Effect of Temperature Variation on Compressive Strength of Concrete with Crushed Ceramic Tile Aggregate and Glass

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Abstract—The present paper investigates the effect of temperature variation on compressive strength of Crushed Ceramic Tile Aggregate (CCTA) and Glass Fibres (GF) incorporated concrete. Compressive strength of concrete is studied with replacement of natural coarse aggregate by CCTA at 0, 25 and 50 % and GF (1 %). The hardened concrete specimens after curing in water for 28 days were thermally treated at 150 and 300□C for 2 hours. The heated specimens are cooled in air and water. The compressive strength of specimens before and after subjecting to elevated temperature was compared with those of the control specimens. The results showed that the addition of CCTA and GF improves the performance of concrete when exposed to elevated temperatures. Strength attained was higher for air cooling than for water cooling.

Index Terms—Concrete, compressive strength, Crushed Ceramic Tile Aggregate (CCTA), Elevated Temperature, Glass Fibres (GF), air cooling, water cooling.

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1 INTRODUCTION

Concrete is the backbone to infrastructure development of a nation because of its low cost, availability of raw materials, strength, and durability. Concerning the construction industry, the main issues are related with the abusive use of natural resources and the production of high amounts of waste. It is therefore of special importance to implement the well-known principle of "3R" (Reduce, Reuse, Recycle) in this area. Utilization of waste materials for partly substitution of the raw materials which would minimize their use, energy consumption and thus reducing the construction cost are preferred.

The nature of construction industry, especially the concrete industry, is such that ceramic wastes can be used safely with no need for dramatic change in production and application process. On one hand, the cost of deposition of ceramic waste in landfill will be saved and on the other, raw materials and natural resources will be replaced, thus saving energy and protecting the environment. The best way for the construction industry to become a more sustainable one is by using wastes from other industries as building materials. Utilization of CCTA in concrete mitigates the problem of waste disposal and abusive use of natural resources.

Concrete material has many advantages for construction, such as its high compressive strength, durability, and economical costs, but it also has shortcomings like low tensile strength and fragility. Using glass fibers in concrete mixtures could considerably improve shortcomings of the ordinary concrete. Glass fibres are made of silicon oxide with addition of small amounts of other oxides. Glass fibres are characteristic for their high strength, good temperature and corrosion resistance, and low price. The properties of ceramic waste coarse aggregate are well within the range of the values of conventional aggregates.

Concrete structural members when used in buildings have to satisfy appropriate fire safety requirements specified in building codes. This is because fire represents one of the most severe environmental conditions to which structures may be subjected; therefore, provision of appropriate fire safety measures for structural members is an important aspect of building design. Concrete buildings which may be subjected to high temperatures during operation or in case of an accidental fire may lead to serious deterioration and explosive spalling. Although concrete has better fire-resistant performances than most construction materials, the strength of concrete will decrease and may burst under high temperature exposure. With an increase in temperature, cracking is initiated due to thermal incompatibilities between the aggregates and the hardened cement paste.

Fig. 1. Waste ceramic tiles

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Fig. 2. Glass Fibres

4 EXPERIMENTAL DETAILS

4.1 Material properties

Ordinary Portland Cement 53 grade conforming to IS 12269: 2013 was used in the study. CCTA was collected locally and was crushed. GF was obtained from Kiran Enterprises, Mangalore. Physical properties of CCTA and GF are shown in Table 1 and 2 respectively. Super plasticizer used in this study is CONPLAST SP 430 in the form of sulphonated naphthalene polymer confirms to IS: 9103-1999 and ASTM 494 type F, to improve the workability of concrete.

TABLE 1
PHYSICAL PROPERTIES OF CAAND CCTA

Properties	**CA**	**CCTA**
Loose density(kg/m^3)	1636	1079
Bulk density(kg/m^3)	1725	1126
Specific gravity	2.82	2.4
Fineness modulus	6.31	5.64
Water absorption(%)	1.8	8.92
Aggregate crushing value(%)	32.41	24.4

TABLE 2
PHYSICAL PROPERTIES OF GLASS FIBRES

Sl. No.	**Properties**	**Values**
1	Diameter	12 μm
2	Specific gravity	2.60
3	Failure strain	3.0%
4	Elasticity	80GPa
5	Tensile strength	2.5GPa

4.2 Mixture Composition

The CCTA were first mixed with water needed for surface dry saturation for half an hour before blending. Coarse aggregate were partially replaced with CCTA in different series. The first three series did not contain GF. The remaining three series contained 1 % GF. The other mixture proportion is same of the first series. Details of mixture proportions were shown inTable 3.

Water/Cement (w/c) ratio was kept constant in all the series and slump values were decreased as replacement ratio was increased. However addition of chemical admixture prevented the existence of very dry mixtures. Each test series consist of 15 nos. of 150×150×150 mm cubes and 150 mm diameter and 300 mm height cylinders. All the specimens were subjected to water curing till the age of testing.

TABLE 3
DETAILS OF MIX PROPORTIONING

Mix	**Cement**	**FA**	**NCA**	**CCTA**	**GF**
C0-0	360	723	1285.75	0	0
C25-0	360	723	964.31	266.72	0
C50-0	360	723	642.87	533.45	0
C0-1	360	723	1285.75	0	3.6
C25-1	360	723	964.31	266.72	3.6
C50-1	360	723	642.87	533.45	3.6

4.3 Elevated temperature exposure

Heating procedure is carried out using an electric oven having a temperature range of 50° to 300°C. At 28 days age of testing, the test specimens were subjected to elevated temperatures at 150° and 300°C for a period of 2 hrs. Then the heated specimens are cooled. Two cooling conditions were chosen. First condition was air cooling i. e., the hot specimens was taken out of the oven and underwent natural cooling in laboratory conditions. Second cooling condition was water cooling for a period of 2 hours i.e., the hot specimens was taken out of the oven and immediately immersed in a fresh water tank. The compressive strength of the concrete samples that were not exposed to high temperature and those that were subjected to high temperature were tested and compared. For each group, three specimens were tested and averaged.

5 TEST RESULTS AND DISCUSSIONS

The average 28 day compressive strength for different concrete mixes subjected to temperature variation is shown in Table 4.

5.1 Effect of CCTA and GF on concrete strength

The Table 4 shows that as the percentage of CCTA increases, compressive strength decreases. The percentage reduction in compressive strength of 25 % and 50 % replacement level is 11.76 % and 26.95 % respectively. Based on the results, the fall of compressive strength and density of concrete is gradual when the replacement increases.

As the percentage of CCTA increases, workability decreases. Workability is also decreased when GF is added and this is due to the non-uniform distribution of the fibers in concrete and higher water absorption of CCTA. Higher water absorption causes improper bonding in the interfacial transition zone and hence the compressive strength decreases. Strength values are gradually decreased, because of higher water absorption, adhered bonding between mortar paste and porcelain surface area and higher content of flaky aggregate (Karakoc., 2013).

Incorporation of GF into the mixes increases the compressive. Beyond 28 days, the bonding between the mortar and glass fibre had developed completely and all the GF specimens had better performance than that of control concrete. The percentage increase when GF is added in 0 %, 25 % and 50 % replacement level is 24.34 %, 23.7 % and 23 % for compressive strength respectively. Thus glass fibres have a good ductile behaviour, which helps in attaining maximum tensile strength. Fig 3 shows the variation in compressive strength of concrete with CCTA with and without GF.

5.2 Effect of Temperature on Concrete Strength

Also Table 4 indicates the increase in temperature leads to reduction in the compressive strength. This is due to the reason that the increasing temperature leads to an increase involume of concrete due to cracks initiation, and defect on the bonding between all components of concrete, causing a reduction in the compressive strength.

When the concrete is heated to 150°C , the free water wihin the concrete starts to evaporate resulting in an increase in porosity and consequently a decrease in the compressive strength of concrete. When the temperature exeeds 150°C, the water begins to vaporise, usually causing a build-up of pressure within the concrete. The internal pressure inside the concrete forces the hardened concrete structure for releasing of vapour to the outer side (Yuksel, 2011).

This investigation shows a higher resistance of fibre reinforced concrete to high temperature when compared to normal concrete. So, glass fibre concrete has better fire resistant characteristics.

5.3 Effect of Cooling Conditions on Concrete Strength

The compressive strength values of specimens cooled in different cooling condition i. e.. air and water cooling, are given in Table 4 respectively. The compressive strength of concretes cooled in air and water, after heating to 150°C and 300°C are plotted in Fig 4 and 5.

TABLE 4
VARIATION OF COMPRESSIVE STRENGTH OF CONCRETE SPECIMENS WITH TEMPERATURE

Cooling condition	**Mix**	**Compressive strength (MPa)**			**Reduction in strength (%)**	
		Laboratory temperature	**150°C**	**300°C**	**150°C**	**300°C**
Air Cooling (24 hours)	C0-0	34.5	32.65	28.15	6.81	18.41
	C25-0	30.44	30.11	27.67	5.95	16.56
	C50-0	25.2	24.1	21.35	7.94	19.64
	C0-1	45.6	43.82	42.28	3.90	7.28
	C25-1	38.92	36.54	34.8	3.83	8.92
	C50-1	32.74	29.5	23.85	6.08	14.94
Water Cooling (2 hours)	C0-0	34.5	30.23	26.73	12.38	22.52
	C25-0	30.44	28.7	25.8	9	19.84
	C50-0	25.2	22.34	19.1	15.71	24.21
	C0-1	45.6	43.6	41.4	4.39	9.21
	C25-1	38.92	37	35.65	7.31	10.70
	C50-1	32.74	27.68	25.84	10.87	21.08

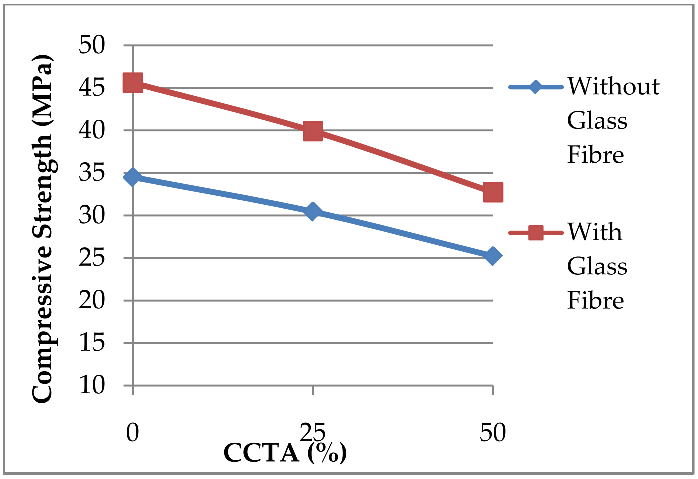
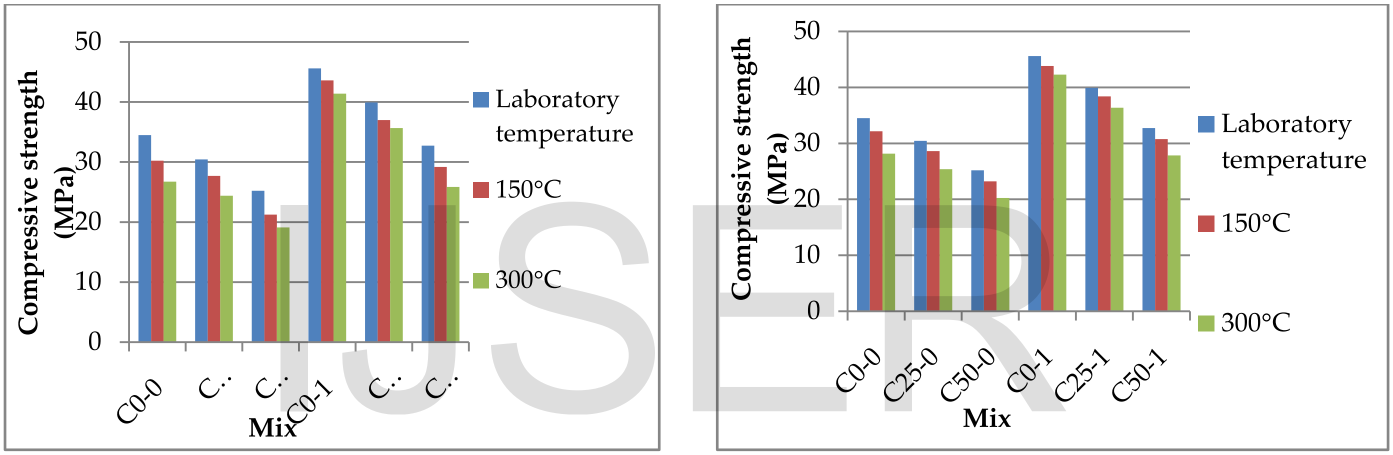
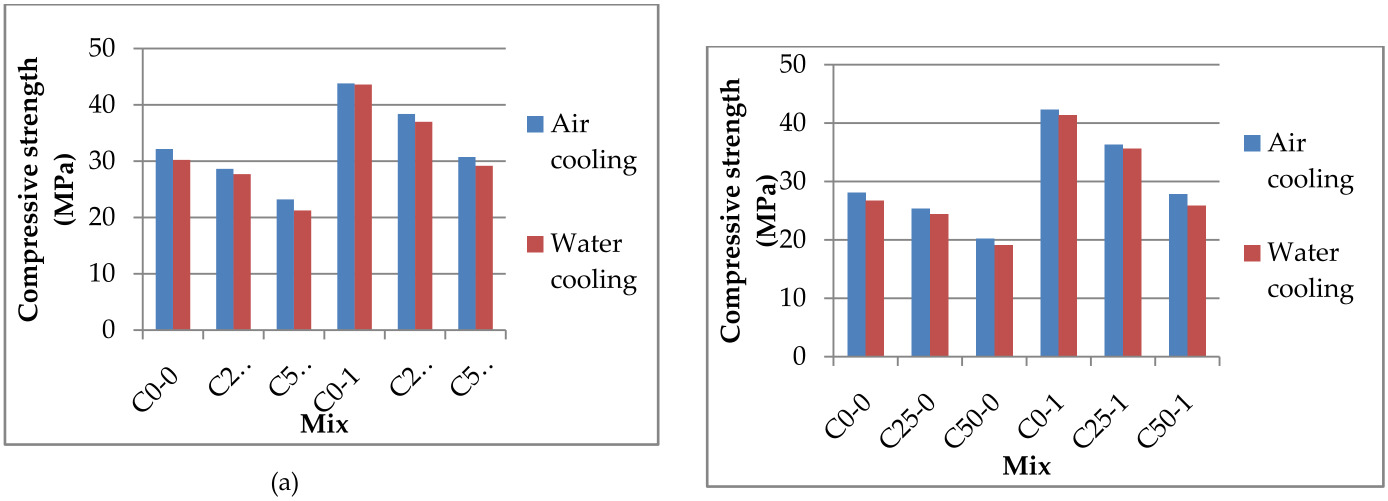


Fig. 3 Variation in compressive strength with different percentages of CCTA



(a) (b)

Fig. 4 Variation of compressive strength of specimens with temperature
(a) Water cooling, (b) Air cooling



(a) (b)

Fig 5 Compressive strength of specimens at different cooling conditions
(a) 150°C, (b) 300°C

It is obvious in these figures that the strength of concrete is influenced by the cooling conditions. The strength of concrete cooled in air after being exposed to the effect of different mixture with 0, 25 and 50 % CCTA and 1 % GF is higher than that cooled in air. This may be due to the rapid immersing of specimens to water. The porous nature of CCTA may also contribute to the reduction in strength. The structure of the cement mortar gets loose because of the pore expansion owing to the vapourisation of absorbed water. During cooling the ionised-CaO decomposed from $Ca(OH)^2$ absorbs water and then becomes $Ca(OH)^2$ again, which results in the expansion of the concrete volume.

Compared to control specimen the strength reduction is lesser for CCTA and GF samples. GF samples showed more resistance to temperature than all other mixes. The decrease in strength reduction for CCTA and GF samples may be due to the reason that ceramic tiles and glass fibres are manufactured at higher temperatures i. e.. above 1200°C. Moreover the strength reduction is less for CCTA mixes than GF mixes. As the temperature is increased the strength of concrete specimens are decreased. Results shows that the reduction is more pronounced for specimens subjected to a temperature of 300°C in both cooling conditions.

6 CONCLUSIONS

- The main conclusions derived from this study may be summarized as follows:
- As the percentage of CCTA increases, workability decreases. Workability is also decreased when GF is added
- Strength properties decrease as percentage of CCTA increases. The percentage decrease for 25 and 50 % replacement are 6.56 % and 11.48 % respectively for compressive respectively. Strength of ceramic concrete decreases due to many reasons such as higher flakiness, improper bonding of the aggregate with cement paste due to porcelain surface and higher water absorption of the ceramic waste aggregate.
- High temperature exposure decreases the strength of concrete. More strength reduction was found for specimens subjected to 300°C
- The experimental result showed that the compressive strength of CCTA concrete had a downward trend and adding appropriate GF (1 %) into specimen could efficiently maintain the strength of concrete after high temperature exposure.
- Natural granite coarse aggregate in concrete can be replace with ceramic waste aggregate as its properties are well within the range of specifications.
- Air cooled specimen's shows higher strength than specimens subjected to water cooling.

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