A STUDY ON HEATING AND COOLING REGIMES OF CONCRETE SPECIMEN AT ELEVATED TEMPERATURE UNDER DIFFERENT DURATION OF EXPOSURE

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Abstract - *Concrete is basically a thermal resistant but concrete gives thermal resistant's only up to a certain temperature limit after which it starts losing its strength. In order to raise the performance of the thermally deteriorated concrete structure, impact of different factors on strength retention such as heating rate, exposure duration, and cooling rate is studied at an elevated temperature from200°C to 800°C at interval of 100°C for duration of ½ hr, 1 hr, 1½hr, 2 hrs, 3 hrs and 4 hrs at 3 different regimes. And it was observed that for all the regimes of heating and cooling concrete exposed to high temperature for larger duration experience higher deterioration. Compressive strength of concrete subjected to slow heating deteriorated more than the one subjected to fast heating. For exposure durations of ½hr, 1hr and 1½hr the strength deterioration with respect to elevated temperature follows the same trend for both the slow and fast heating rates. For higher exposure durations the concrete experiences severe deterioration for slower heating rate and higher exposure temperatures, since the presence of heat is for longer duration*

***Key Words*: Fast heating, Furnace cooling, Slow heating, Sudden cooling**

1. INTRODUCTION

Concrete is been a favorable building material because of its unique property of thermal resistance and high compressive strength, so it is mainly applied in civil engineering structures. Concrete is made of heterogeneous mixture consisting of cement paste and coarse and fine aggregates which could be poured in any form by mixing it in fluid state. The strength properties of concrete depend largely on the bond between paste of cement and the aggregates. There is thermal incompatibility between the two phases which promotes cracking when the concrete is heated. Cement paste hydrates at about 110°Celcius, then the decomposition of Ca $(OH)_2$ will be noticed above 300°Celcius. Above 600°C calcium silicate hydrates. The aggregates tends to expand due to the exposure of temperature. Concrete should have the ability to withstand elevated temperatures. Concrete used for structures such as commercial and domestic buildings, is not designated to withstand elevated temperatures. Moreover fire accidents takes place very rarely in such buildings. Designing the building as fire resistant is also uneconomical. So the study of concrete strength degradation after the concrete is exposed to elevated temperature is necessary to determine the damage that has occurred and also to plan the repair strategies in order to regain its strength. The factors determining the strength holding characteristics of concrete when subjected to increasing rate of temperatures depends on heating rate, exposure duration, and cooling rate. Extent of Impact of these factors on strength retention is studied at various elevated temperature range from 200° C to 800°C.

1.2 AIM

To evaluate the characteristics strength of thermally deteriorated concrete under different cooling regimes at elevated temperature and different duration of exposure

1.3 OBJECTIVE

1. To focus on study of compressive strength characteristic of the concrete exposed to elevated temperatures
2. To study the effect of cooling regimes on the concrete.
3. To determine the change in the exposed surface characteristics of the concrete.
4. To determine the weight lost due to elevated temperature.
5. To evaluate the effect of heating rate on strength retention characteristics of concrete exposed to elevated temperature (SH and FH).
6. To evaluate the effect of cooling ways on strength retention characteristics of concrete (comparison with R1 and R2).

2. MATERIAL TESTINGS

2.1 Cement

For the entire experimental work, a popular Ramco cement a commercial brand of Ordinary Portland cement (OPC) 43 grade is used.

Table 1:- Physical Tests on Cement

Sl. no	Test conducted	Results obtained	Requirements as per I.S	Remarks
1	Specific gravity	3.12	--	
2	Normal consistency	29%	--	
3	Setting times (min)	Initial 65	Not less than 30 min	Satisfies codal requirements
		Final 270	Not more than 600 min	
4	Fineness, m^2/kg	330	Not less than 300 m^2/kg	
5	Soundness, mm	Expansion : 2.50	Not more than 10 mm	

2.2 Fine aggregates

River sand obeying to zone III (I.S 383-1970 grading requirements) with specific gravity 2.65 is been used.

Table 2:- Tests conducted on fine aggregate

Sl.no	Property			According to
1	Specific gravity		2.65	IS: 2386 (Part III)-1963
2	Bulk density	Loose	1463kg/m^3	
		Compact	1661kg/m^3	
3	Moisture content		nilL	

2.3 Coarse aggregates

The physical tests were conducted to evaluate the properties of coarse aggregate

Table 3:- Tests conducted on coarse aggregate

Sl.no	Property			According to
1	Specific gravity		2.77	IS: 2386 (Part III)-1963
2	Bulk density	Loose	1360kg/m^3	
		Compact	1527kg/m^3	
3	Moisture content		nil	

2.4 Superplasticizer

CONPLAST SP 430 is liquid based on sulphonated naphthalene polymer in brown liquid instantly saturated in water. Specific gravity of 1.22 should can be used for the concrete

2.5 Water

Water is an important constituent of concrete as it actually supports for the chemical reaction with cement. Ordinary potable water available in the laboratory should be used both for mixing and curing of concrete.

3. MIX PROPORTION

Concrete Mix is prepared using Ordinary Portland Cement (OPC – 43 Grade), crushed granite aggregates (10 mm down and 20 mm down) and river sand. Mix design of concrete is based on the guidelines given in IS10262-1982. The mix proportion adopted for the present investigation is as shown in Table 4

Table 4:- Mix proportion

Water	Cement	Fine aggregate	Coarse aggregate	
0.45	1	1.198	2.923	
			30 % 10mm = 0.877	70% 20mm = 2.046

4. TEST PROCEDURE

Experimental procedures followed related to three phases of experimental investigation are detailed in the following section. Experiment procedures broadly involved exposure of cubes to elevated temperatures and cooling them. Various heating and cooling regimes studied are given in table 5. Later the visual observation, weight fluctuation and the residual strengths after cooling and also curing was found.

Table 5:- Heating and cooling regimes studied

Sl. No.	Heating	Cooling
Regime 1	Fast heating	Furnace cooling
Regime 2	Fast heating	Sudden cooling
Regime 3	Slow heating	Furnace cooling

4.1 Exposure to elevated temperature

Each of the concrete cubes were allowed to get exposed to heat from all six sides and to ensure that small pieces of tiles were placed below the specimen for flow of heat.. Temperature range studied is from 200°C to 800°C at an interval of 100°C. After the target temperature is reached the specimen are maintained at that temperature duration of ½ hour, 1 hour, 1½hr, 2 hours, 3 hours and 4 hours.

4.2 Cooling of heated concrete specimen

Cooling of the specimen is done in two ways i,e furnace cooling method and sudden cooling method. In furnace cooling method the furnace was switched off for certain duration of time and the specimen were kept in the furnace until the interior of the furnace reaches ambient temperature. In sudden cooling method the hot specimen is taken out from the furnace and suddenly immersed into the water till it reaches ambient temperature.

4.3 Weighing the specimen

The concrete specimen is weighed before and after exposure to elevated temperature to observe the variation in the loss of weight when the specimen is subjected to different elevated temperatures.

4.4 Compression strength test

After curing for 28 days compression strength determination test is conducted. After curing the cubes for the desired age it is taken out of the pool, wiping the surface of the cubes it is kept in the compression testing machine

5. RESULTS AND DISCUSSIONS

5.1 VISUAL OBSERVATIONS

5.1.1 Cracking

When the concrete is subjected to elevated temperature of 200^{0}C, 300^{0}C and 400^{0}C showed no visible cracking for all the three regimes. Concrete surface subjected to 500^{0}C exhibited fine cracks which was visible. Cracks were distributed in the surface of the cubes but noticed more on the edges. A web interconnected cracks were observed for all the specimen exposed to 700^{0}C and 800^{0}C. The crack patterns for each temperature exposure were similar for all the three regimes.

5.1.2 Spalling

In this experiment the concrete exposed to 200^{0}C to 500^{0}C did not produce any spalling, but only minor cracks were observed from 500^{0}C to 600^{0}C. From 700^{0}C to 800^{0}C outer edge of the concrete cube specimen started to spall off slightly.

5.1.3 Colour change

In this study below 300^{0}C, the concrete color did not change. The colour change in the surface of the concrete is observed when the specimen was exposed to 400^{0}C. As the temperature increased from 700^{0}C to 800^{0}C grey color is noticed.

5.2 EVALUATION OF WEIGHT LOSS

Specimen weights before and after exposure to higher temperatures were taken for weight loss evaluation. Average percentage loss in weight were determined of concrete for different temperatures of exposure.

Table 6:- Variation of average % loss in weight of concrete subjected to different elevated temperatures

Exposure Temperature(°C)	Average % loss in weight
ROOM	0
200	0.532
300	0.992
400	2.358
500	3.227
600	3.876
700	4.425
800	5.229

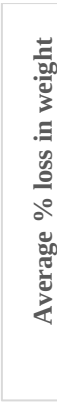

Chart:-1 Graph showing variation of average % loss in weight with elevated temperatures

5.2 STRENGTH OF THERMALLY DETERIORATED CONCRETE

5.2.1 Residual Strength of Concrete Subjected to Regime-1

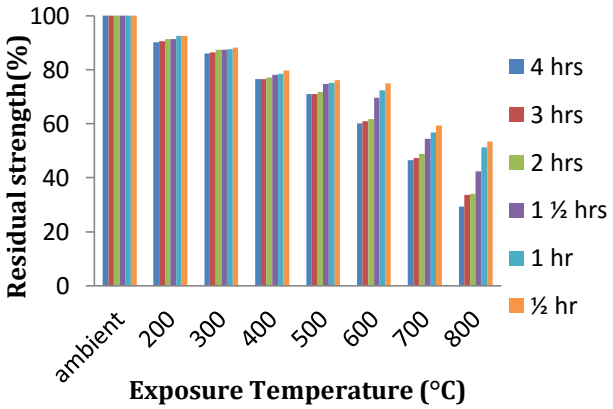

Chart:-2 Residual strength of concrete subjected to Regime-1

Regime 1 comprises of the least severe combination of heating and cooling rates. From chart 2 it can be seen that the residual strength decreases with the increase in exposure duration for each temperature studied. However the deterioration of concrete strength with

increase in exposure duration is marginal for temperatures up to 500°C.

Steep reduction in strength is observed between with the exposure durations of 1½hr to 2hr, which means that major deteriorating reactions in hardened cement paste occurs for exposure duration of 1½hr to 2hr and exposure temperatures of 500°C and above. Beyond for 3hr and 4hr effect exposure duration on strength retention is marginal for all exposure durations, which means that the deteriorating reactions have already taken place.

5.2.2 Residual Strength of Concrete Subjected to Regime-2

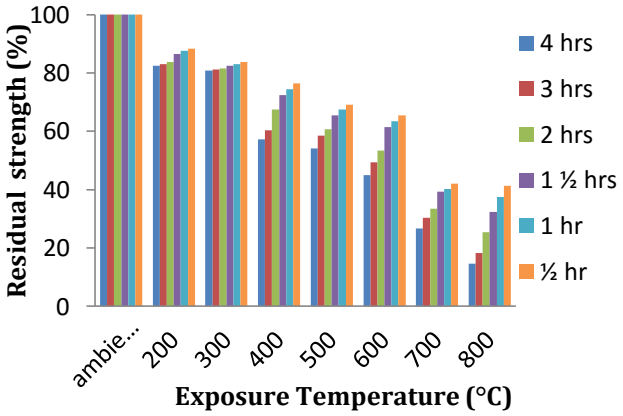

Chart 3:- Residual strength of concrete subjected to Regime-2

In regime 2 the concrete specimen after heating are subjected to sudden cooling, hence the concrete experiences higher deterioration in strength in the cooling phase. As seen in chart 3, the effect of exposure duration is very clearly visible for the temperatures of 400°C and above. For lower temperatures of 200°C and 300°C the strength retained is not found to be much affected by the duration. This means that sudden cooling created larger deterioration of strength for higher exposure duration.

5.2.3 Residual Strength of Concrete Subjected to Regime-3

Strength retained after subjecting the concrete to Regime-3 is represented in the chart 4. Concrete retained lower strength for all the exposure temperatures with increase in exposure duration.

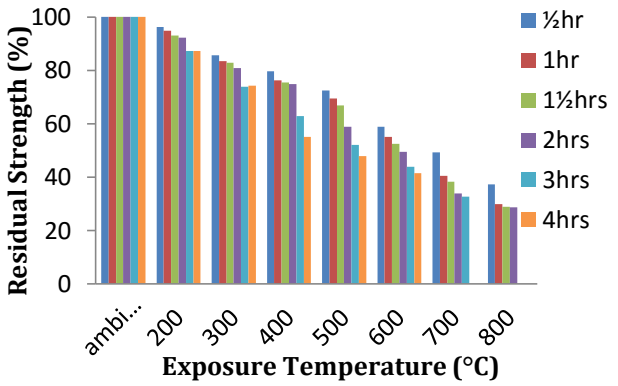

Chart 4:- Residual strength of concrete subjected Regime-3

Regime-3 shows considerable amount of higher deterioration of strength for higher exposure durations for all the temperatures studied. For each temperatures studied steep reduction in strength retained, is found when exposure duration is increased from 2hr to 3hr.

5.3 INFLUENCE OF HEATING RATE ON STRENGTH RETENTION CHARACTERISTICS OF CONCRETE EXPOSED TO ELEVATED TEMPERATURES

A comparative study of strength of concrete subjected to Regime 1 and Regime 3 is made in order to study the influence slow heating (SH) and fast heating (FH) on strength retention characteristics of thermally deteriorated concrete.

Chart 5 (a) and (b) less than 5% difference between SH and FH in retained strengths is obtained for concrete subjected to elevated temperatures up to 500°C. For higher exposure temperatures SH retains lower strength.

For the case of 1½hr retention time as shown in Chart 5(c), except for the exposure temperature of 200°C, for all other temperatures, SH retained lower strength as compared to FH.

From the chart 5(d), the concrete exposed to 200°C for 2hr retained about 92% of the unexposed strength for both the heating rates. For exposure temperatures of 300°C and 400°C FH retains about 6.5% and 2.1% higher residual strength than SH. For higher exposure temperatures of 500°C, 600°C and 700°C, SH retains lower strength as compared to FH. The difference between retained strengths after exposure to FH and SH reduced to about 5.4% for exposure temperature of 800°C.

From the chart 5(e). The difference increases with the increase in exposure temperature. Concrete specimen after exposure to 800°C, SH, had undergone severe damage and were not amenable for testing.

From the chart 5(f) for concrete exposed to elevated temperatures with two heating rates. For 200°C exposure, FH retains about 90% of strength at ambient conditions and SH retains about 3% lower strength i.e. about 87%. The difference between retained strengths for FH and SH increases with the increase in the exposure temperature up to 600°C.

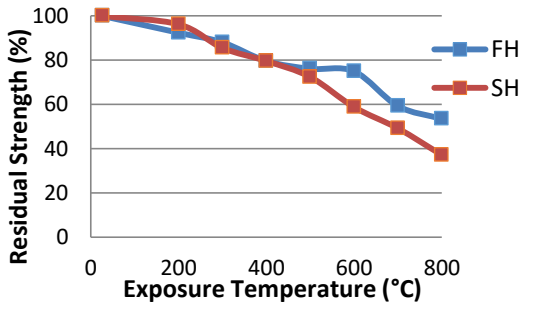

Chart 5(a)

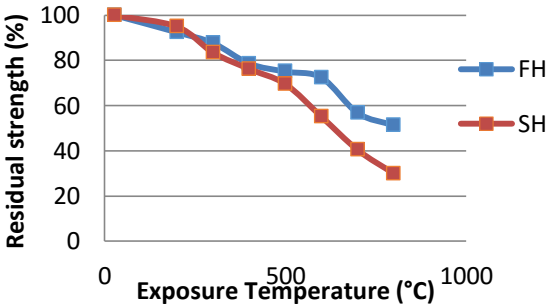

Chart 5(b)

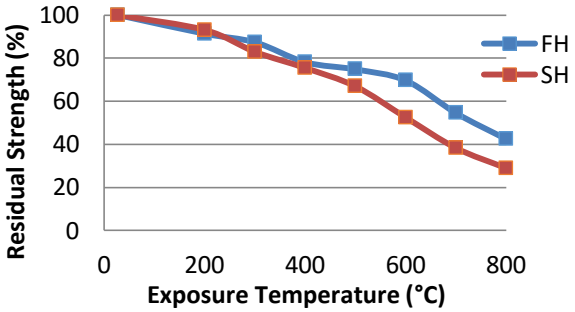

Chart 5(c)

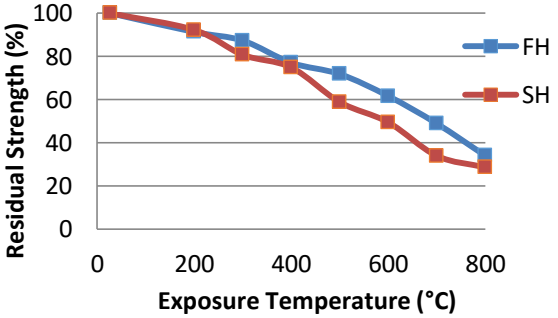

Chart 5(d)

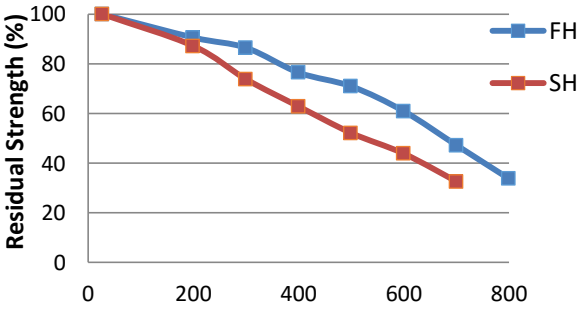

Chart 5(e)

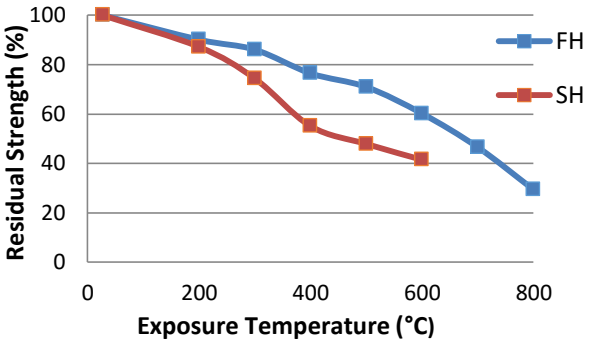

Chart 5(f)

Chart 5 (a)-(f) Strength deterioration of concrete subjected to elevated temperatures for six exposure durations

5.4 EFFECT OF COOLING METHOD ON STRENGTH RETENTION CHARACTERISTICS OF CONCRETE

Results of experiments carried out to quantify the extent of influence of sudden cooling and slow cooling at room temperature is reported in this section. The residual strengths of concrete subjected to Regime 1 and Regime 2 are compared.

At each temperature from 200°C to 800°C the strength loss due to sudden cooling is found to be higher than the strength loss due to furnace cooling. This is attributed to high temperature gradients that are developed due to quenching of heated specimens in water.

For the exposure temperature of 200°C to 500°C the residual strength is found not to be sensitive to the exposure duration for FC, however for exposure temperature of 600°C to 800°C the strength is found to deteriorate more for exposure duration of 2hr to 4hr and the residual strength is about 60% to 30% respectively of the ambient strength.

But for the case of sudden cooling the strength deteriorates with increase in exposure duration for temperatures above 400°C. The difference between residual strengths due to FC and SC increases with the exposure duration for all exposure temperatures.

Concrete exposed to lower temperatures of 200°C and 300°C, the difference in the retained strengths for FC and

SC, varies slightly with the exposure duration. The difference between SC and FC is found be lower for exposure duration of 2hr, 3hr and 4hr. The difference is largest for 700°C exposure for all the exposure durations.

6. CONCLUSIONS

1. Concrete colour changes from normal to brownish pink for 400°C exposure, to grey for 700°C to 800°C.
2. Concrete experienced cracking with increase in the exposure temperature irrespective of exposure duration and heating rate.
3. Concrete exposed to 700°C and 800°C suffered heavy cracking and spalling for both the heating rates and for all the exposure durations.
4. Weight gradually decreases as the concrete specimen is exposed to greater temperature exposures.
5. For all the heating and cooling regimes studied concrete exposed to high temperature for larger duration experience higher deterioration.
6. For exposure durations of ½hr, 1hr and 1½hr the strength deterioration with respect to elevated temperature follows the same trend for both the slow and fast heating rates. For higher exposure durations the concrete experiences severe deterioration for slower heating rate and higher exposure temperatures, since the presence of heat is for longer duration.
7. The effect of heating rate on strength retention is large for the concrete subjected to temperatures of 500°C.

7. SCOPE OF FUTURE WORK

1. Determination of strength loss can be done for different grades of concrete when exposed to different temperature or different duration or the combination of both.

2. Concrete can be exposed to real fire for different duration for the determination of residual strength.

3. Other characteristics of strength and durability of concrete after temperature exposure can be evaluated by different tests.

4. Tests can be carried out for concrete added with different admixtures.

5. Same test and analysis can be carried out for different types of concrete like Self compacting concrete, High performance concrete, Light weight concrete etc.

6. Temperature exposure can be studied for the duration in increments of 50^0 for detailed investigation.

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