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Research paper

Study on Effect of Thermal Cycles on Strength Properties of SCC

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Abstract

Impact of elevated temperature on the properties of concrete is critical for imperviousness to fire considers. The fire stays a standout amongst the most genuine possibilities unsafe to any building. The effect of sustained temperature on the properties of concrete is important for fire resistance studies. The fire remains one of the most serious potentials hazardous to any building. The main objective of this study was to conduct an exploratory work towards the development of a suitable SCC mix design using local aggregates and to evaluate the performance of the selected SCC mix under thermal variations. Trials mixes using Okamura method of mix design were carried out for the 4 different mix proportions to achieve the final mixes which satisfy all the workability properties. The specimens were cast and cured for 7 & 28 days. Considering the specimens cured for 7 & 28 days as a reference, specimens were subjected to the requisite number of thermal cycles at two different temperatures as 1000C & 1200C. Variation in weight of the specimen after the requisite number of thermal cycles was recorded, then the compressive strength & split tensile strength of thermally treated concrete specimens was determined. The result shows a relative decrease in the strength of thermally treated each specimen as compared to its original strength before heating. The replacement of ordinary Portland cement by mineral admixtures in concrete caused an increase in strength as compared to control mix. The replacements of OPC by Micro Silica have shown the highest strength and fly ash mix shown least strength in this experimental work.

Keywords: *Self Compacting Concrete, Fly Ash, GGBS, Micro Silica, Elevated Temperature, Compressive Strength, Split Tensile strength.*

1. Introduction

Concrete is a material often used in the construction of high rise buildings and in case of unexpected fire, the concrete properties are changes after the fire. Elevated temperature in concrete structures will cause the development of cracks. These cracks propagation may eventually cause loss of structural integrity and be shorting of service life. The Properties of concrete is of very much important for fire resistance studies. Concrete structures when subjected to high temperatures, the compressive strength and performance variations are to be investigated.
Under the category of high-performance concrete, the Self Compacting Concrete is classified with excellent deformability in the fresh state and high resistance to segregation and has to be placed and compacted under its self-weight without applying any external vibration. When compared to ordinary and self compacted concrete, high performance concrete has been shown to have greater risks of deterioration during fire exposure. The same high performance concrete conditions are applied for when self-compacted concrete is susceptible to fire damage. It is also important to address any additional conditions that may arise for self-compacted concrete behaviour.

2. Literature Review

R.Vasusmitha et al. (1) carried out the mechanical properties of High Strength Self Compacting concrete subjected to sustained high Temperatures of 200o C, 400o C and 600o C with the concrete exposure for duration of 4,8,12 Hours of Grade M80 Mix. The results obtained were, the loss of Compressive Strength and Split Tensile strength were nearly 14 % and 9 % at 200o C and 400o C for 12 hrs and 24 % and 18 % at 200o C and 400o C for 12 hrs. The percentage weight loss of Cube Specimens and Cylinder Specimens were nearly 4 % and 8 % at 200o C and 400o C for 12 hrs and 3 % and 7 % at 200o C and 400o C for 12 hrs.
Huai-Shuai Shang et al. (2) obtained thermal properties of high-performance concrete (HPC) with fly ash for use in fire resistance calculations and these properties included are compressive strength, cubic compressive strength, cleavage strength, flexural strength, and the ultrasonic velocity at various temperatures (20o C, 100o C, 200o C, 300o C, 400o C and 500o C) of high-performance concrete. The change of surface characteristics with the temperature was observed.
M. A. Helal et al. (3) reported that the influence of high temperature on the properties of self-compacted concrete (SCC) compared with the ordinary concrete (NC) was investigated. The effect of cooling technique on the properties of SCC and NC was discussed. The properties of SCC and NC were measured after exposure to 200o C, 400o C, and 600ºC for two hours. The

Results obtained from this work was to show that the mechanical properties decreased with increasing temperatures.

K. Chandramouli1 et al. (4) have reported on the experimental study on the compressive strength of ordinary grade of concrete such as M20, M30, M40 and M50 subjected to thermal cycles at a temperature of 50º C. The experimental programme on concrete specimens of size 100 x 100 x 100 mm cubes were cast for testing compressive strength. The test specimens were de-moulded after 24 hours of air cooling and kept for water curing for 28 days. The decrease in compressive strength of ordinary concrete mixes in comparison with zero thermal cycles for 50° C is observed to be varied from 14 to 23 % for 28, 56, 90, and 180 thermal cycles.

3. Materials Used

The performance measures described above can be used to investigate different solutions to address potential improvements on traffic operations at intersections serving more than one mode of transportation. This kind of evaluation can be performed for an isolated intersection or an urban corridor with several intersections.

3.1. Cement

Ordinary Portland cement of 53 grades available in the local market is used in the investigation.

3.2. Coarse aggregate

The granite jelly of 12.5mm passing is used. The sieve analysis of coarse aggregates conforms to the specifications of IS 383: 1970 for graded aggregates and specific gravity.

3.3. Admixtures

a) Chemical Admixtures

The Super Plasticizer used are Poly-carboxylated Ether based Super Plasticizer namely GLENIUM B233 which is Brown Color and free-flowing liquid and having Relative density 1.09+0.01 and pH value greater than 6 and Chloride Content < 0.2%. Flow tests were carried out on pastes containing different water to powder ratios or different super plasticizer dosages with a Marsh cone. Superplasticizer dosage of about 0.8% was determined in powder mass as the optimum dosage to above Mix.

b) Mineral Admixtures

FLY ASH: Fly ash when used as a mineral admixture in concrete, improves its strength and durability characteristics. Fly ash is used as about 30% partial replacement of cement.

GGBFS: Slag is a by-product of the iron industry, generally used to replace Portland cement in concrete mixtures. GGBFS is used as about 30% partial replacement of cement.

Micro Silica

Commercially available Micro silica is used. Micro Silica (very fine non-crystalline silicon dioxide) is a by-product of the manufacture of silicon, ferrosilicon or the like, from quartz and carbon in the electric arc furnace.

Table 1: Properties of materials used

Property	**Value**
Specific Gravity of C.A	2.65
Specific Gravity of F.A	2.63
Specific Gravity of Cement	3.14
Specific Gravity of fly ash	2.28
Specific Gravity of GGBFS	2.82
Specific Gravity of Micro silica	2.25
The bulk density of C.A (rodded density) kg/m^3	1.63

4. Experimental Programme

There is no standard procedure available for designing the mix proportions for Self Compacting Concrete and hence proportion is based on the Experimental trail was adopted. Water to powder ratio was kept at about 1 & Super plasticizer dosage of about 0.8% for all mix proportions of concrete. The Mix proportion for SCC is reported below:

- Trials mixes using Okamura method of mix design were carried out for the following 4 mix proportions to achieve the final mixes, which satisfies all the workability properties.

MIX -1: SCC with 100% cement
MIX -2: SCC with 70% & 30% fly ash
MIX -3: SCC with 70% & 30% GGBFS
MIX -4: SCC with 90% & 10% Micro silica

- The cubes & cylinders were cast and cured for 7 & 28 days. And the specimens were tested for strength values @ 7 & 28 days.
- Considering the specimens cured for 7 & 28 days as a reference, are subjected to the requisite number of thermal cycles at two different temperatures as given below:
  - 7 days cured specimens – 7 & 28 thermal cycles @ 100o C & 120 o C
  - 28 days cured specimens – 7 & 28 thermal cycles @ 100o C & 120 o C
- Also, change of weight of specimen after each thermal cycle was recorded.

4.1. Thermal Cycles Procedure

In this present work, two cases of thermal cycles were chosen. In one case, concrete specimens were heated to a maximum temperature of 1000C.In another case, specimens were heated to 1200C. The specimens were heated in an oven from room temperature to the maximum temperature at an increasing rate about 3 hours, maintaining the maximum temperature for next 5 hours constant and then letting it cool down to room temperature for 16 hours. All these constitute 1 thermal cycle. The specimens were subjected to 0,7,28 such thermal cycles. Also, changes in the weight of specimens after each thermal cycle were recorded.

4.2. Compressive Strength & Split Tensile Strength Test

The compressive strength & split tensile strength of thermally treated concrete specimens were determined under CTM.

Table 2: Details of No. of specimens required

Calculation for the number of specimens required for one mix proportion				
Curing period	Thermal cycles	Number of cubes for		
		Reference mix	100^0C	120^0C
7	7	3	3	3
	28		3	3
28	7	3	3	3
	28		3	3
Total cubes		6	12	12

Calculation of number of specimens required for all 4 mix proportions
Total mix proportions = 4
Total cubes 4 x (6+12+12) = 120
Total cylinders 4x (6+12+12) =120
Total specimens 120 x 2 = 240

Total quantity of materials required for this study for one mix proportion:
Size of cube: 150mm x 150mm x 150mm
= 0.0037 m^3
Size of cylinders: 150mm x 300mm
= 0.0053 m^3
Total volume: (0.0037 + 0.0053) x 30
= 0.27 m^3

Table 3: Details of the total quantity of materials required

Mix naming	Total volume	Cement (kg)	Fly ash (kg)	GGBFS (kg)	Micro silica (kg)	F.A (kg)	C.A (kg)	Water (liters)	SP (liters)
C	0.27	158.20	-	-	-	216.84	215.64	50.38	1.26
F	0.27	110.74	34.46	-	-	216.84	215.64	50.38	1.16
G	0.27	110.74	-	42.62	-	216.84	215.64	50.38	1.23
SF	0.27	142.38	-	-	11.33	216.84	215.64	50.38	1.22
Total		522.06	34.46	42.62	11.33	867.36	862.56	201.52	4.87

5. Results and Discussion

The compressive strength & splitting tensile strength of thermally treated concrete specimens were determined. The result shows a relative decrease in the strength of thermally treated each specimen as compared to its original strength before heating. The replacement of ordinary Portland cement by mineral admixtures in concrete caused an increase in strength as compared to control mix. The replacements of OPC by Micro silica have shown the highest strength and fly ash mix shown least strength in this experimental work.

Table 4: Fresh properties of final mix proportions

MIX	Mix-1	Mix-2	Mix-3	Mix-4
Slump flow (mm)	680	690	675	670
J-ring (mm)	8	7	9	6
V-funnel (sec)	10	8.5	11	11.5
L-box (H_1/H_2mm)	0.91	0.93	0.9	0.88
U-box (H_1H_2mm)	22	19	24	26

The results obtained were, the % loss of Compressive Strength & tensile strength at 0, 7 & 28 thermal cycles were maximum for mix-1 at both the temperature cases and it was minimum for mix-4 for both the temperatures.

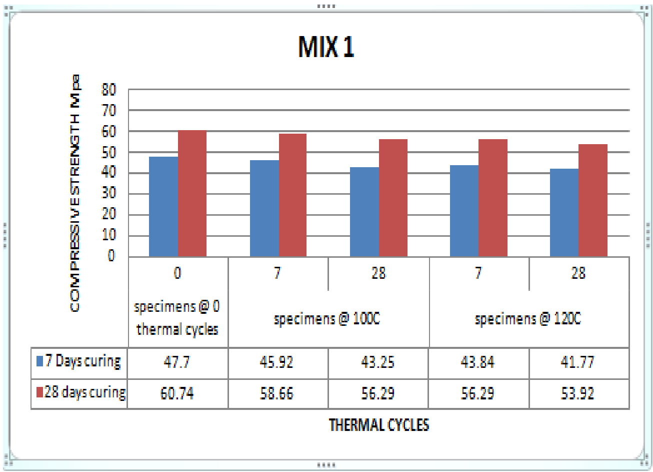

Fig.1: Graphical representation of the variation in compressive strength with the thermal cycle for mix-1

For 7 days cured specimens of mix-1, subjected to 7 & 28 thermal cycles @ 1000C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 4 to 9% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 5 to 11%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 9 to 13% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 8 to 13%.
For 28 days cured specimens of mix-1, subjected to 7 & 28 thermal cycles @ 1000C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 4 to 8% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 5 to 7%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 8 to 12% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 7 to 12%

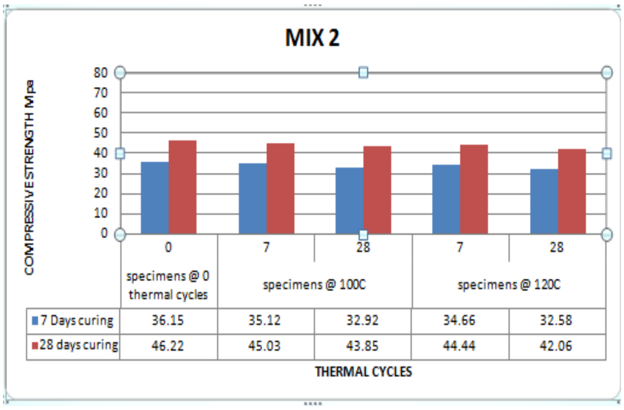

Fig.2: Graphical representation of the variation in compressive strength with the Thermal cycle for mix-2

For 7 days cured specimens of mix-2, subjected to 7 & 28 thermal cycles @ 1000C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 3 to 9% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 6 to 8%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 4 to 10% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 8 to 11%.
For 28 days cured specimens of mix-2, subjected to 7 & 28 thermal cycles @ 1000C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 3 to 6% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 4% to 5%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 4 to 9% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 5 to 10%.

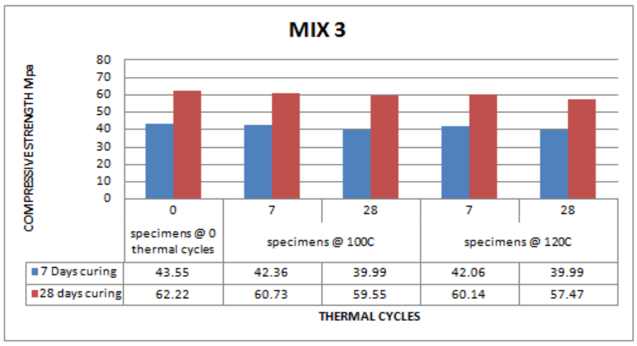

Fig.3: Graphical representation of the variation in compressive strength with the Thermal cycle for mix-3

For 7 days cured specimens of mix-3, subjected to 7 & 28 thermal cycles @ 1000C, the % of the decrease in compressive strength zero thermal cycle varies from 3 to 9% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 5 to 8%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 4 to 9% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 6 to 10%.

For 28 days cured specimens of mix-3, subjected to 7 & 28 thermal cycles @ 1000C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 3 to 5% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 5 to 7%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of decrease in compressive strength with respect to zero thermal cycle varies from 4 to 8% and the % of decrease in tensile strength with respect to zero thermal cycle varies from 5 to 9%.

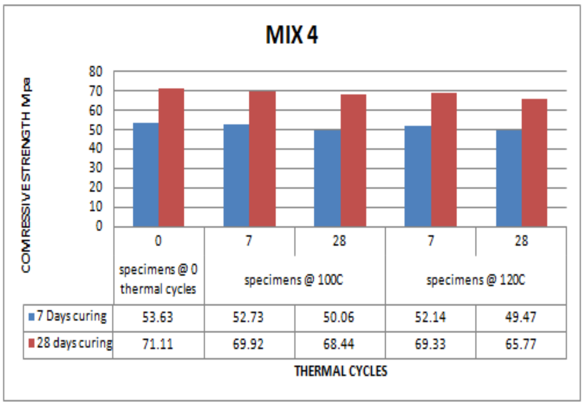

Fig. 4: Graphical representation of the variation in compressive strength with the Thermal cycle for mix-4

For 7 days cured specimens of mix-4, subjected to 7 & 28 thermal cycles @ 1000C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 2 to 7% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 4 to 6%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 3 to 8% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 4 to 8%.

For 28 days cured specimens of mix-4, subjected to 7 & 28 thermal cycles @ 1000C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 2 to 4% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 4 to 6%. Similarly, specimen subjected to 7 & 28 thermal cycles @ 1200C, the % of the decrease in compressive strength with respect to zero thermal cycle varies from 3 to 8% and the % of the decrease in tensile strength with respect to zero thermal cycle varies from 4 to 8%.

6. Conclusions:

In this study, fresh, hardened properties and durability of self-compacting concrete were investigated by using mineral admixtures namely fly ash, GGBS, and micro silica at different replacement rates for cement. The investigations are carried out according to appropriate criteria given by European standards. In the present study, such properties of self-compacting concrete produced with mineral admixtures are investigated based on fresh concrete tests, specifically workability, strength and durability tests. Based on the experimental study the following conclusions can be drawn

- A mix design based on Okamura and Ozawa method can be successfully employed for achieving SCC. The method is simple and reduces the number of trials for achieving SCC.
- All the Mix proportions developed satisfied the requirements of SCC specified by EFFNARC.
- It is observed that, in comparison with zero thermal cycles, there is a decrease in strength (compressive & tensile) values with increase in thermal cycles @ 1000C & 1200C for both 7 & 28 days cured SCC specimens of all 4 mix proportions.
- It is noticed that the % decrease in strength is more for 7-days cured specimens as compared to 28-days cured specimens. Self Compacting Concrete has higher strength loss than Ordinary Conventional Concrete and is more susceptible to explosive spalling when exposed to higher temperatures.
- The reduction in weight of specimen is more at initial thermal cycles as compared to later thermal cycles. The more reduction in weight at initial thermal cycles may be due to the sudden loss of water from concrete.

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