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Influence of Elevated Temperature on the Properties of M60 Grade Metakaolin High Strength Concrete

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Abstract - The use of supplementary cementitious materials (SCMs) such as fly ash (FA), ground granulated blast furnace slag (GGBS), silica fume (SF) and metakaolin (MK) as part of binders for concrete has been increasing throughout the world, particularly in the production of high strength and high performance concrete . For high-rise constructions, it is important that concrete structures endure fire conditions for a specified time and stay structurally safe from the point of view of saving life and protecting property. In the present paper deals with the study of the properties of M60 grade high strength concrete by incorporating metakaolin as a mineral admixture along with suitable superplasticizers. The properties such as weight loss, compressive strength and split tensile strength are to be studied by exposing them to different time durations of exposure with varying elevated temperatures. A 10% replacement of the cement by MK resulted in satisfactory mean target compressive strength and workability. It showed that the compressive and split tensile strength of M 60 grade HSC was decreased with increased temperature from 100 to 500^{0}C and increased exposed time durations i.e. 1, 2 and 3hrs**.**

Index Terms - Elevated temperature, HSC, silica fumes, metakaolin, fire exposure duration, etc.

1. INTRODUCTION

Increasing population together with growing social and commercial activities but limited land available is one of the common problems encountered in most modern countries which consequently led to more and more medium and high-rise buildings either built closely to each other or in complex form. The recent trend in this country is to construct the high-rise buildings, bridges and many other prestigious projects using high strength concrete(HSC). This is due to the significant economic, architectural, and structural advantages that the HSC can provide as compared to conventional normal strength concrete (NSC).

Metakaolin (MK) is a recent addition in the list of pozzolanic materials. It is a thermally activated alumino-silicate produced from kaolinite clay through a calcining process. Unlike other pozzolans, MK is a primary product, not a secondary product or by-product. In buildings, HSC structural members are designed to satisfy the requirements of serviceability and safety limit states.

One of the major safety requirements in building design is the provision of appropriate fire safety measures for structural members.

2. EXPERIMENTAL PROGRAM

The present study is used to find out the desirable contents of metakaolin (MK) and suitable chemical admixture for development of M60 grade HSC mixes (proposed variation of MK is 5%, 10%, 15% & 20%). Also the present investigation is to evaluate the compressive strength, split tensile strength and weight loss of concrete when subjected to varying elevated temperatures such as 100ºC, 200ºC, 300ºC, 400ºC and 500ºC of M60 grade HSC incorporating metakaolin and by exposing them to different time durations such as 1hr, 2hr and 3hr.

Therefore total number 45 cube specimens [150x150x150mm] and 45 cylinder specimens [200x100] were cast. After the heat treatment cubes and cylinder specimens were cooled in air directly, i.e Dry cooling condition.

3. TEST DATA FOR MATERIALS

3.1. Cement

Ordinary Portland cement (Ultratech OPC cement) was used throughout the work. The important tests carried out for cement and physical properties of cement used are as shown in Table 3.1.

Table 3.1. - Physical properties of cement

Properties	**Average Values for OPC used in the present Investigation**	**Standard Values of OPC as per IS : 269 (1997)**
Specific Gravity	3.15	-
Consistency (%)	29 %	-
Initial Setting Time (min)	165	>30
Final Setting Time (min)	245	<600
Soundness (mm)	1.0	<10
Compressive strength (MPa) 28 – days	69	>33

3.2. Coarse aggregate

A crushed basalt rock of 20mm maximum size was used as coarse aggregates. The following tests were carried out on the coarse aggregate samples. Physical properties of coarse aggregate used are as mentioned in 3.2.

Table 3.2.- Physical properties of coarse aggregate

Property	Average Values
Fineness Modulus	2.56
Specific Gravity	2.88
Water absorption (%)	1.35
Surface moisture of coarse aggregate (%)	1.0

3.3. Fine aggregates

Locally available river sand was used as fine aggregate. The tests carried out on the fine aggregate and physical properties of fine aggregates are as shown in Table 3.3.

Table 3.3.- Physical properties of fine aggregates

Property	Average Values
Fineness Modulus	3.03
Specific Gravity	2.35
Water absorption (%)	2.08
Surface moisture of fine aggregate (%)	2.04

From sieve analysis, sand is medium sand conforming to Zone-II.

3.4. Water

Clean portable water was used for mixing.

3.5. Admixtures

3.5.1.Superplasticizer

BASF GLENIUM B276 SURETEC with a Proportion of 1 to 2% with respect to weight of cement was used to achieve the desired workability.

3.5.2. Metakaolin

The important physical properties for the metakaolin were mention in Table 3.4.

Table 3.4. - Physical properties of metakaolin

Item	Standard Values
Lime Reactivity (Chappelle Test)	740-1000 mg/gm
+300 mesh w/w % (Max)	10 %
Moisture w/w % (Max)	0.5 - 10
XRD	Metakaloin
Loss on Ignition (%)	0.5-1/5
Appearance	Off- White
pH (10% solids)	4.0 - 5.0
Bulk Density (Kg/1)	0.4 - 0.5
Blaine value (cm^2/g)	22000 - 25000
Specific Gravity	2.6

4. MIX-DESIGN OF M-60 GRADE CONCRETE (AS PER 10262-2009)

The bureau of Indian standard, recommended a set of procedure for ‘design of concrete mix’ mainly based on the work done in national laboratories. The mix design procedures are covered in IS10262-2009. The methods given can be applied for both medium strength and high strength concrete

4.1. METHOD-I:- M60 grade concrete mix design without mineral admixture as per I.S. 10262-2009

4.1.1 Stipulations for proportioning

1. Grade designation: M60
2. Type of cement: OPC 53 grade
3. Maximum nominal size of aggregate: 20 mm
4. Minimum cement content: 320 kg/m^3
5. Workability: 75-100 mm (slump)
6. Exposure condition: Mild
7. Degree of supervision: Good
8. Type of aggregate: Crushed angular
9. Chemical admixture type: Superplasticizer

4.1.2. Final mix proportions

As compressive strength of above mix is not within the limit as per IS. Hence by referring two-three trials by adjusting different W/C ratios and proportions of F.A. and C.A., Mix proportion is finalized.

Table 4.1.- Final mix proportion

Cement (kg/m^3)	Water (kg/m^3)	Fine aggregate (kg/m^3)	Coarse Aggregate (kg/m^3)	SP (kg/m^3)
447	150	680	1240	7

4.1.3. Percentage replacement of metakaolin (MK) as part of OPC for 3 cubes

Table 4.2.- Percentage replacement of MK as part of OPC

% Replacement of MK	**Final Mix Proportion**					
	Cement (kg)	**MK (kg)**	**Water (kg)**	**Fine aggregate**	**Coarse Aggregate**	**SP (kg)**
0	1.509	0	0.516	2.295	4.185	0.023
5	1.425	0.075	0.566	2.358	4.438	0.023
10	1.358	0.151	0.614	3.341	4.752	0.023
15	1.283	0.226	0.652	3.453	5.143	0.023
20	1.207	0.302	0.674	3.756	5.436	0.023

4.2. METHOD-II :- M60 grade concrete mix design with mineral admixture as per I.S. 10262-2009. (using metakaolin as part replacement of OPC)

4.2.1. Stipulations for proportioning

1. Grade designation: M60
2. Type of cement: OPC 53 grade
3. Maximum nominal size of aggregate: 20 mm
4. Minimum cement content: 320 kg/m^3
5. Workability: 75-100 mm (slump)
6. Exposure condition: Mild
7. Degree of supervision: Good
8. Type of aggregate: Crushed angular
9. Chemical admixture type: Superplasticizer
10. Type of mineral admixture: Metakaolin

4.2.2. 5 % REPLACEMENT

- Final mix proportions

As compressive strength of above mix is not within the limit as per IS. Hence by referring two-three trials by adjusting different W/C ratios and proportions of F.A. and C.A., Mix proportion is finalized

Table 4.3. - Final mix proportion

Cement (kg/m^3)	Water (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (kg/m^3)	MK (kg/m^3)
415.625	143	650	1245	7	21.875

4.2.3. 10 % REPLACEMENT

- Final mix proportions

As compressive strength of above mix is not within the limit as per IS. Hence by referring two-three trials by adjusting different W/C ratios and proportions of F.A. and C.A., Mix proportion is finalized

Table 4.4.- Final mix proportion

Cement (kg/m^3)	Water (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (kg/m^3)	MK (kg/m^3)
393.75	142.5	644	1244	7	43.75

4.2.4. 15 % REPLACEMENT

- Final mix proportions

As compressive strength of above mix is not within the limit as per IS. Hence by referring two-three trials by adjusting different W/C ratios and proportions of F.A. and C.A., Mix proportion is finalized

Table 4.5.- Final mix proportion

Cement (kg/m^3)	Water (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (kg/m^3)	MK (kg/m^3)
371.88	142	643	1242	7	65.62

4.2.5. 20 % REPLACEMENT

- Final mix proportions

As compressive strength of above mix is not within the limit as per IS. Hence by referring two-three trials by adjusting different W/C ratios and proportions of F.A. and C.A., Mix proportion is finalized

Table 4.6.- Final mix proportion

Cement (kg/m^3)	Water (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)	SP (kg/m^3)	MK (kg/m^3)
350	144	641	1242	7	87.5

5. RESULT

5.1 Compressive strength* results when concrete are subjected to room temperature as per Method-I & II

Table 5. - Compressive strength as per Method-I & II

Sr. No.	Mix Proportion (%)	METHOD-I		METHOD-II	
		Compressive Strength (N/mm^2)	Workability (mm)	Compressive Strength (N/mm^2)	Workability (mm)
1	MK-0	64.76	70	66.67	72
2	MK-5	71.11	76.3	71.77	77
3	MK-10	68.97	79	69.77	80
4	MK-15	67.60	83	68.00	82
5	MK-20	65.11	88	65.33	86

* After 28 days

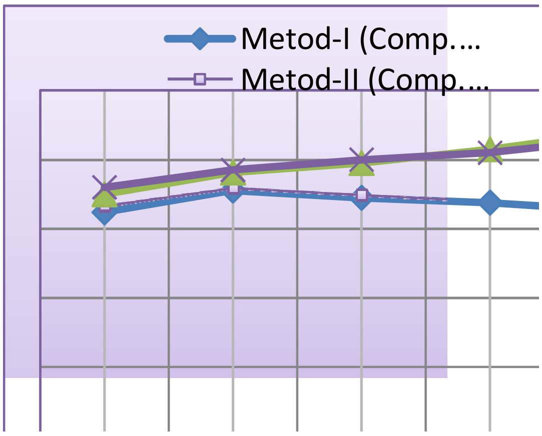

Figure 5.1 Overall comparison of method-I and method-II

From the above figure 5.1, it can be seen that compressive strength increases from 0 to 5% replacement of OPC by MK and beyond 5% strength decreases, subsequently. But the mean target strength is accomplished by 5 and 10% replacement of OPC by MK. Therefore, 5 and 10% of replacement are seemed to be desirable.

From the figure 5.1, workability increases with increase in percentage replacement of OPC by MK. But the desirable workability (75-100 mm) is obtained from 5% replacement of OPC by MK.

Now considering figure 5.1, the optimum percentage could be 5 and 10. But when we deal with high rise structures and high strength concrete, more workability can reduces pumping cost of concrete to high altitude. Thus 10% replacement is 'desirable'. Therefore we can design M60 grade HSC by incorporating MK as 10% replacement of OPC.

5.2 Overall compressive strength after elevated temperature

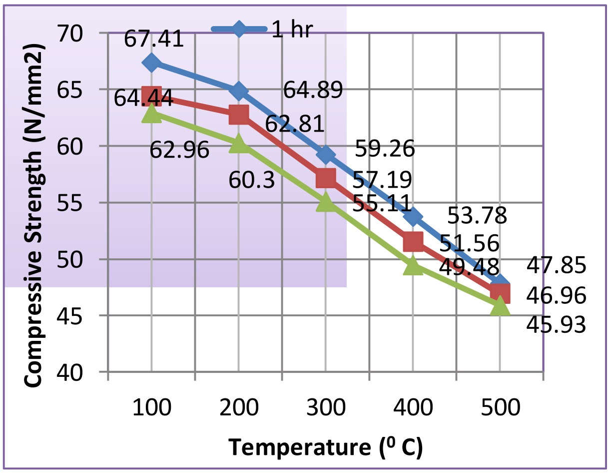

Figure 5.2 Compressive strength after elevated temp.

As per Figure 5.2, for ordinary portland cement concrete (M 60 grade) containing 10% metakaolin, it is seen that as temperature goes on increasing from 100 to 500 ^{0}C the compressive strength goes on decreasing for each constant time duration. Also it can be observed that compressive strength decreases for specific temperature when subjected to varying time durations. The 3 hrs time exposure duration shows least compressive strength for all temperature intensities as compared to other i.e. 1 and 2 hrs time exposure duration.

5.3 Overall weight of concrete cubes after elevated temperature

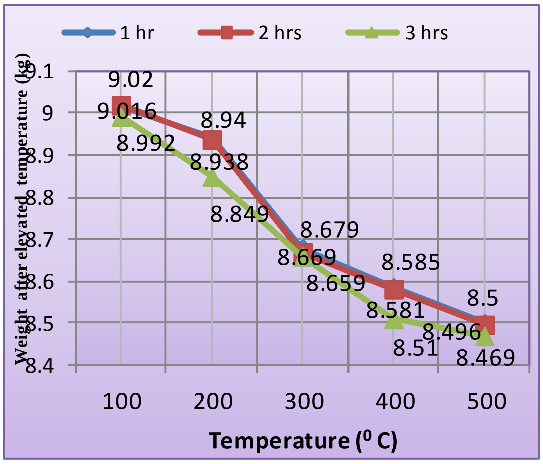

Figure 5.3 Overall weight loss of concrete after elevated temp.

As per Figure 5.3, for ordinary portland cement concrete (M60 grade) containing 10% metakaolin, it is seen that as temperature goes on increasing from 100 to 500 ^{0}C the weight of concrete goes on decreased for each constant time duration. Also it can be observed that weight of concrete decreased for specific temperature when subjected to varying time durations. From the above graph the variation patterns of weight of concrete after elevated temperature for 1 and 2 hrs time duration are approximately follow same path which shows that weight loss for 1 and 2 hrs time duration are approximately same. For 300 ^{0}C weight loss of concrete for all time durations is about same.

5.4 Overall split tensile strength after elevated temperature

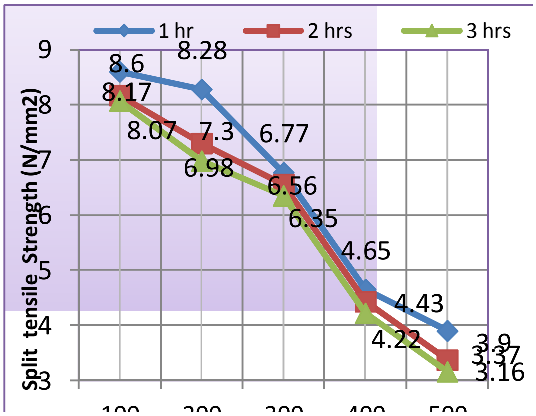

Figure 5.4 Split tensile strength after elevated temp.

As per Figure 5.4, for ordinary portland cement concrete (M 60 grade) containing 10% metakaolin, it is seen that as temperature goes on increasing from 100 to 500 ^{0}C the split tensile strength goes on decreasing for each constant time duration. Also it can be observed that split tensile strength decreases for specific temperature when subjected to varying time durations. The 3 hrs time exposure duration shows least split tensile strength for all temperature intensities as compared to other i.e. 1 and 2 hrs time exposure duration.

5.5 Overall weight of concrete cylinders after elevated temperature

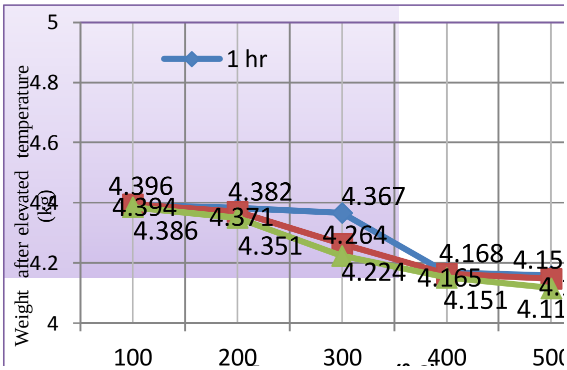

Figure 5.5 Overall weight of concrete after elevated temp.

As per Figure 5.5, for ordinary portland cement concrete (M 60 grade) containing 10% metakaolin, it is seen that as temperature goes on increasing from 100 to 500 ^{0}C the weight of concrete goes on decreased for each constant time duration. Also it can be observed that weight of concrete decreased for specific temperature when subjected to varying time durations. From the above graph the variation patterns of weight of concrete after elevated temperature for 1 and 2 hrs time duration are approximately follow same path which shows that weight loss for 1 and 2 hrs time duration are approximately same.

6. CONCLUSION

1. The desirable content of metakaolin is 10% for development of M60 grade HSC as it gives satisfactory mean target compressive strength and workability than any other proportions.
2. The weight losses of cubes are 0.117 to 4.369%, 0.214 to 4.396% and 0.373 to 4.414% for 1, 2 and 3 hr exposure, respectively for M60 grade HSC.
3. The compressive and split tensile strength of M 60 grade HSC was linearly decreased with increased temperature from 100 to 500^{0}C and increased exposed time durations i.e. 1, 2 and 3hrs.

4. To achieve M60 grade HSC made up of 10% of MK is workable w.r.t. compressive and split tensile strength up to 200^{0}C temperature.
5. For M60 grade HSC the maximum percentage decrement in compressive strength are 6.99, 9.97 and 13.57 for 1, 2 and 3 hr exposure up to 200^{0}C temperature, respectively.
6. It is found that the lowest compressive strength 45.93 N/mm^2 was obtained at 500^{0}C temperature with 3 hrs time duration.
7. The weight losses of cylinders are 0.235 to 4.634%, 0.278 to 4.702% and 0.324 to 4.739% for 1, 2 and 3 hr exposure, respectively for M60 grade HSC.
8. For M60 grade HSC the lowest split tensile strength 3.16 N/mm^2 was obtained at 500^{0}C temperature with 3 hrs time duration.

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