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Effect of High Temperature on Compressive Strength of Concrete

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Abstract: *This work was carried out to assess the effect of high temperatures on compressive strength of concrete. Effect of fire on concrete is a relatively less explored area because of the lesser use of RCC structures in Europe/USA as compared to steel structures. Ninety concrete cubes of 150 mm size, divided equally over three different grades of design mix concrete viz. M: 30, M: 25 & M: 20 were cast. After 28 days' curing & 24 hours' air drying, the cubes were subjected to different temperatures in the range of 200°C to 800°C, for two different exposure times viz. 1 hour & 2 hours in an electric furnace. The heated cubes were cooled at room temperature for 24 hours & then subjected to cube compressive strength test. Results revealed fairly robust performance up to 500°C, with strength coming down only slightly. Up to this stage, the fire affected structural members remain serviceable although the factor of safety would come down. Affected structure/ structural members would require minor repairs & patchwork to recuperate. At or @ 650°C, the fall in concrete strength would be a cause for concern. Major retrofitting might be required. At or beyond 650°C, concrete stood completely decimated.*
***Keywords**: RCC, Fire, Compressive Strength of concrete*

I. Introduction

Fire is an emergency, from which no structure, howsoever well-built, is immune. With the increased incidents of major fires in buildings; assessment, repairs and rehabilitation of fire damaged structures has become a topic of interest. RCC in relation to fire is relatively less explored because of the lesser use of RCC structures in Europe/USA as compared to steel structures. There is an urgent need to collect more data & lay more emphasis on design oriented "Passive measures" rather than just relying on fire fighting measures known as "Active measures". Whereas, the earthquakes in India during last couple of decades have resulted in a lot of awareness & concern amongst individuals, media & authorities, the same can't be said about fire. Ignorance on part of the consultants & civic authorities has resulted in structures that are sub-standard from fire resistance view point. There is an urgent need to gather additional information about performance of R.C.C. under fire in order to create a general awareness & improve the existing practices & Code provisions.

This work provides an insight in to the strength of concrete at high temperatures. The research involved casting 90 concrete cubes of 150 mm size, divided equally over three different grades of design mix concrete viz. M: 30, M: 25 & M: 20. After 28 days' curing & 24 hours' air drying, the cubes were subjected to different temperatures in the range of 200°C to 800°C, for two different exposure times viz. 1 hour & 2 hours in an electric furnace. The heated cubes were cooled at room temperature for 24 hours & then subjected to cube compressive strength test. Results add to the available database & provide useful information about the performance of concrete made by using the aggregates available in this part of the world, during calamities like fire.

II. Previous Research

Khoury Gabriel A. et al. [1] did research work on effect of elevated temperatures on concrete. As per them, basic creep studies at constant temperatures indicated a marked increase in creep above 550–600°C for cement paste and lightweight concrete which suggested that the structural, though not necessarily the refractory, usefulness of Portland cement-based concretes in general would be limited to temperatures below 550–600°C.

Chakrabarti S. C. et al. [2] conducted an extensive test program for assessing the residual strength of concrete after fire. The authors proclaimed that the concrete actually gained some strength between 100 to 300°C in the presence of siliceous & carbonaceous aggregates. Some other researchers too have reported this phenomenon which has more detractors than supporters. As per the authors, concrete didn't lose much of its strength up to 500°C & in fact regained 90% of lost strength up to this temperature after about a year. The theory of fire affected concrete regaining some of its strength with time is not an established one. Concrete cubes heated beyond 800°C for 4 hours started crumbling after 2-3 days.

Phan Long T. et al. [3] performed experiments on high-strength concrete (HSC) and normal strength concrete (NSC) at elevated temperature in order to study the phenomenon of explosive spalling associated with HSC & suggest further research needs. The differences were found to be most pronounced in the temperature range of 200°C to 400°C.

High strength concrete is a material often used in the construction of high rise buildings. Ravindrarajah R. [4] et al. summarized and discussed the degradation of the strengths and stiffness of high-strength concrete in relation to the binder material type. The results showed that the binder material type had a significant influence on the performance of high-strength concrete particularly at temperatures below 800°C. The influence of the binder material type was significantly decreased at temperature of 1000°C. The strengths and stiffness of high-strength concrete were reduced with the increase in temperature without any threshold temperature level.

III. Experimental Work

An electric furnace was used to heat the specimens. The maximum attainable temperature in this furnace was 1000°C. The inner depth of the furnace was 1000mm. Initially the furnace was heated to the required temperature and when the required temperature was attained the specimens were put inside with the door closing tightly so that no air could enter. Each time 3 cubes were kept at various temperatures and the same procedure was repeated for 1 & 2 hours time duration. After the specified time duration, the cubes were taken out & air cooled at room temperature for 24 hours.

The moulds were of 150 mm size conforming to IS: 10086-1982 [6]. In assembling the mould for use, the joints between the sections of mould were thinly coated with oil and a similar coating of oil was applied between the contact surfaces at the bottom of the mould and the base plate in order to ensure zero leakage during the filling. The interior surfaces of the steel moulds were thinly coated with oil to prevent adhesion of concrete.


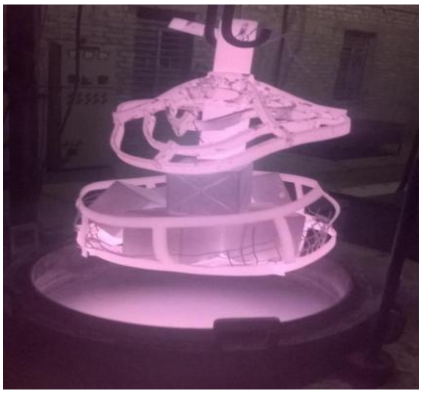

Figure 1. Electric Furnace **Figure 2**. Hot Cubes Being Taken Out Of Furnace

The specimens for testing were concrete cubes. Thirty concrete cubes of size 150mm were cast for each grade of concrete. Three different grades of design mix concrete, M: 30, M: 25 & M: 20 were used. Mix design was carried out using the Ambuja method of design, a popular mix design method in India suggested by the Swiss cement manufacturing giant, Holcim Ltd. Cement & aggregates from the same batch were used for all the specimens.

Cement used was Birla OPC conforming to IS 8112-1989 [7]. Manufacture's certificate was obtained for the batch. Fine aggregates consisted of natural river sand conforming to Zone II of IS 383-1970 [8]. The coarse aggregates consisted of crushed hard blue granite passing through 20 mm sieve & retained on 4.75mm sieve. Potable water was used.

Table 1: Cube casting schedule

SR. NO	Grade & Proportion	Date of Casting Cubes	Notation	Curing Period In Days	Type Of Cement	No. of Cubes
1	M 30 (1: 2.03: 2.63)	22-02-2014	F1 - F30	28	Birla 53 Grade OPC	30
2	M 25 (1: 2.29: 2.97)	23-02-2014	F31 - F60	28	Birla 53 Grade OPC	30
3	M 20 (1:2.57 :3.32)	24-02-2014	F61 - F90	28	Birla 53 Grade OPC	30

All the cubes (90 in all) were cured in a curing tank for 28 days & then tested on the 30th day. Nine specimens (3 of each concrete grade) were tested for compressive strength at room temperature, and the results were tabulated. Nine specimens each (3 of each concrete grade) were heated in the electrical furnace at 350°C for 1 hour and 2 hour respectively without any disturbance. Same procedure was repeated for 9 specimens each at 500°C, 650°C and 800°C. However, at 200°C the cubes were heated for 2 hours only, as only 30 cubes were cast for each grade. After heating, specimens were kept aside for normal cooling at atmospheric temperature for 24 hours.

Figure 3: Casting of Cubes

Figure 4: Cube compression test

After air cooling, the cubes were subjected to compressive strength test on a cube testing machine as per IS: 516 – 1959 (Reaffirmed 1999) [9].

IV. Scrutiny Of Results

Table 2 below depicts the compression test results obtained for M: 30 grade of concrete. For the sake of brevity, the tables for M: 25 & M: 20 Grade concrete are omitted. Fig. 5 & Fig. 6 below are graphical manifestation of the same results. A careful glance at these plots shows persistent fall in compressive strength of concrete at elevated temperatures. Along with the compressive strength, change in appearance & colour was also noted down.

A careful study of these tables & graphs would reveal that, up to 350°C, the fall in compressive strength was negligible at less than 10%. At 500°C, the values of cube compressive strength became conscious of exposure time. For one hour exposure time, the fall remained negligible at @ 10% but almost doubled to @ 20 % for two hour’s exposure time. Still, it is clear that up to 500°C, only factor of safety will come down but the structure/member will remain serviceable. Beyond this, the fall in cube compressive strength became louder & louder. The percentage fall at 650°C was between 30-40 %. Concrete strength became low & unacceptable. The percentage fall at 800°C was @ 50 % for one hour exposure time & more than 60% for two hours exposure time. A higher exposure time, resulted in an inferior response across all grades, especially so at higher temperatures. Higher concrete grades gave seemingly higher strengths in absolute terms. But the percentage fall remained identical across all concrete grades.

Visual inspection of the heated samples revealed minor cracking up to 500°C but pronounced cracking beyond that. At 800°C, concrete looked in bad shape. Colour changes after heating were also studied. Normal grey colour of cement was maintained up to 200°C & even at 350°C. But at 350°C, brownish patches developed. At 500°C, the grey shade became darker but at 650°C, it became whitish grey. At 800°C, the colour got changed to buff (yellowish brown).

Table 2: Compressive strength of concrete grade M: 30

No.	Temperature (°C)	Heating Time (Hrs.)	Failure Load (N)	f_{ck} (N/mm²)	Average	Average Fall (%)
1	30	0	830000.00	36.89	40.89	0
2	30	0	880000.00	39.11		
3	30	0	1050000.00	46.67		
4	200	2	750000.00	33.33	37.33	8.70
5	200	2	870000.00	38.67		
6	200	2	900000.00	40		
7	350	1	880000.00	39.11	37.48	8.34
8	350	1	780000	34.67		
9	350	1	870000	38.67		
10	350	2	860000	38.22	36.44	10.88
11	350	2	710000.00	31.56		
12	350	2	890000.00	39.55		

13	500	1	760000	33.78	36.45	10.85
14	500	1	870000.00	38.67		
15	500	1	830000.00	36.89		
16	500	2	730000	32.44	30.51	19.24
17	500	2	630000	28		
18	500	2	700000	31.11		
19	650	1	680000	30.22	28	31.52
20	650	1	610000	27.11		
21	650	1	600000	26.66		
22	650	2	680000	30.22	25.63	37.31
23	650	2	570000	25.33		
24	650	2	480000	21.33		
25	800	1	420000.00	18.67	20.45	49.98
26	800	1	450000.00	20		
27	800	1	510000.00	22.67		
28	800	2	300000.00	13.33	15.11	63.04
29	800	2	340000.00	15.11		
30	800	2	380000.00	16.89		

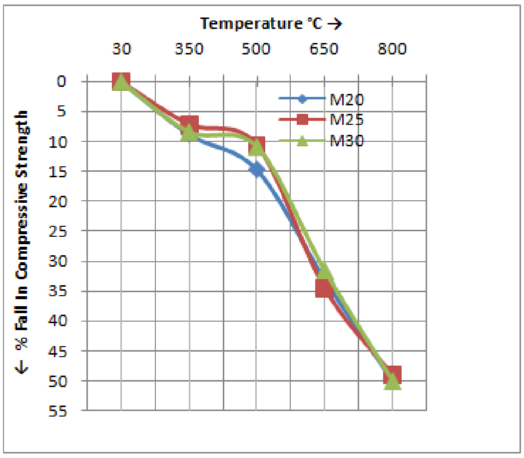

Figure 5: % Fall in compressive strength after 1 hour

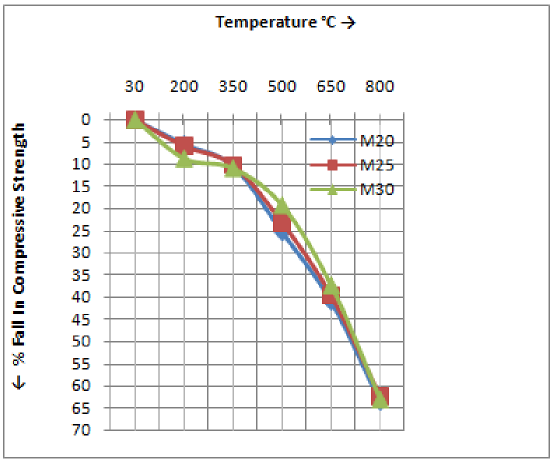

Figure 6: % Fall in compressive strength after 2 hours

V. Conclusion

Based on the results & their scrutiny, the following conclusions could be drawn:

1. Up to 350°C, concrete remains almost unaffected in appearance & strength.
2. At 500°C, quality of concrete suffers slightly & strength too comes down. Structure/ structural members remain serviceable although the factor of safety comes down. Affected structure/ structural members will require minor repairs & patchwork to recuperate.
3. At or @ 650°C, the fall in concrete quality & strength becomes a cause for concern. Major retrofitting might be required.
4. Beyond 650°C, concrete stands decimated on all accounts. Affected members/portion will require replacement.
5. Higher exposure time results in greater damage. This calls for active measures to limit exposure time.
6. Within the ambit of NSC (Normal strength concrete), higher grade concrete performs better in absolute terms.

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