Experimental Study on Ternary Blended Concrete under Elevated Temperatures

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Abstract— Fire is a standout amongst the most dangerous forces to which a building structure can be exposed, frequently presenting concrete elements to high temperatures bringing about deterioration, aggregate fall and total collapse of the structure. The relative properties of cement after such an introduction are of extraordinary significance regarding serviceability of structures. Silica fume (SF) and Metakaolin (MK) have been found to be useful pozzolanic materials in terms of its superior durability, high strength, impermeability, low porosity and resistance to fire. In this paper, the performance behavior of the concrete under elevated temperature extending from 200ºC - 800 ºC with an interim of 200 ºC for duration of one hour was observed and compared with the Ternary Blended Concrete (TBC) concrete containing SF and MK to the control concrete. After exposure to temperature, samples were cooled and the tests such as Compressive strength, Split tensile strength, Ultrasonic pulse velocity test, Acid attack test and Rapid chloride permeability test were conducted and compared with the unheated concrete of all mixes. Taking SF 10% constant for all mixes with varying proportions of MK as 5%, 10%, 15%, 20% as a replacement of cement were studied. Elevated temperature also results with crack formation and increasing target temperature caused more cracks. Test results displayed the concrete containing 10% SF with 15% MK revealed splendid mechanical and durability properties under elevated temperature than other mixes.

Key words: Silica Fume (SF), Metakaolin (MK) Elevated Temperature, Compressive Strength, Weight Loss

I. INTRODUCTION

Concrete is the most versatile building materials being utilized all around the world. For construction materials, concrete has high resistant to elevated temperature when compared to other building materials like steel and wood etc., However, it is pertinent upto a possible temperature level in a given period of time. Concrete materials are highly susceptible to high temperatures due to fire accident or when it is nearest to reactors or furnaces. When it surpasses its time under high exposures, it leads to severe changes resulting in collapse of structure such as spalling, causing cracks, forming large pores and deplete the bond between aggregate – cementations materials.

The characteristics properties such as modulus of elasticity, volume deformation, structural integrity, strength of the structural elements are notably reduced during these exposures. This may finally end up with severe structural changes and failures. And so, the behavior of concrete elements remains after such an accident are still crucial for detecting load carrying capability and for restoring the destructive structures. The physical structure and chemical composition of the materials transforms considerably when rising to highest temperature. Thus, the temperature effect on the concrete and the outcome of incorporation of three cementitious materials in concrete under elevating temperatures are discussed in this study.

II. LITERATURE REVIEW

Omer arioz has examined the influence of higher temperature on the mechanical and physical characteristics of concrete containing two types of aggregates namely crushed limestone and river gravel. The samples were exposed to temperature 400ºC to 1200 ºC. The results displayed that the strength of concrete under elevated temperatures was more pronounced for mix having river gravel as an aggregate, because of the presence of siliceous components of the river gravels. At 600 ºC, the concrete begins to cracks and became extensive at 800 ºC and above. As the temperature raises, the weight and relative strength of the concrete specimens reduced and sharp reduction was noticed beyond 800 ºC and they observed that aggregate type and water cement ratio were not significant on weight loss of the concrete.

M.saridemir, M.H.Severcan, M.Cifikli, S.Celikten, F.Ozcan, C.D.Atis had performed the research on the exposure of elevated temperature on the micro structural properties and strength of the concrete containing blends of MK and ground pumice and concrete containing only ground pumice. The tests specimens were subjected to temperatures of (250,500,750 ºC) and the results was compared to the unheated concrete and after air cooling phase of heated concrete. And they analyzed the alterations in the interface, aggregates and in the matrix were examined by SEM, XRD and PLM analyzes indicates the rising target temperature resulting in decrement in mechanical properties and the concrete were more vulnerable to crack formation. They displayed the concrete mixture containing 5% MK and 5%GP shows enhanced resistance to heat than normal concrete of all the curing time.

M.bastami A, Chaboki khiabani, M. baghbadrani, M.kordi has approached the effects of elevating temperature on compressive strength, mass loss and the spalling ratio of high strength concrete. Four parameters were defined in their studies namely sand ratio, SF ratio, amount of SF addition and water to ratio subjected to the temperature upto 800 ºC. They observed that type of aggregate plays an vital role on the thermal properties of concrete and addition of SF statistically showed significant impact on increasing spalling. It revealed the dosage of SF has major effects on the compressive strength of the concrete above 300 ºC. SF controls the spalling and plays a vital role on enhancement of compressive strength of the concrete. They came to know that the spalling decreases drastically when water to binder levels increased in concrete containing SF paved the new rule for different water to binder ratio.

Alaa.M.Rashaad had examined the concrete containing flyash with SF replacement of 10%, 20% by weight of the concrete and compared to the concrete containing neat Portland cement. The test samples were initiated to elevated temperature. Compressive strength and weight losses of concrete were examined and the decomposition phases were analyzed using SEM and XRD. They observed that SF blends displayed higher relative strength after different heat treatments and proves better heat resistant upto 600 ºC due to the reaction of free lime with pozzolans and thus rapid improvement in the strength was obtained due to transformation of semicrystalline CSH phase to tobomonite phase.

Magda I.Mousa had analyzed the effect of outcome under elevated temperature on the concrete containing SF and with different sizes and ratios of recycled tire rubber. The addition of SF content upto 20% markedly ameliorated the compressive strength even under elevating temperature 800 ºC. They have seen sharp reduction in the strength between 300 ºC to 800 ºC because of the initiation of internal cracks arrived due to volume expansion of concrete. And the reduction of residual strength were more in the concrete without SF. Adding of 3% tire rubber with using dolomite and 20% SF showed some more improved resistance to fire.

III. MATERIALS

A. Cement

Although all materials that go into concrete mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand and stone together and second to fill up the voids in between sand and stone particles to form a compact mass. Although it constitutes only about 20 per cent of the volume of concrete mix, it is the active portion of binding medium and is the only scientifically controlled ingredient of concrete. Any variation in its quantity affects the compressive strength of the concrete mix. In the present investigation, Ordinary Portland Cement (OPC) of 53 Grade was used for all concrete mixes.

B. Coarse Aggregate

The coarse aggregate is defined as that retained on 4.75 mm IS sieve. To increase the density of the resulting concrete mix, the coarse aggregate is frequently used in two or more sizes. Two types of aggregates with different sizes have been used in the present study. The details of the same are as below:

- Aggregate passing 20 mm sieve
- Aggregate passing 10 mm sieve.

The coarse aggregate used were washed and kept in water for 24hr to remove dust and dirt and were dried to surface dry condition.

C. Fine Aggregate

IS: 383-1970 defines the fine aggregate, as the one passing 4.75mm IS sieve. The fine aggregate is often termed as a sand size aggregate. Locally available riverbed sand was used in the present study. The per cent passing 600 micron sieve = 62.35. The sand conforms to grading Zone – III as per IS: 383 – 1970 respectively.

D. Water

Water Available in our lab is used in this investigation.

E. Silica Fume

Silica fume, the very powdered noncrystalline silicon dioxide (SiO_2) is the byproduct obtained from the production of ferro silicium alloys obtained at temperature of nearly 2000°C shows excellent performance in concrete. SF passing through 45µm sieve with specific gravity of 2.5 were used. These acts as a filler material and it have been used as a effective pozzolanic cementitious material to make the concrete to achieve high strength. SF content taken is 10% by the weight of the cement content is used. MICROSILICA or SILICA FUMED is the most regularly utilized mineral admixture in high quality cement. It has turned into the picked top choices for high quality cement and is a decent pozzolan and can be utilized as a part of a major path, Adding to the solid blend will drastically improve the workability, quality and impermeability of cement blends while making the solid strong to compound assaults, scraped spot and fortification consumption, expanding the far reaching quality. There is a developing interest in the creation of concrete blends, superior cement, and high quality, low penetrability concrete for use in scaffolds, marine condition, and atomic plants.

1) Advantages and its uses

It is a very reactive and powerful pozzoloanic material because of its fine particle size and high purity of SiO_2 (99.5%) content. It enhances the mechanical properties, durability and constructability in concrete and used in the production of high strength and high execution concrete.

It is used in the production of high execution concrete structures like bridge's where the strength also, durability properties of the cement is required. It is used in the production of high execution concrete structures like bridge's where the strength furthermore, durability properties of the cement is required.

It can be used to build marine structures as it reduces the harm caused due to the response of chloride and various chemicals, it helps in protection of steel from rust and corrosion furthermore, increases the life of the structure.

F. Metakoline

MK is produced by the calcination of unadulterated or refined mud at temperatures of 650-850° C and by granulating it in this manner to accomplish a fineness of 700-900 m^2/kg. It is very esteemed reactive pozzolona. Because of its glassy components, Metakolin possess esteemed pozzolanic activity. Besides its filling effect in concrete materials, the calcium hydroxide present in the cement reacts with MK gives rise to formation of more CSH (calcium silicate hydrate) gel in the major bonding phase of the concrete.

Calcium hydroxide is the leading element in the concrete weakens the interface between cementitious materials – aggregate materials, thus it affects the characteristics properties of concrete. The substitution of MK with cement takes up the calcium hydroxide presents transforms to CSH gel which in turn highly enhances the mechanical and durability characteristics in the interfacial phase of concrete.

IV. RESULTS AND DISCUSSIONS

A. Preliminary Tests

In the first stage of the project work, the theoretical investigation and literature review are carried out and the following results are obtained.

– The specific gravity of the cement tested is 3.12
– The specific gravity of the fine aggregate tested is 2.4
– The specific gravity of the coarse aggregate tested is 2.6
– Fineness modulus of the fine aggregate tested is 2.4
– Fineness modulus of the coarse aggregate tested is 2.6
– Finesse of cement is 95%
– Soundness of cement is 0.53mm
– Water content for the mix is 197 L
– Bulk density of cement is 492.5 kg/m^3
– Bulk density of the fine aggregate is 663.822 kg/m^3
– Bulk density of the coarse aggregate is 1083.07 kg/m^3
– The mix design for M_{30} concrete

B. Compressive strength

At 7 and 28 days strength of the concrete specimen of each mixtures at respective curing age are tested in the compressive testing machine. For each mixtures, three specimens are casted and the average value of the compressive strength are tabulated in the table and plotted in the graph given below. This tabulation shows the compressive strength taken at different temperatures (200, 400, 600, 800 °C) with unheated sample for all the five types of mixtures given below.

Mixes	Compressive strength of Concrete (MPa)				
	unheated	200 °C	400 °C	600 °C	800 °C
Type 1	25.4	23.63	21.4	21.8	13.5
Type 2	37.5	36.4	34.5	32.8	27.48
Type 3	46.7	41.1	44.3	40.2	35.66
Type 4	48.25	46.5	44.85	40.6	37.5
Type 5	43.45	40.55	40	38.6	35

Table 1: Compressive strength (MPa) values of all mixes for 7 days

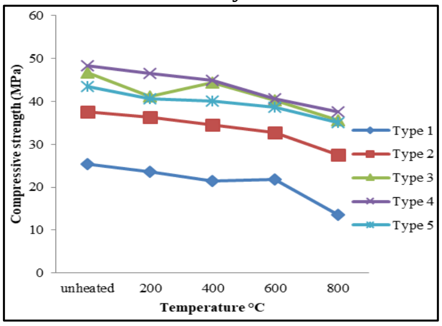

Fig. 1: Compressive Strength (N/mm^2) for 7 days.

MIXES	Compressive strength of Concrete (MPa)				
	unheated	200 °C	400 °C	600 °C	800 °C
Type 1	47.7	45.2	43.2	36.9	29
Type 2	50	48.5	45.4	37.65	35.23
Type 3	52.23	49.2	47.2	39.2	38.76
Type 4	55.4	53.7	51.2	45.5	40.84
Type 5	50.22	47.8	43.2	35.45	32.8

Table 2: Compressive strength (MPa) values of all mixes for 28 days

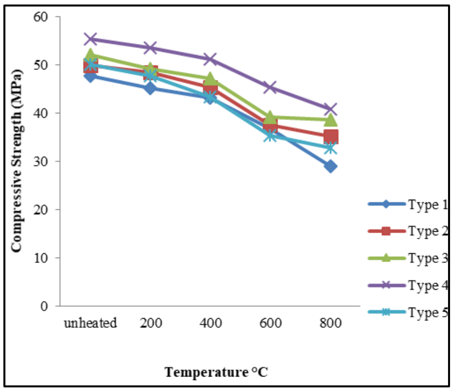

Fig. 2: Compressive Strength (N/mm^2) for 28 days.

From this fig 1 and 2, it is seen that the strength of the concrete decreases with increase of target temperature. When compared to all other mixes, concrete containing blends of SF and MK shows higher compressive strength over the control concrete. On 7th and 28th day, the unheated specimen has maximum compressive strength obtained for mix containing 15% MK and 10% SF shows 48.5 MPa and 55.4 MPa respectively. However, increase in the temperature suppresses the concrete strength, blends of SF and MK makes the concrete more resistant to heat. This is due to the formation of calcium silicate hydrate gel where it takes up the calcium hydroxide and enhances the mechanical properties of the concrete. It is noticed that addition of MK upto 15% with 10% SF statistically displayed higher compressive strength than the control concrete and concrete containing 20% MK. Surface cracking was observed after 600 °C, and it get increased to the temperature about 800 °C. Change of colour was seen at the temperature 800 °C

C. Split Tensile Strength

The split tensile strength of the concrete on 28 days curing of the concrete are tested in the Compressive testing machine. For each mixtures, three specimens are casted and the average value of the compressive strength are tabulated in the table and plotted in the graph given below.

MIXES	Split tensile strength of Concrete (MPa)				
	unheated	200°C	400°C	600°C	800°C
Type 1	2.45	2.16	2.03	1.066	0.653
Type 2	3.85	3.47	2.515	2.32	1.656
Type 3	3.96	3.55	2.76	2.46	1.98
Type 4	4.02	3.66	2.88	2.5	2.06
Type 5	3.72	3.32	2.48	2.15	1.784

Table 3: Split Tensile Strength (Mpa) Values of All Mixes at 28 Days

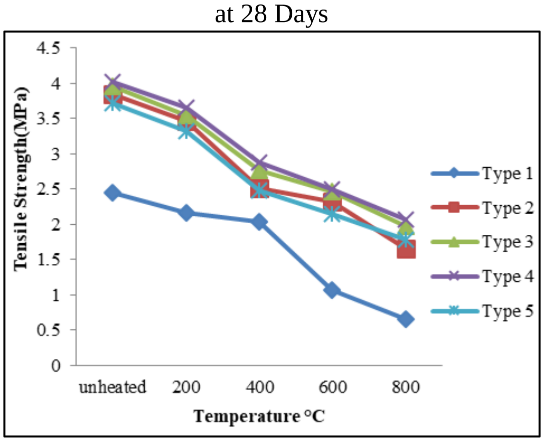

Fig. 3: Split Tensile Strength (N/mm^2) for 28 days.

From the fig 3, it agree with compressive strength of the concrete and shows splendid tensile strength over control concrete. All the blends, revealed excellent tensile strength compared to the control concrete, where type 4 mix arrived little more strength in accordance with other blends.

D. Ultra-Sonic Pulse Velocity

The cube specimens of 100 x 100 x 100 mm was casted and examined the pulse velocity of the various types of mixtures subjected to temperatures to the unheated specimens. The average value is taken and is tabulated in the table 4.

Mixes	UPV Strength of Concrete (MPa)				
	unheated	200°C	400°C	600°C	800°C
Type 1	4.98	4.02	3.45	3.26	2.03
Type 2	5.58	4.23	3.86	3.48	2.64
Type 3	5.88	5.21	4.78	4.72	2.55
Type 4	6.6	5.88	5.23	4.85	3.66
Type 5	5.76	5.36	4.69	4.48	2.86

Table 4: UPV Test values AT 28 days

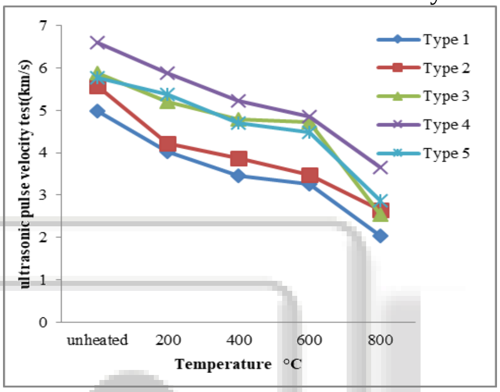

Fig. 4: Ultrasonic pulse velocity test graph

At the temperature up to 400 ºC, the UPV shows some good quality of concrete. After when it exposed to 800 ºC, the quality of concrete become poor. Type 4 mix shows superior quality due to better material homogeneity upto the temperature 800 ºC, whereas under 800 ºC, the quality of concrete is highly degraded due to its increased porosity shows poor performance of the concrete for all other mixes.

E. Acid Attack Test

The acid attack test on concrete was carried out on 100x100x100 mm cube specimen for type 4 and type 1 mix. This graphs shows the loss in weight (%) of the concrete on 14 and 28 days of curing of both mixes In this test, the maximum percentage loss in weight 0.5 and 0.487 is obtained for normal and type 4 concrete mix on 14^{th} day whereas 1.25 and 1.15 percentage loss in weight was obtained on 28^{th} day. And the percentage loss in compressive strength were seen to be 12 to 20 % and 11 to 18 % for normal and type 4 concrete mix. It shows the acid attack was detrimental for normal concrete than blends of SF and MK.

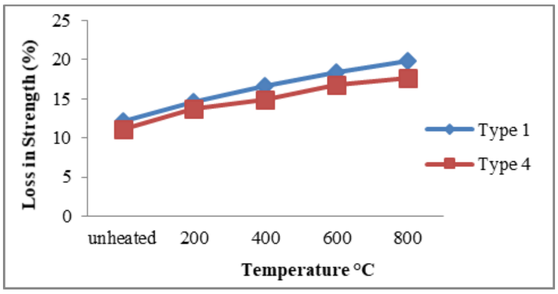

Fig. 5: Loss in Strength

F. RCPT Test

The core specimen of size 50 x 100 mm was casted and tested for the chloride penetration of the concrete. As the compressive strength, ultrasonic pulse velocity test and split tensile strength displayed type 4 mix containing 15% MK + 10% SF as the optimum percentage of replacement of concrete under higher temperatures than the other mixes. Hence, the durability characteristics was performed to compare the results of type 4 mix to the type 1 (control concrete).

Mixes	RCPT test of Concrete (MPa)				
	unheated	200 °C	400 °C	600 °C	800 °C
Type 1	1503	1605	1800	2026	2475
Type 4	1366	1582	1750	1980	2178

Table 5: RCPT Test values AT 28 days

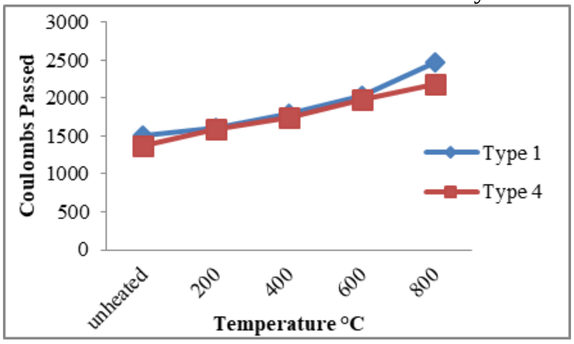

Fig. 6: Rapid chloride permeability test graph

The rapid chloride permeability test shows the chloride penetration resistant of the concrete. It is seen that there is a slight supercilious outcome for the blended concrete than the control concrete. The penetration range is moderate above 800 ºC and penetration of chloride is seen to be low in all the cases. Because of the low permeability and filling effects of pozzolanic material, the penetration is less to small percent compared to the normal concrete.

V. CONCLUSION

- On 7^{th} and 28^{th} day, the unheated specimen has maximum compressive strength obtained for the mix containing 15% MK and 10% SF shows 48.5 MPa and 55.4 MPa respectively.
- Surface cracks observed at temperature 600 ºC and it gets more pronounced to further temperature and change of colour also seen at this temperature.
- Increasing the target temperature lowers the strength of the concrete in all mixes.
- However, increase in the temperature suppresses the concrete strength, blends of SF and MK makes the concrete more resistant to heat.
- The blends of SF and MK shows excellent tensile strength than the control concrete.
- Ultrasonic pulse velocity shows superior quality concrete for type 4 mix because of its better material homogeneity.
- The acid attack test of control concrete shows lower strength with reduction in the weight of concrete. The percentage loss of strength is between 12 to 20% and 11 to 18 % in case of control concrete and type 4 mix respectively.

- The chloride penetration is higher in control concrete whereas it is lower in type 4 because of the filling effect of the pozzolonic material.
- From all the mixes, type 4 mix proven to be better at elevated temperatures than the others.

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