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Flexural Toughness of Ternary Blended Steel Fibre Reinforced Concrete Subjected to Sustained Elevated Temperature

KEYWORDS: flexural toughness, ground granulated blast furnace slag, fly ash, high temperature, thermal incompatibilities.

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ABSTRACT *In this paper, an attempt is made to study the flexural toughness of steel fibre reinforced concrete with ternary blends. The mix design was carried out for M30 grade concrete which yielded a proportion of 1:1.86: 2.41 with a w/c ratio of 0.45. Before mixing, 30% of cement was replaced by (FA + SF) or (FA+GGBFS) or (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. A detailed investigation is made to study the flexural toughness of steel fibre reinforced concrete with ternary blends on the beam specimen when subjected to sustained elevated temperature of 200°C, 400°C, 600°C, 800°C and 1000°C for 3 hours and then allowed to cool.. It can be concluded that 30% replacement of cement by (10+20) proportions of (FA+GGBFS) in ternary blended SFRC yields higher strength.*

Introduction

When concrete is subjected to 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. The maximum exposure temperature, exposure time, heating and cooling rates are among the most important factors. In these processes, the removal of free water, absorbed and chemically bounded water affected the porosity, capillary and the microstructure of cements. In the temperature range (100 – 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 550°C, the reduction of strength in the range 55 – 70 % and dehydroxylation of $Ca(OH)_2$ takes place. The dehydration of calcium silicate hydrated and the thermal expansion increase internal stresses and micro cracks which are induced through the cementing material. Fire is generally extinguished by water and CaO turns into $Ca(OH)_2$ causing cracking and crumbling of concrete. The alterations produced by high temperatures are more evident when the temperature surpasses 500°C. CSH gel, which is the strength giving compound of cement paste, decomposes further above 600 – 800°C. At 400°C gel-like hydration products are decomposed. At 600°C, $Ca(OH)_2$ is dehydroxylated, and $CaCO_3$ dissociates to CaO and CO_2 accompanied with the recrystallization of non-binding phases from hydrated cement under re-combustion are dominant processes between 600°C and 800°C. This stage of concrete is characterized by the collapse of its structural integrity, revealing residual compressive strength. [1.]. The pozzolanic material such as silica fume (SF), ground granulated blast furnace slag (GGBFS), fly ash (FA), rice husk ash (RHA) and metakaolin (MK) have shown to improve the microstructure of cement paste by densifying the cement paste matrix and improving interfacial zone. The use of appropriately proportioned, binary, ternary and tertiary blends allows the effects of one SCM to compensate for the inherent shortcomings of another.

The hydrates, such as calcium silicate hydrate (CSH) phases produced as a result of consumption of free lime $Ca(OH)_2$ 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. The addition of polypropylene fibers minimizes fire induced spalling in the concrete members. One of the most accepted theory is that by melting at a relatively low temperature of 170°C (338°F) polypropylene fibers create 'channels' for the generated steam pressure (within the concrete) to escape, thus preventing the small 'explosions' that cause spalling. The amount of polypropylene fibers needed to mitigate spalling is about 0.1-0.15% (by volume). This technique is highly effective for concrete used in tunnel linings as tunnels are susceptible to fires with very high heating rates. Alternatively steel fibers can also be used to enhance fire resistance of HSC members. The addition of steel fibers enhances the tensile strength of concrete and reduces spalling.

RESEARCH SIGNIFICANCE

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 aimed at generating experimental data necessary for characterizing the behavior of SFRC with ternary blends when exposed to elevated temperatures.

EXPERIMENTAL PROGRAMME

Main objective of this experimental investigation is to study the flexural toughness 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.

The mix design was carried out to obtain a M30 grade concrete as per IS: 10262-2009 which yielded a proportion of 1:1.86: 2.41 with a w/c ratio of 0.45. 1% steel fibres by volume was added to the mix and the entire concrete was agitated thoroughly to get a homogeneous mix. After 90 days curing, the specimens were placed in the heating chambers. For assessing the flexural toughness of SFRC with ternary blends at elevated temperatures standard specimen of beam of size 100 x 100 x 500 mm were cast . All the specimens (after 90 days of curing) were placed in the heating chambers (furnace) for 3 hours After 3 hours, all the specimens were removed and cooled to room temperature and then tested . While static flexural strength test was conducted on simply supported beams under third point loading, setting were made to collect load deflection data in tabular as well

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as graphical form(2). In general load and deflection increases almost proportionately up to the first crack. for their respective strengths. Toughness is calculated by determining the area under load deflection curve using NCSS software(3). The area beneath this load/deflection graph is a measure of the energy required to achieve a certain deflection and is a measure of the ductility that a fibre reinforced composite possesses. The term "toughness" has been coined to convey the existence of the post cracking region of the load/deflection graph for a fibre reinforced concrete. The Japan society of civil engineers (2) determine the energy required for deflecting beam by a specified amount. JSCE-SF4 was used to calculate the toughness factor in Nmm^{-2} which is described below.

Flexural toughness factor $= \frac{T_b \times L}{\delta_{tb} \cdot b \times h^2}$

Tb = area up to L/150

δtb=deflection at L/150 which is a fixed multiple of the first crack deflection.
L = Span of the specimen
b = Width of the specimen
h = Depth of the specimen

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.

- **Superplasticizer:**

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 :**

Fly ash, silica fume, metakaolin and ground granulated blast furnace slag used in the experimentation

Observation and discussions

Table 1 Overall results of toughness factor for ternary blended steel fibre reinforced concrete without subjecting to temperature and when subjected to sustained elevated temperature of 200°C, 400°Cand 600°C

Percentage replacement of cement byTernary blends	Without subjecting to temperature (MPa)			Subjected to 200°C (392°F) (MPa)			Subjected to 400°C(752°F) (MPa)			Subjected to 600°C (1112°F) (MPa)		
	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)	(FA+GGBFS)	(FA+MK)
(0+0)	2.71	2.71	2.71	2.00	2.00	2.00	1.71	1.71	1.71	1.35	1.35	1.35
(30+0)	3.16	3.16	3.16	2.14	2.14	2.14	1.76	1.76	1.76	1.45	1.45	1.45
(25+5)	3.6	3.59	3.53	3.14	2.65	3.19	1.99	1.99	1.95	1.72	1.94	1.77
(20+10)	4.26	3.89	4.21	3.24	2.87	3.45	2.19	2.00	1.99	1.64	2.06	1.94
(15+15)	4.48	4.06	4.71	3.31	2.89	3.78	2.75	2.66	2.67	1.63	2.12	2.29
(10+20)	4.8	4.78	4.2	3.54	3.53	3.60	3.27	3.14	2.17	1.61	3.09	1.94
(5+25)	4.31	3.27	3.87	3.18	3.15	3.49	2.87	2.45	2.06	1.53	2.42	1.79
(0+30)	4.03	3.94	3.54	2.98	2.91	3.32	2.17	2.39	1.93	1.07	2.12	1.43

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Table 2 Overall results of toughness factor for ternary blended steel fibre reinforced concrete when subjected to sustained elevated temperature of 800°C (1472°F) and 1000°C (1832°F)

Percentage replacement of cement by Ternary blends	Subjected to 800°C (1472°F) (MPa)			Subjected to 1000°C (1832°F) (MPa)		
	(FA+SF)	(FA+GGBFS)	(FA+MK)	(FA+SF)	(FA+GGBFS)	(FA+MK)
(0+0)	0.77	0.77	0.77	0	0	0
(30+0)	0.78	0.78	0.78	0	0	0
(25+5)	0.72	0.92	0.82	0	0	0
(20+10)	0.70	1.09	0.87	0	0	0
(15+15)	0.65	1.45	1.09	0	0	0
(10+20)	0.61	1.56	0.92	0	0	0
(5+25)	0.59	1.33	0.87	0	0	0
(0+30)	0.45	1.25	0.73	0	0	0

Fig. 1 Furnace for heating the samples

Observation and Discussion

Thus upto 400°C all the ternary blended steel fibre reinforced concrete show much better performance and flerural toughness than the reference concrete, with combination (FA+GGBFS) showing the best resistance followed by (FA+SF) and then (FA+MK). All the specimens did not show any discoloration or surface cracks.

At 600°C, the specimens 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. 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 flexural toughness at a cement replacement level of (10+20) . Beyond this replacement the flexural toughness shows a decreasing trend. No surface cracks were observed at 600°C. But there was a color change from grey to pink.

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. 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 flexural toughness at a cement replacement level of (15+15). Beyond this replacement, the flexural toughness shows a decreasing trend. No surface cracks were observed at 600°C. But there was a color change from grey to pink. 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. 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). 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 flexural toughness silica fume content in it increases . The specimens 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 buildup of pore pressure within the cement paste. 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 flexural strength at a cement replacement level of (10+20). Beyond this replacement, the flexural strength shows a decreasing trend. Minor cracks were observed at 800°C . But there was a color change from grey to whitish.) 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 flexural strength at a cement replacement level of (15+15). Beyond this replacement, the flexural strength shows a decreasing trend. Minor surface cracks were observed . But there was a color change from gray to whitish.

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.

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). 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. 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.

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Conclusion

(1) Ternary blended steel fibre reinforced concrete with (FA+SF) combination and with a cement replacement level of (10+20) shows better flexural toughness to a sustained elevated temperature of 200°C and 400°C.

(2) Ternary blended steel fibre reinforced concrete with (FA+GGBFS) combination and with cement replacement level of (10+20) shows better flexural toughness to a sustained elevated temperature of 200°C and 400°C.

(3) Ternary blended steel fibre reinforced concrete with (FA+MK) combination and with cement replacement level of (15+15) shows better flexural toughness to a sustained elevated temperature of 200°C and 400°C.

(4) It has been found that the ternary blended steel fibre reinforced concrete containing (FA+GGBFS) and (FA+MK) offer higher flexural toughness to sustained elevated temperatures upto 600°C and 800°C, where as the blend containing (FA+SF) offers resistance only upto 400°C also (FA+GGBFS) shows higher flexural toughness to sustained elevated temperature of 600°C and 800°C than the combination of (FA+MK).

(5) Ternary blended steel fibre reinforced concrete with the combination of (FA+GGBFS) can sustain to a little extent of sustained elevated temperature of 1000°C where as the combination of (FA+SF) and (FA+MK) show very poor performance at 1000°C.

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