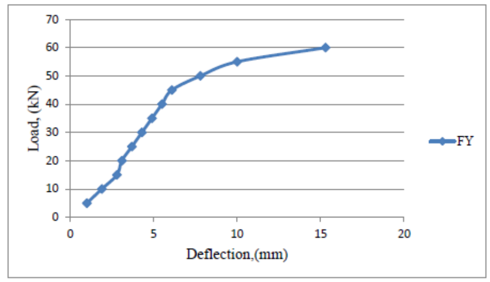

Figure 9. Load-Deflection Behaviour of Fly Ash

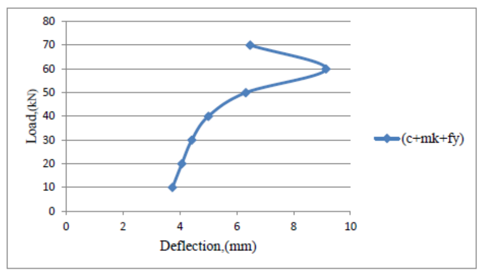

Figure 10. Load-Deflection Behaviour of (C+MK+FY)

VIII. CRACK PATTERN AND FAILURE MODE

Cracks and failure pattern are shown in Figure 11 &12. First flexural cracks were formed in the constant moment zone and these cracks are extended vertically upwards and developed gradually wide as the load is increased. As the load increases, the extreme fibre stresses in bending increase until the tensile strength of concrete is reached. This causes flexural cracking initially in the constant moment region. Flexural cracking causes a marked reduction in stiffness as shown by a sudden change of gradient in the response. Cracks are started in the shear spans of the beam also with increased loads. The final failure of the beam is described by large strains in the steel reinforcement & considerable deflection near collapse followed by extensive cracking.

Figure 11. Crack Pattern for Control Beam

Figure 12. Crack Pattern for Optimum Mix Beam

IX. WATER ABSORPTION RESULT

Durability of concrete is an important factor to know the durability life of structures. Replacement of individual mineral admixtures gives their early and ultimate water absorption at the ages of 7 and 28 days. Metakaolin 10% has low water absorption because of their strength is higher than compared to other percentages. Likewise fly ash water absorption decreases as the strength of the fly ash increases. It is worth noting that according to concretes with early water absorptions of less than 3%, between 3% and 5%, and higher than 5% can be classified as good, average, and poor quality, respectively. Therefore, according to these classifications, all of the concrete mixes investigated in the present study showed a low absorption which indicated ''good'' concrete quality. The low water absorption values attained in this study can be attributed to the limited pore connectivity and reduced porosity of the concrete mixes.

Table 9 Water Absorption

Mixes	Water Absorption (%)	
	Early	Ultimate
Control Mix	0.85	1.52
MK 5%	0.54	0.82
MK 10%	0.51	0.77
MK 15%	0.61	0.92
MK 20%	0.64	0.97
FY 15%	0.56	0.80
FY 30%	0.47	0.69
FY 45%	0.50	0.71
FY 60%	0.59	0.85

X. CONCLUSION

From the experimental results presented in this study, the following conclusions can be drawn,

From the literature, this scenario has been observed only in concrete produced with low water/cement ratio in conjunction with use of super plasticizer. The effect of metakaolin is to reduce the workability of HSC with greater reducing effects at high replacement levels. The influence of fly ash and metakaolin on the workability of HSC is the same as that observed in normal strength concrete, which is to improve the workability.

From the results maximum reduction of strength was obtained at 60% of flyash replaced with cement and more than 20% of metakaolin gives reduction in strength and terinary combination of flyash, metakaolin replaced with cement obtained maximum strength as per given grade of concrete control mix of cube obtained 100% of the grade of concrete M60.

The beam control mix and optimal mixes (10%MK+30%) showed the initial crack and ultimate load.

From the results observed individual replacements of fly ash and metakaolin gives an optimal strength and formed a ternary combination replaced with cement gives maximum strength at 10% of MK and 30% of fly ash to produce a High Strength Concrete.

REFERENCES

[1] BlessenSkariahThomas, RameshChandraGupta, VinuJohnPanicker. “Experimental and modelling studies on high strength concrete containing waste tire rubber”. Sustainable Cities and Society: 19(2015):68–73.

[2] Hans Beushausen, Thomas Dittmer,Construction and Building Materials: “The influence of aggregate type on the strength and elastic modulus of high strength concrete”. (2015): 132–139.

[3] HeshamDiab, “Compressive strength performance of low- and high-strength concrete soaked in mineral oil”, Construction and Building Materials: 33(2012):009.

[4] Huajian Li, Fali Huang, Guanzhi Cheng, YongjiangXie, Yanbin Tan, Linxiang Li, Zhonglai ,Construction and Building Materials:. “Effect of granite dust on mechanical and some durability properties of manufactured sand concrete” 109 (2016):41–46.

[5] Kamal, Safan, Etman, Salama.R.A, “Behavior and strength of beams cast with ultra high strength concrete containing different types of fibers”. HBRC Journal: 10(2014): 55–63.

[6] Karen, Caballero-Morrison.E, Bonet.J.L, Juan Navarro-Gregori, Pedro Serna Ros, “An experimental study of steel fiber-reinforced high-strength concrete slender columns under cyclic loading”. Engineering Structures: 57(2013), 565–577.

[7] MegatJohari.M.A, Brooks.J, ShahidKabir, Patrice Rivard, “Influence of supplementary cementitious materials on engineering properties of high strength concrete”. Construction and Building Materials: 25(2011), 2639–2648.

[8] Mohamed Elchalakani, “High strength rubberized concrete containing silica fume for the construction of sustainable road side barriers”. Structures: 1(2015), 20–38.

[9] Mohammad Mohammadhassani, ShatirahAkib, Mahdi Shariati, MeldiSuhatril,ArabnejadKhanouki.M.M, “An experimental study on the failure modes of high strength concrete beams with particular

of high strength steel fiber reinforced concrete". Procedia Engineering: 111(2015), 390 – 397.

[10] Nikolay, Karpenkoa, Alexandra, Mishinac, Vladimir, Travushb, "Impact of growth on physical, mechanical and rheological properties references to variation of the tensile reinforcement ratio". Engineering Failure Analysis: 41(2014), 73–80

[11] Okoye ,Singh "Mechanical Properties of HighVolume Fly Ash Concrete" IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) volume 13, Issue 3, (2016),1-18.

[12] RatthasakPrommasa, ThaweesakRungsakthaweekulb, "Effect of Microwave Curing Conditions on High Strength Concrete Properties". Energy Procedia: 56(2014), 26 – 34.

[13] Ravandaekishore, "Study on Strength Characteristics of High Strength Rice Husk Ash Concrete". Procedia Engineering: 14(2011), 2666–2672.

[14] VahidAfroughsabet, TogayOzbakkaloglu, "Mechanical and durability properties of high-strength concrete containing steel and polypropylene fibers". Construction and Building Materials: 94(2015), 73.

[15] Xiao-Yong Wang, Ki-Bong Park, "Analysis of compressive strength development of concrete containing high volume fly ash". Construction and Building Materials: 98(2015), 810–819