RESEARCH PAPER | Engineering | Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

Influence of Sustained Elevated Temperature on Characteristic Properties of Ternary Blended Steel Fibre Reinforced Concrete

KEYWORDS Ternary blended steel fibre reinforced concrete, fly ash, silica fume, metakaolin, ground granulated blast furnace slag, compressive strength, tensile strength, elevated temperature.

Deepa A Sinha	Dr. A.K.Verma	Dr. K.B. Prakash
Associate Professor, Structural Engineering Dept, BVM Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India.PIN 388120.	Professor & Head, Structural Engineering Dept, BVM Engineering College, Vallabh Vidyanagar, Anand, Gujarat, India.PIN388120.	Principal, Govt. Engineering College, Devagiri, Haveri, Karnataka, India.PIN 581110.

ABSTRACT *Main objective of this experimental investigation is to study the behaviour of M30 ternary blended steel fibre reinforced concrete when subjected to different sustained elevated temperature such as 200°C, 400°C, 600°C, 800°C and 1000°C for 3 hours. 30% of cement is replaced by ternary blend combinations such as (FA+SF), (FA+GGBFS) and (FA+MK). The proportions of (FA+SF) or (FA+GGBFS) or (FA+MK) are (0+0), (30+0), (25+5), (20+10), (15+15), (10+20), (5+25) and (0+30). The residual strength characteristics such as compressive strength and tensile strength are studied. It has been found that the TBSFRC containing (FA+GGBFS) and (FA+MK) offer higher resistance to sustained elevated temperatures upto 600°C and 800°C, where as the blend containing (FA+SF) offers resistance only upto 400°C.*

INTRODUCTION:

Subjecting concrete to a higher temperature (e.g. due to accidental fire etc.) leads to severe deterioration and it undergoes a number of transformations and reactions, thereby causing progressive breakdown of cement gel structure, reduced durability, increased tendency of drying shrinkage, structural cracking and associated aggregate color changes. At elevated temperatures, the incompatibility of thermal deformations of the constituents of concrete initiates cracking. Internal stress is caused by a microstructure change due to dehydration and steam pressure buildup in the pores. [1]

The maximum exposure temperature, exposure time, heating and cooling rates are among the most important factors. At high temperatures, the removal of free water, adsorbed and chemically bound water affect the porosity, capillary and the microstructure of cements. In the temperature range 100°C – 300°C, free and bound water from C-S-H gel is evaporated. Above 300°C a reduction in strength in the range of 15 – 40 % occurs. At 500°C, the reduction of strength in the range 55 – 70 % and dehydroxylation of $Ca(OH)_2$ takes place. The dehydration of calcium silicate hydrate and the related thermal expansion increase the internal stresses and micro cracks which are induced through the cementing material. Hydrated hardened concrete/mortar contains a considerable proportion of free calcium hydroxide. Around 400°C to 500°C calcium hydroxide losses its water, leaving calcium oxide. If this, calcium oxide is wetted after cooling or exposed to moist air, it rehydrates to calcium hydroxide accompanied by large expansion in volume. This may disrupt concrete which has withstood fire hazard without actual disintegration. Total dehydration is only complete at 800°C or above. At this temperature most of the decompositions are irreversible so damage to concrete is essentially permanent. Exposure to sustained temperatures of 650°C to 820°C makes the concrete friable, porous and after cooling usually can be taken apart with fingers.[2]

At elevated temperature decomposition of calcium hydroxide to calcium oxide occurs. If calcium oxide is wetted again or exposed to moist air, it rehydrates to calcium hydroxide accompanied by large expansion in volume which will disrupt concrete. This disadvantage can be minimized by reducing the calcium hydroxide content in the cement by addition of suitable pozzolanic materials. The pozzolanic material such as silica fume, ground granulated blast furnace slag, fly ash and metakaolin[7] have shown to improve the microstructure of cement paste by densifying the cement paste matrix and improving interfacial zone. The hydrates, such as CSH phases produced as a result of consumption of free $Ca(OH)_2$ by the above pozzolanas, are deposited within the pore system and around the grains of the concrete constituents. This leads to the formation of a denser concrete microstructure. Therefore the effect of pozzolanas on the microstructure and phase composition of concrete is important for fire-resistance studies. [3,4]

Incorporating a single supplementary cementitous material (SCM) like fly ash (FA), silica fume(SF), metakaolin(MK), ground granulated blast furnace slag(GGBFS) to improve a concrete rheology or a specific durability property, however, may have associated limitations with its use (depending on the SCM), such as low early age strength, extended curing periods, increased admixture use, increased plastic shrinkage cracking, and freeze/thaw scaling in the presence of de-icer salts. The use of appropriately proportioned ternary blends allows the effects of one SCM to compensate for the inherent shortcomings of another. Such concretes have been found to exhibit excellent fresh and mechanical properties. [5]

Addition of steel fibres helps to resist the pore pressure created and arrests the cracks and expansion, thus increasing the tensile strength. The addition of polypropylene fibres minimizes fire induced spalling in the concrete members. The addition of steel fibres enhances the tensile strength of concrete and reduces spalling. Also, hybrid (mixture of polypropylene and steel) fibres have been shown to be effective in minimizing spalling and thus enhancing the fire resistance of concrete structures. [6]

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

RESEARCH SIGNIFICANCE

Developments in 1990s have seen a marked increase in the number of structures involving the first time heating of concrete. These include nuclear reactor pressure vessels, storage tanks for hot crude oil and hot water, coal gasification and liquefaction vessels, pavements subjected to jet engine blast, and in areas exposed to fire. [7,8] The extensive use of concrete as a structural material in all the above mentioned structures and public utility buildings, multistory buildings, exposed to the elements of terrorism necessitated the need to study the behavior of concrete at high temperature and its durability for the required needs. As SFRC with ternary blends possesses a number of advantages it is essential that the fundamental behavior of SFRC with ternary blends under elevated temperatures is clearly understood. The performance characteristics of SFRC with ternary blends when exposed to elevated temperatures are important to reduce the risk of structural collapse in the event of fire. Hence, the present research programme is aimed at generating experimental data necessary for characterizing the behavior of SFRC with ternary blends when exposed to elevated temperatures

MATERIALS USED

- **Cement:**
  53 grade ordinary portland cement (OPC), with specific gravity 3.15, initial setting time 120 minutes and final setting time 220 minutes, and 7 day compressive strength of 29N/mm^2 and 28 day compressive strength of 54N/mm^2, complying with IS: 12269 – 1987 was used.
- **Fine aggregates:**
  Locally available sand with specific gravity of 2.67, falling under the zone-II, complying with IS: 383 – 1970 was used.
- **Coarse aggregates:**
  Locally available coarse aggregates of 12mm and down size having a specific gravity of 2.74, complying with IS: 383 – 1970 was used.
- **Steel fibres:**
  Steel fibers of 30 mm length and 0.7 mm thickness with corrugated shape which gave an aspect ratio of 42 were used. The steel fiber was added by 1% of volume fraction. Crimped steel fibres were used, since it helps in proper bonding.
- **Super plasticizer:**
  Conplast SP 430, complying with IS: 9103 – 1979 was used, to impart workability. It was based on sulphonated naphthalene formaldehyde. Super plasticizer was used at the rate of 0.78% by weight of cement.
- **Pozzolanas :**
  Properties of fly ash, silica fume, Ground granulated blast furnace slag and metakaolin used in the experimentation are given in table 1 to 5.

EXPERIMENTAL PROGRAMME

Main objective of this experimental investigation is to study the behaviour of ternary blended steel fibre reinforced concrete when subjected to different sustained elevated temperatures such as 200°C, 400°C, 600°C, 800°C and 1000°C for 3 hours. 30% of cement is replaced by ternary blend combinations such as (FA+SF), (FA+GGBFS) and (FA+MK). The proportions of (FA+SF) or (FA+GGBFS) or (FA+MK) are (0+0), (30+0), (25+5), (20+10), (15+15), (10+20), (5+25) and (0+30). The residual strength characteristics such as compressive strength and tensile strength are studied. The mix design was carried out for M30 grade concrete as per IS: 10262-2009[9] which yielded a proportion of 1:1.86: 2.41 with a w/c ratio of 0.45. The dosage of superplasticizer used was 0.78% (by weight of cement). The cement, sand and coarse aggregates were weighed according to the proportion of 1:1.86: 2.41 and dry mixed. Before mixing, 30% of cement was replaced by (FA+SF), (FA+GGBFS) and (FA+MK) according to the proportions such as (0+0), (30+0), (25+5), (20+10), (15+15), (10+20), (5+25) and (0+30) respectively. The required amount of water was added to this dry mix and intimately mixed. The calculated quantity of superplasticizer was now added and mixed thoroughly. After this, 1% steel fibres by volume was added to the mix and the entire concrete was agitated thoroughly to get a homogeneous mix. Then the mix was placed layer by layer in the moulds to cast the specimens. The specimens were prepared both by hand compaction as well by imparting vibrations through vibrating table. The specimens were finished smooth and kept under wet gunny bags for 24 hours after which they were cured for 90 days. After 90 days curing, the specimens were placed in the heating chamber, where in they were subjected to 200°C or 400°C or 600°C or 800°C or 1000°C as the case may be for 3 hours. An electrical furnace consisting of 14 elements of Canthol wire giving electrical load of 14KW was used for sustained elevated temperature test of concrete specimens. Furnace was cubical in shape of size 2x2x2 feet with a volume of 8 cubic feet, with temperature indicator, temperature sensor and ampere rating. There is a knob to set the desired oven temperature. The rate of temperature rise was 3°C/minute. The figure 1 shows the furnace used for heating the samples. Compressive and tensile strength were found as per IS. [10, 11]

Table 1 Physical properties of Wanakbori fly ash

Properties	Results	Requirement as per IS 3812-2003
Fineness, specific surface area (m^2/kg)	333	>320
Particles retained on 45 micron. IS sieve (Wet sieving) in %	3.5	<34
Lime reactivity, average compressive strength in N/mm^2	4.58	>4.5
Compressive strength at 28 days in N/mm^2.	17.3	>80% of the strength of corresponding plain cement mortar works

Table 2 Chemical properties of fly ash

Properties	Results obtained	Requirement as per IS 3812-2003
Silicon dioxide (SiO_2) + Aluminum Oxide ($A1_2O_3$)+Iron Oxide (Fe_2O_3) present by mass Min.	95.0	> 70 Min.
Silicon dioxide (SiO_2), percent by mass Min.	62	> 35 Min.
Total Sulphur as Sulphur trioxide (SO_3), percent by mass Max.	31	< 3.0 Max.
Available Alkalis as sodium Oxide (Na_2O) in percent by mass Max.	NIL	> 1.5 Max.
Loss on ignition, in percent by mass Max.	0.87	< 5.0 Max.
Moisture content %	0.132	3.0 Max.

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

Table 3 Physical and chemical properties of silica fume

Sr. No.	Particulars	Test results	Requirement as per ASTM C-1240-03
Physical properties			
1	Particles retained on 45 micron Sieve (%)	0.4%	Max 10%
2	Bulk density kg/cum	640	500 to 700
3	Specific gravity	2.2	2.2 to 2.4
4	Surface area (m^2/gm)	20	Min. 15
Chemical properties			
1	SiO_2	90.3%	Min 85%
2	Moisture content	0.6%	Max 3%
3	Loss of ignition @ 975°C	2.1%	Max 6%
4	Carbon	0.8%	Max 2.5%

Table 4 Physical and chemical properties of GGBFS

Characteristics	Test result	Requirements as per BS-6699
Fineness m^2/kg	380	275(Min)
Soundness, Le-Chatelier Expansion (mm)	0	10(max)
Initial setting time (min)	210	Not less than IST of OPC
Insoluble residual (%)	0.11	1.5(max)
Magnesia content (%)	8.06	14(Max)
Sulphide content (%)	0.9	2.0 (Max)
Sulphite content (%)	0.28	2.5(Max)
Loss on ignition (%)	0.68	3.0 (Max)
Characteristics	Test result	Requirements as per BS-6699
Manganese content (%)	0.24	2.0(Max)
Chloride content (%)	0.001	0.10 (Max)
Moisture content (%)	0.01	1.0 (Max)
Glass content (%)	95.34	67(Min)
Compressive strength (N/mm^2)		
After 7 days	30.66	12 (Min)
28 days	48.6	32.5(Min)

Table 5 Physical properties of Metakaolin

Physical properties	Results
Average particle size	1.5 µm
Residue 325 mesh,	0.5 %
B.E.T. Surface area,	15 m^2/gm
Pozzolanic reactivity,	1050 mg
Specific gravity	2.5
Bulk density,	300 ± 30 gm/lt
Brightness	80 ± 2
Physical form	Off-white power

EXPERIMENTAL RESULTS

Tables 6, 7, 8 and 9 respectively gives the overall results of compressive and tensile strength of ternary blended steel fibre reinforced concrete when subjected to different sustained elevated temperature such as 200°C, 400°C, 600°C, 800°C & 1000°C for 3 hours.

Table 6&7 Overall results of compressive strength for ternary blended steel fibre reinforced concrete with and without subjecting to temperature of 200°C, 400°C, 600 °C, 800 °C and 1000 °C

Percentage replacement of cement by ternary blends	Without subjecting to temperature, 90 days			Subjected to 200°C						Subjected to 400°C					
	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)	
	Comp. strength (MPa)	Comp. strength (MPa)	Comp. strength (MPa)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)
(0+0) Ref. Mix.	60.67	60.67	60.67	56.15	92.55	56.15	92.55	56.15	92.55	39.85	65.68	39.85	65.69	39.85	65.68
(30+0)	61.33	61.33	61.33	57.19	93.25	57.19	93.25	57.19	93.25	43.26	70.54	43.26	70.54	43.26	70.54
(25+5)	64.37	62.15	62.22	60.44	93.89	59.41	95.59	60.44	97.14	45.78	71.12	44.24	71.18	44.37	71.31
(20+10)	64.7	63.04	63.85	62.67	96.86	60.44	95.89	62.67	98.15	47.63	73.62	48.89	77.56	48.89	76.57
(15+15)	66.22	63.26	64.59	63.41	95.76	60.89	96.25	63.48	98.28	48.52	73.27	50.44	79.74	51.19	79.25
(10+20)	67.33	64.00	62.96	64.59	95.93	61.63	96.30	61.78	98.13	50.15	74.48	51.85	81.02	49.78	79.07
(5+25)	64.59	62.07	62.37	61.04	94.50	59.41	95.70	60.89	97.63	46.89	72.59	46.67	75.18	47.56	76.25
(0+30)	64.15	61.70	60.74	60.3	94.00	58.81	95.32	58.96	97.07	44.44	69.28	44.89	72.75	43.11	70.97

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

Table 7

Percentage replacement of cement by ternary blends	Subjected to 600°C						Subjected to 800°C						Subjected to 1000°C					
	(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)	
	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength `(MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)	Comp. strength (MPa)	Resi. strength (%)
(0+0) Ref Mix	36.77	60.61	36.77	60.61	36.77	60.61	18.07	29.78	18.07	29.79	18.07	29.78	0	0	0.00	0.00	0	0
(30+0)	37.19	60.64	37.19	60.64	37.19	60.64	18.22	29.71	18.22	29.71	18.22	29.71	0	0	0.00	0.00	0	0
(25+5)	27.97	43.45	38.07	61.26	37.93	60.95	17.04	26.47	18.52	29.80	20.15	32.39	0	0	2.22	3.58	0	0
(20+10)	26.28	40.62	38.96	61.81	38.59	60.44	15.50	23.96	18.67	29.61	20.24	31.70	0	0	3.11	4.94	0	0
(15+15)	24.44	36.91	39.11	61.83	39.04	60.44	14.96	22.59	19.26	30.44	20.30	31.43	0	0	4.30	6.79	0	0
(10+20)	23.97	35.60	40.30	62.96	37.78	60.00	12.03	17.87	20.15	31.48	15.32	24.33	0	0	4.89	7.64	0	0
(5+25)	22.67	35.09	34.81	56.09	33.33	53.44	8.86	13.72	17.78	28.64	11.88	19.05	0	0	4.52	7.28	0	0
(0+30)	21.33	33.26	27.56	44.66	26.96	44.39	5.33	8.31	16.00	25.93	6.22	10.24	0	0	3.26	5.28	0	0

Table 8

Percentage replacement of cement by ternary blends	Without subjecting to temperature			Subjected to 200°C						Subjected to 400°C					
	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)	
	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)	Tensile strength (MPa)	Resi. Strength (%)	Tensile strength (MPa)	Resi. Strength (%)	Tensile strength (MPa	Resi. Strength (%)	Tensile strength (MPa	Resi. Strength (%)	Tensile strength (MPa	Resi. Strength (%)	Tensile strength (MPa	Resi. Strength (%)
(0+0)	6.19	6.19	6.19	5.90	95.32	5.90	95.32	5.90	95.32	4.47	72.26	4.47	72.26	4.47	72.26
(30+0)	6.27	6.27	6.27	6.00	95.72	6.00	95.72	6.00	95.72	4.54	72.39	4.54	72.39	4.54	72.39
(25+5)	6.54	6.37	6.44	6.29	96.18	6.13	96.21	6.24	96.85	4.65	71.10	4.62	72.53	4.64	72.09
(20+10)	6.72	6.47	6.74	6.47	96.26	6.28	97.06	6.67	98.98	4.80	71.40	4.67	72.18	4.97	73.78
(15+15)	6.94	6.62	6.94	6.71	96.69	6.46	97.58	6.75	97.22	5.17	74.44	5.10	76.97	5.24	75.46
(10+20)	7.01	6.89	6.79	6.82	97.32	6.79	98.55	6.44	94.78	5.44	77.54	5.52	80.12	4.99	73.52
(5+25)	6.59	6.58	6.65	6.28	95.30	6.37	96.81	6.21	93.37	4.92	74.66	5.10	77.51	4.79	72.08
(0+30)	6.44	6.30	6.43	6.14	95.34	5.90	93.65	5.94	92.45	4.68	72.67	4.72	74.92	4.57	71.03

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

Table 9

Percentage replacement of cement by ternary blends	Subjected to 600^0C						Subjected to 800^0C						Subjected to 1000^0C					
	(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)		(FA+SF)		(FA+GGBFS)		(FA+MK)	
	Tensile strength (MPa)	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)	Tensile strength (MPa	Resi. strength (%)
(0+0)	3.96	64.03	3.96	64.03	3.96	64.03	1.95	31.56	1.95	31.56	1.95	31.56	0.00	0.00	0.00	0.00	0.00	0.00
(30+0)	4.01	63.89	4.01	63.89	4.01	63.89	1.99	31.74	1.99	31.74	1.99	31.74	0.00	0.00	0.00	0.00	0.00	0.00
(25+5)	3.19	48.78	4.10	64.36	4.09	63.45	1.90	29.00	2.12	33.28	2.08	32.24	0.00	0.00	0.00	0.00	0.00	0.00
(20+10)	3.07	45.68	4.20	64.90	4.30	63.84	1.74	25.89	2.31	35.70	2.17	32.20	0.00	0.00	0.00	0.00	0.00	0.00
(15+15)	2.94	42.42	4.29	64.78	4.53	65.26	1.70	24.47	2.41	36.40	2.26	32.63	0.00	0.00	0.00	0.00	0.00	0.00
(10+20)	2.76	39.37	4.44	64.51	4.23	62.26	1.60	22.82	2.45	35.61	2.12	31.27	0.00	0.00	0.00	0.00	0.00	0.00
(5+25)	2.69	40.81	3.82	58.05	3.61	54.35	1.56	23.63	2.03	30.85	2.03	30.51	0.00	0.00	0.00	0.00	0.00	0.00
(0+30)	2.59	40.29	3.21	50.95	3.54	55.03	1.39	21.58	1.79	28.41	1.89	29.35	0.00	0.00	0.00	0.00	0.00	0.00

The mathematical models are developed using regression analysis for the strength characteristic of ternary blended steel fibre reinforced concrete when subjected to different sustained elevated temperatures using the above results. The best fit biquardratic polynomial equations are obtained for compressive strength and tensile strength. The equations generated will help in finding out the compressive strength and tensile strength strength of ternary blended steel fibre reinforced concrete at any desired temperature.

Mathematical modeling for compressive strength.

A) Mathematical modeling for compressive strength of ternary blended steel fibre reinforced concrete with (FA+SF) combination, (FA+GGBFS) combination and (FA+MK) combination

Following table 10, 11 and 12 gives the equations developed for compressive strength of ternary blended steel fibre reinforced concrete with (FA+SF) combinations, (FA+GGBFS) combination and (FA+MK) combination respectively.

. In the equations,

y= Compressive strength in MPa.

x = (T-400)/200

where T is temperature in degree centigrade,

Table 10 Biquadratic polynomial equations derived for the compressive strength of ternary blended steel fibre reinforced concrete with (FA+SF) combinations.

Sr. No	Percentage replacement of cement by (FA+SF)	Equations
1.	(0+0) Ref.mix	$y = -0.0079x^4 - 0.0067x^3 - 0.0313x^2 - 5.2176x + 43.7442$
2.	(30+0)	$y = -0.0024x^{-4} – 0.0101x^3 - 0.2671x^2 - 5.2529x + 46.1184$
3.	(25+5)	$y = -0.0297x^{-4} + 0.1920x^3 + 0.1391x^2 - 8.7890x + 44.8401$
4.	(20+10)	$y = -0.0335x^4 + 0.2599x^3 + 0.0335x^2 - 9.9768x + 46.0674$
5.	(15+15)	$y = -0.0354x^4 + 0.2836x^3 + 0.0718x^2 - 10.6255x + 46.0708$
6.	(10+20)	$y = -0.0237x^{-4} + 0.2712x^3 - 0.2601x^2 - 10.9805x + 47.6242$
7.	(5+25)	$y = -0.0110x^{-4} + 0.2171x^3 - 0.4410x^2 - 10.2808x + 45.1337$
8.	(0+30)	$y = -0.0036x^4 + 0.2033x^3 - 0.5559x^2 - 10.4772x + 43.6771$

Table 11 Biquadratic polynomial equations derived for the compressive strength of ternary blended steel fibre reinforced concrete with (FA+GGBFS) combinations.

Sr. No	Percentage replacement of cement by (FA+GGBFS)	Equations
1.	(0+0) Ref.mix	$y = -0.0079x^4 - 0.0067x^3 - 0.0313x^2 - 5.2176x + 43.7442$
2.	(30+0)	$y = -0.0024x^4 - 0.0101x^3 - 0.2671x^2 - 5.2529x + 46.1184$
3.	(25+5)	$y = -0.0040x^4 + 0.0237x^3 - 0.3043x^2 - 5.7664x + 47.5210$
4.	(20+10)	$y = 0.0078x^4 + 0.0010x^3 - 0.6873x^2 - 5.5739x + 50.8395$
5.	(15+15)	$y = 0.0095x^4 + 0.0062x^3 - 0.7682x^2 - 5.6141x + 51.8479$
6.	(10+20)	$y = 0.0117x^4 - 0.0043x^3 - 0.8319x^2 - 5.4465x + 53.1299$
7.	(5+25)	$y = -0.0022x^4 + 0.0676x^3 - 0.4454x^2 - 6.5519x + 47.9506$
8.	(0+30)	$y = -0.0216x^4 + 0.1864x^3 - 0.0610x^2 - 8.4932x + 44.2572$

Table 12 Biquadratic polynomial equations derived for the compressive strength of ternary blended steel fibre reinforced concrete with (FA+MK) combinations.

Sr. No	Percentage replacement of cement by (FA+MK)	Equations
1.	(0+0) Ref. mix	$y = -0.0079x^4 - 0.0067x^3 - 0.0313x^2 - 5.2176x + 43.7442$
2.	(30+0)	$y = -0.0024x^4 - 0.0101x^3 - 0.2671x^2 - 5.2529x + 46.1184$
3.	(25+5)	$y = -0.0188x^4 + 0.0725x^3 - 0.0455x^2 - 6.2261x + 47.3765$
4.	(20+10)	$y = -0.0132x^4 + 0.0784x^3 - 0.3232x^2 - 6.5224x + 50.7308$
5.	(15+15)	$y = -0.0087x^4 + 0.0711x^3 - 0.4860x^2 - 6.5198x + 52.4120$
6.	(10+20)	$y = 0.0100x^4 + 0.0253x^3 - 0.9034x^2 - 6.3022x + 51.7402$
7.	(5+25)	$y = 0.0082x^4 + 0.0693x^3 - 0.8573x^2 - 7.3330x + 49.1769$
8.	(0+30)	$y = 0.0071x^4 + 0.1238x^3 - 0.8027x^2 - 8.6668x + 44.7827$

Mathematical modeling for tensile strength.

B) Mathematical modeling for tensile strength of ternary blended steel fibre reinforced concrete with (FA+SF) combination, (FA+GGBFS) combination and (FA+MK) combination

Following table 13, 14 and 15 gives the equations developed for ternary blended steel fibre reinforced concrete with (FA+SF) combinations, (FA+GGBFS) combination and (FA+MK) combination respectively.

. In the equations, y= Tensile strength in MPa. And x = (T-400)/200

where T is temperature in degree centigrade,

Table 13 Biquadratic polynomial equations derived for the tensile strength of ternary blended steel fibre reinforced concrete with (FA+SF) combinations.

Sr. No	Percentage replacement of cement by (FA+SF)	Equations
1.	(0+0)	$y = -0.0004x^4 - 0.0006x^3 - 0.0306x^2 - 0.5169x + 4.8042$
2.	(30+0)	$y = -0.0005x^4 + 0.0002x^3 - 0.0294x^2 - 0.5328x + 4.8756$
3.	(25+5)	$y = -0.0033x^4 + 0.0190x^3 + 0.0178x^2 - 0.8550X + 4.6908$
4.	(20+10)	$y = -0.0031x^4 + 0.0214x^3 + 0.0074x^2 - 0.9349x + 4.7947$
5.	(15+15)	$y = -0.0032x^4 + 0.0253x^3 - 0.0053x^2 - 1.0276x + 5.0150$
6.	(10+20)	$y = -0.0030x^4 + 0.0285x^3 - 0.0213x^2 - 1.0989x + 5.1469$
7.	(5+25)	$y = -0.0026x^4 + 0.0226x^3 - 0.0097x^2 - 0.9674x + 4.7191$
8.	(0+30)	$y = -0.0025x^4 + 0.0222x^3 - 0.0099x^2 - 0.9625x + 4.5461$

Table 14 Biquadratic polynomial equations derived for the tensile strength of ternary blended steel fibre reinforced concrete with (FA+GGBFS) combinations.

Sr. No	Percentage replacement of cement by (FA+GGBFS)	Equations
1.	(0+0)	$y = -0.0004x^4 - 0.0006x^3 - 0.0306x^2 - 0.5169x + 4.8042$
2.	(30+0)	$y = -0.0005x^4 + 0.0002x^3 - 0.0294x^2 - 0.5328x + 4.8756$
3.	(25+5)	$y = -0.0010x^4 + 0.0017x^3 - 0.0206x^2 - 0.5490x + 4.9569$
4.	(20+10)	$y = -0.0019x^4 + 0.0044x^3 - 0.0028x^2 - 0.5733x + 5.0172$
5.	(15+15)	$y = -0.0015x^4 + 0.0045x^3 - 0.0231x^2 - 0.5835x + 5.3225$
6.	(10+20)	$y = -0.0012x^4 + 0.0055x^3 - 0.0432x^2 - 0.6262x + 5.6831$
7.	(5+25)	$y = -0.0011x^4 + 0.0076x^3 - 0.0390x^2 - 0.6777x + 5.1953$
8.	(0+30)	$y = -0.0013x^4 + 0.0093x^3 - 0.0222x^2 - 0.7063x + 4.6883$

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

Table 15 Biquadratic polynomial equations derived for the tensile strength of ternary blended steel fibre reinforced concrete with (FA+MK) combinations.

Sr. No	Percentage replacement of cement by (FA+MK)	Equations
1.	(0+0)	$y = -0.0004x^4 - 0.0006x^3 - 0.0306x^2 - 0.5169x + 4.8042$
2.	(30+0)	$y = -0.0005x^4 + 0.0002x^3 - 0.0294x^2 - 0.5328x + 4.8756$
3.	(25+5)	$y = -0.0012x^4 + 0.0036x^3 - 0.0195x^2 - 0.5880x + 4.9932$
4.	(20+10)	$y = -0.0015x^4 + 0.0068x^3 - 0.0255x^2 - 0.6571x + 5.3340$
5.	(15+15)	$y = -0.0005x^4 + 0.0012x^3 - 0.0452x^2 - 0.5941x + 5.5743$
6.	(10+20)	$y = -0.0003x^4 - 0.0000x^3 - 0.0376x^2 - 0.5816x + 5.2744$
7.	(5+25)	$y = -0.0016x^4 + 0.0074x^3 - 0.0068x^2 - 0.6898x + 4.8885$
8.	(0+30)	$y = -0.0010x^4 + 0.0039x^3 - 0.0146x^2 - 0.6296x + 4.7084$

OBSERVATIONS AND DISCUSSIONS

1. It was observed that at sustained exposure to 200 °C the various mixes gave better residual strength than the reference mix. It was observed that the reference mix returned 92.55% residual strength but the ternary blended mixes returned a very healthy residual strength as follows: (FA+SF) combination with (10+20) gave 95.9%, (FA+GGBFS) with (10+20) returned with 96.3% and (FA+MK) with (15+15) returned with 98.3% . Further all the specimens did not show any discolouration or surface cracks.

   Similar trend of observations are made in tensile strength of ternary blended steel fibre reinforced concrete with all the combination.

   Also it was observed at sustained exposure to 400 °C the various mixes gave better residual strength than the reference mix. It was observed that the reference mix returned around 65.58% residual strength that is the decrease in strength was almost 35%, but the blended mixes returned a very high residual strength as follows: (FA+SF) combination with (10+20) gave 75%, (FA+GGBFS) with (10+20) returned with 81% and (FA+MK) with (15+15) returned with 79% , further all the specimens did not show any discolouration or surface cracks.

   Thus upto 400 °C all the ternary blended steel fibre reinforced concrete show much better performance than the reference concrete, with combination (FA+MK) showing the best resistance followed by (FA+GGBFS) and then (FA+SF), also it was seen that the combination (FA+SF) gave the highest strength values at 90 days of 67.3MPa but the strength weakened by 4% and 25% at 200 °C and 400 °C compared to the combination (FA+MK) and (FA+GGBFS) which returned the compressive strength figures of 64.6 MPa and 64 MPa at 90 days, but the strength weakened by 1.7% and 3.7% at 200 °C and 20% and 19% at 400 °C respectively.

   This may be attributed to the fact that the synergistic effect of the ternary blended combination can change the morphological structure of concrete by densifying the cement paste matrix and improving the interfacial zone. Also the replacement level of (10+20) with (FA+SF) and (FA+GGBFS) and replacement level of (15+15) with (FA+MK) probably have the higher pozzolanic reaction which can convert calcium hydroxide to calcium silicate hydrate gel. In addition, the physical effect of fine grains allows denser packing within the cement matrix and reduces the wall effect in the transition zone between the paste and aggregates thus returning higher strength for 90 days.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with (FA+SF) at replacement level of (10+20) combination returns the highest strength value for 90 days & for 200 °C but the resistance offered to sustained elevated temperature of 200 °C and 400 °C is found to be better for the mix (FA+MK) for (15+15) followed by (FA+GGBFS) for (10+20). The order of preference can be given as (FA+MK), (FA+GGBFS) and finally (FA+SF). This may be due to the fact that metakaolin in its finest form may undergo the pozzolanic reaction along with cement and fly ash and give the resistance to resist the thermal stresses caused by sustained elevated temperature of 200°C and 400°C. Also metakaolin may densify the micro structure of concrete.
2. It is observed from the experimental results that the ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to a sustained elevated temperature of 600°C for 3 hours shows a decreasing trend of compressive strength as silica fume content in it increases.

   A similar trend was observed even with the tensile strength. At 600°C, the specimen with the combination of (FA+SF) have shown sufficient surface cracks with a color change from pink to deep red. The residual strength is also observed to decrease as the silica fume content increases. This can be attributed to the fact that silica fume being very fine makes the concrete dense and brittle at 600°C. Higher susceptibility of concrete with (FA+SF) combination to explosive spalling and cracking is due in parts to its lower permeability which limits the ability of water vapour to escape from the pores. This results in buildup of pore pressure within the cement paste.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to sustained elevated temperature of 600°C shows poor performance.
3. It is observed that the ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 600°C for 3 hours shows higher compressive strength at a cement replacement level of (10+20). Beyond this replacement the compressive strength shows a decreasing trend. Similar observations were made with the tensile strength. No surface cracks were observed

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

at 600°C. But there was a color change from grey to pink. The residual strength also shows peak of 63% at a replacement level of (10+20). This may be due to the fact of synergistic action of the combinations of (FA+GGBFS) at a cement replacement level of (10+20). Since ground granulated blast furnace slag has a rough textured surface, small pores are left within the concrete which can accommodate the vapour pressure due to rise in temperature and there by inducing resistance to concrete to sustain the temperature.

Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 600°C shows better performance.

4. It is observed that the ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 600°C for 3 hours shows higher compressive strength at a cement replacement level of (15+15). Beyond this replacement, the compressive strength shows a decreasing trend. Similar observations were made with the tensile strength. No surface cracks were observed at 600°C. But there was a color change from grey to pink. The residual strength also shows peak of 60% at a replacement level of (15+15).

   This may be due to the fact of synergistic action of the combinations of (FA+MK) at a cement replacement level of (15+15). Since metakaolin is a good pozzolanic material it can change the morphological structure of concrete thus improving the inter facial zone.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 600°C shows better performance.

5. It is observed that the ternary blended steel fibre reinforced concrete with (FA+GGBFS) has shown more residual strength at sustained elevated temperature of 600°C as compared to the combinations of (FA+SF) and (FA+MK). The order of preference can be given as (FA+GGBFS), (FA+MK) and finally (FA+SF). This may be due to the fact of the rough textured nature of GGBFS which results in small pores in concrete within which the pore pressure can be accommodated due to rise in temperature.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) shows higher resistance to sustained elevated temperature of 600°C as compared to the combinations of (FA+SF) and (FA+MK).

6. It is observed from the experimental results that the ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to a sustained elevated temperature a 800°C for 3 hours shows a decreasing trend of compressive strength as silica fume content in it increases. The loss of weight is due to the dehydration of calcium hydroxide in cement.

   A similar trend was observed even with the tensile strength. At 800°C the specimens with the combination of (FA+SF) have shown severe cracks. The residual strength is also observed to decrease as the silica fume content increases. This can be attributed to the fact that silica fume being very fine makes the concrete dense and brittle at 800°C. Higher susceptibility of concrete with (FA+SF) combination to explosive spalling and cracking is due in parts to its lower permeability which limits the ability of water vapour to escape from the pores. This results in build up of pore pressure within the cement paste.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to sustained elevated temperature of 800°C shows poor performance.

7. It is observed that the ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 800°C for 3 hours shows higher compressive strength at a cement replacement level of (10+20). Beyond this replacement, the compressive strength shows a decreasing trend. Similar observations were made with the tensile strength. Minor cracks were observed at 800°C. But there was a color change from grey to whitish. The residual strength also shows peak of 31.48% at a replacement level of (10+20).

   This may be due to the fact of synergistic action of the combinations of (FA+GGBFS) at a cement replacement level of (10+20). Since ground granulated blast furnace slag has a rough textured surface, small pores are left within the concrete which can accommodate the vapour pressure due to rise in temperature and there by inducing resistance to concrete to sustain the temperature.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 800°C shows better performance.

8. It is observed that the ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 800°C for 3 hours shows higher compressive strength at a cement replacement level of (15+15). Beyond this replacement, the compressive strength shows a decreasing trend. Similar observations were made with the tensile strength. Minor surface cracks were observed at 800°C. But there was a color change from gray to whitish. The residual strength also shows peak of 31.43% at a replacement level of (15+15).

   This may be due to the fact of synergistic action of the combinations of (FA+MK) at a cement replacement level of (15+15). Since metakaolin is a good pozzolanic material it can change the morphological structure of concrete thus improving the interfacial zone.

   Thus it can be concluded that the ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 800°C shows better performance.

9. It is observed that the ternary blended steel fibre reinforced concrete with (FA+GGBFS) has shown more residual strength at sustained elevated temperature of 800°C as compared to the combinations of (FA+SF) and (FA+MK). The order of preference can be given as (FA+GGBFS), (FA+MK) and finally (FA+SF).

   This may be due to the fact of the rough textured nature of GGBFS which results in small pores in concrete within which the pore pressure can be accommodated due to rise in temperature.

   Thus it can be concluded that the ternary blended

Volume : 4 | Issue : 8 | August 2014 | ISSN - 2249-555X

steel fibre reinforced concrete with the combination of (FA+GGBFS) shows higher resistance to sustained elevated temperature of 800°C as compared to the combinations of (FA+SF) and (FA+MK).

10. It is observed that the ternary blended steel fibre reinforced concrete with the combinations (FA+SF) and (FA+MK) when subjected to 1000°C have shown a crumbling effect and disintegration with severe cracks and spalling. Even these specimens could not be replaced from the oven to a safer place. The color was changed to total white. The specimens with the combination of (FA+GGBFS) have not crumbled much. Even though there were few serious cracks they could be tested on compression testing machine and have yielded the compressive strength.

    This may be due to the fact that GGBFS being more reactive in pozzolanic action have not allowed the serious cracks to appear. Thus it can be concluded that ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) can sustain to a little extent the sustained elevated temperature of 1000°C where as the combination of (FA+SF) and (FA+MK) show very poor performance at 1000°C.

CONCLUSIONS

a. Ternary blended steel fibre reinforced concrete with (FA+SF) combination and with a cement replacement level of (10+20) shows better resistance to a sustained elevated temperature of 200°C.
b. Ternary blended steel fibre reinforced concrete with (FA+GGBFS) combination and with cement replacement level of (10+20) shows better resistance to a sustained elevated temperature of 200°C.
c. Ternary blended steel fibre reinforced concrete with (FA+MK) combination and with cement replacement level of (15+15) shows better resistance to a sustained elevated temperature of 200°C.
d. Ternary blended steel fibre reinforced concrete with the combination of (FA+MK) show higher resistance to sustained elevated temperature of 200°C or 400°C as compared to the combination of (FA+SF) and (FA+GGBFS).
e. Ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to sustained elevated temperature 600°C shows poor performance.
f. Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 600°C shows better performance.
g. Ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 600°C shows better performance.
h. Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) shows higher resistance to sustained elevated temperature of 600°C as compared to the combinations of (FA+SF) and (FA+MK).
i. Ternary blended steel fibre reinforced concrete with the combination of (FA+SF) when subjected to sustained elevated temperature 800°C shows poor performance.
j. Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) when subjected to sustained elevated temperature of 800°C shows better performance.
k. Ternary blended steel fibre reinforced concrete with the combination of (FA+MK) when subjected to sustained elevated temperature of 800°C shows better performance.
l. Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) shows higher resistance to sustained elevated temperature of 800°C as compared to the combinations of (FA+SF) and (FA+MK).
m. Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) can sustain to a little extend of sustained elevated temperature of 1000°C where as the combination of (FA+SF) and (FA+MK) show very poor performance at 1000°C.
n. The equations generated will help in finding out the strength of ternary blended steel fibre reinforced concrete at any desired temperature.

ACKNOWLEDGEMENT

The authors like to express their deep sense of gratitude and sincere thanks to Sophisticated Instrumentation Centre for Applied Research and Testing (SICART), and Charutar Vidya Mandal (CVM) Trust, Board of Management and Principal of Birla Vishvakarma Mahavidhyalaya, Engineering college ,Vallabh Vidyanagar, Gujarat for all the encouragement and cooperation given in conducting the experimental investigation. The authors also sincerely thank all the research contributors whose research publications have been referred in the preparation of this paper. Thanks are also due to the authorities of Ultra Tech Cement Ltd. for the material support and to FOSROC Chemicals India Pvt Ltd.for superplasticizer and Stewols India Pvt Ltd for steel fibres and Elkem Materials for Silica fume, 20 Microns, Vadodara for metakaolin, Heidelberg cement, brand Duracem, New Mumbai for Ground granulated blast furnace slag and to Wanakbori Thermal Power station for Fly Ash.

REFERENCE 1. Mehta P K & Monteiro J M Paulo, "Concrete Microstructure, Properties and Materials". Mc. Graw Hill Publisher, Kindle Edition. | 2. Eva Lubloy and Gyorgy L. Balazs, "Post heating behaviour of concrete" 2009 International workshop on concrete spalling due to fire exposure. eipzing, Sep. 2009 (pp 301-311) ISBN 978-3-00-028604-9 | 3. Mohamad Heikal "Effect of elevated temperature on the physico-mechanical and micro structural properties of blended cement pastes", Bulding Research Journal, vol 56,2008 (pp 157-172) | 4. Ravindrarajah R Sri R Lopez & Reslan H "Effect of elevated temperature on the properties of high-strength concrete containing cement supplementary materials", Centre for Built Infrastructure Research, University of Technology, Sydney, March-2002, 9th international conference on durability of building materials and components, Brisbane, Australia,17-20th March, 2002 (pp 1-9) | 5. Nabil Bouzoubaa, Alain Biledeau, Vasanthy sivasundaram, Benoit Fournier & Dean M Golden, " Development of ternary blends for high performance concrete", ACI Material Journal, Jan-Feb 2004, (pp 19-28) | 6. Kodur Venkatesh and Raut Nikhil, " Performance of concrete structures under fire hazards : Emerging Trends ", Indian Concrete Journal, Apr-Jun 2010, (pp 7-18) | 7. Morsey M S, Alsayed S H, Aquel M, "Effect of Elevated Temperature on Mechanical Properties and Microstructure of Silica Flour Concrete" International Journal of Civil & Environmental Engineering" IJCEE-IJENS Vol. : 1 | 8. Prakash K. B, Krishnamurthy B. S, "Effect of high temperature on addition of three industrial wastes as pozzolanas and rubber latex on the properties of Concrete as stated in a well recognized site (www.nbmcw.com). | 9. 16. IS 10262: 2009, "Recommended guidelines for concrete mix design." | 10. 17. IS:516-1959: " Method of testing for concrete strength." | 11. 18. IS 5816-1999 "Splitting tensile strength of concrete method of test". |