PERFORMANCE OF CONCRETE AT ELEVATED TEMPERATURES

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Abstract: Fire accidents are common in buildings due to several reasons and also Aircraft pavements are also exposed to high temperatures during takeoff and landing of Aircrafts and also, they are exposed to high temperatures during summer. Hence it is necessary to know the behaviour of concrete at elevated temperatures. This study presents the experimental results of the effect of temperature on the strength in compression of M45 grade concrete. A total of 42 cubes were cast, with mix proportions of 1:1.69: 2.626 cement: fine aggregate: coarse aggregate and 0.43 as water cement ratio for these investigations. The specimens are removed from moulds kept for curing in water for age of 7 and 28 days. At desired age, the specimens are removed from curing tank and exposed to various temperatures for 1 hour duration and tested in compression at room and elevated temperatures of 27, 50 to 300°C at intervals of 50°C. The results have revealed that the strength has been increased with in increase in temperature up to 250°C and decreased at 300°C.

Keywords: Temperature, fly ash, compressive strength, moisture loss.

1.0 Introduction:

In general, the temperature of concrete structures subjected to room temperature, the value of which is about 27°C during construction and their service life. The present codes of construction and design provides the safety of these structures at room temperature. The method for development of urbanization, construction rate and hazards related to it has been elevated; one such main source is fire accident in buildings. Structure can experience fire accident, but because of which, the structure cannot be deprived off or abandoned. It becomes a challenge for the civil engineering community to make a structure functionally viable after the damage due to fire accident.

Sometimes the temperature may enormously rise or fluctuate, particularly during summer, and hence, the strength of concrete is affected significantly. Hence it is necessary for engineers to find the strength of concrete in compression at high temperatures for knowing...
the behaviour of structures at elevated temperatures for application in research. Though empirical approaches of providing minimum cover to concrete due concern of the resistance to fire has been the norm, a more sensible approach to be identified from arithmetical proof. Hence the investigators have exposed the concrete cube specimens to different temperatures of above room temperature and the behaviour in compression at different ages of concrete was observed. This paper presents the test results of experimental investigations of concrete residual compressive strength; after exposed to different ranges of temperature from 100°C to 300°C at interval of 50°C and also, the loss of moisture of the concrete cubes was studied. However based on the availability of equipment, this study is limited to temperature range up to 300°C and the M45 grade of concrete is considered as the lower grades of M25 and M30 have been investigated by the previous investigators and the age of specimens for curing is taken at 7 and 28 days.

2.0 Literature Review

The studies of researchers on the effect of rise in temperature on with and without partly replaced concrete were reviewed in this literature study; some of the most relevant ones are presented below.

Morsy et al. [11] have investigated, effect of rise in temperature on strength properties, phase composition and microstructure of silica fume concrete by using blended cement; consisting of OPC and silica fume. The cement was partly replaced by 0 to 20% of silica fume at intervals of 5 with a water/binder ratio of 0.5. After 24 hours of cast the specimens are demoulded and were cured initially for 24 hours at 100% relative moisture and then cured in water for 28 days. Then the specimens were exposed to temperatures of 100, 200, 400, 600 and 800°C for 2 hours. The specimens tested for compression, indirect tension, phase composition and microstructure of silica fume concrete and the results were compared with those of the controlled concrete specimens without silica fume (OPC). They have concluded that addition of silica fume to OPC will improve the strength of concrete with blended cement at high temperatures.

Abhinandan R. Gupta [1] has studied the performance of concrete in compression for which he cast the cubes of M20 grade concrete with water/cement ratio of 0.5; at age of 28 days and tested by exposing the specimens different temperatures ranging from room temperature to 600°C for 1 h duration. It was reported that the strength obtained at room temperature i.e. 34°C was 18.81 N/mm², whereas at for the specimens exposed to 150°C the compressive strength rised up to 20.57 KN/m². However, at 300 °C the compressive strength was reduced to 16.51 N/mm². With further rise in temperature up to 450°C, the strength of concrete rised
to the value 18.66 kN/m². At 600°C the specimens were broken, resulting in fewer bonds. Cracks with white spots were observed and resulting in reduced compressive strength of 15.16 N/m². Hence it can be seen that at 150 °C the strength increases by 9.03% and at 300°C it got reduced to 12.23%. Further it was observed that at 450°C the strength was reduced by 0.80% and at 600°C the concrete got fully broken.

Hassan [3] studied the influence of temperature on bond strength of - carbon fibered reinforced concrete, casting 54 pullout cube specimens with reinforcing steel bars and tested. The total specimens were made in to three groups to study the influence on bond strength and bond strength - slip response by adding various quantities of discrete carbon fibre of 0.0, 0.75 and 1.0% by weight of cement and exposing to room temperature and a range of temperatures of 150, 250, 350,450 and 550°C. Along with specimens with pull-out; 9 cubes of the same size and pull-out (3 cubes from each set of concrete mix) were also tested in compression. It was reported from the test results; that the percentage of residual bond strength for the concrete with 0.75% carbon fibre reinforcement by weight of cement (28%) is inferior to basic concrete and the concrete with 1.0% carbon fibre reinforcement; which are the same (32%) for the concrete with 0.75% carbon fibre reinforcement by weight of cement (28%) and at 550 °C.

Khan et al. [10] studied the influence of high temperature on compressive strength of high-volume fly ash concrete, by casting cubes of 100 mm replacing cement by fly ash in the range of 40-60% by mass of cement. The cubes after 28 days of curing are subjected to various temperatures between 100-900°C and tested under compression. It was found that the compressive strength of concrete improved first with rise in temperature up to 300°C, and further rise in temperature, the compressive strength was reduced. It was also noticed that the weight loss was increased with an rise in temperature. No formation of cracks was observed up to 500°C and micro cracks appeared at 600°C. The specimens of lower fly ash (40%) disintegrate at 800°C, while cubes with 50 and 60% fly ash content disintegrated at 900°C. Further it was reported that crack formation at 600°C and chemical changes occurs at temperatures above 600°C. It was also reported that the specimens with different water/cement ratios and same fly ash (50%). The reduction in compressive strength with rise in temperature was more for the specimen with low water/binder ratio than that of the specimens with higher water/ binder ratio [17].

Nwankwo and Achenu [12] investigated the compressive behaviour of concrete in compression of four types of concrete cubes of 150mm; consisting: (1) Control concrete with OPC of 1:2:4 mix proportions , (2) Concrete cubes of same proportions with 3% volume
fraction of sisal fibre of length 40mm. (3) Concrete containing OPC, fly ash and CWCCB with the same fine aggregate, coarse aggregate and sisal fibre, at ratios of 50, 30 and 20% of total binding material respectively. (4) Ternary mix of OPC, fly ash and CWCCB using the fine, coarse aggregates of same proportions and with sisal fibre content, with 0.6 water/c ratio for all mixes, at ratios of 50, 30 and 20% of total cementitious material respectively. The specimens can dry and exposed to high temperatures of 100, 150, 200, 300, 400 and 600°C for 2 hours. It was reported that, in range of temperatures of 100°C to 600°C, the ternary concrete with 30% fly ash and CWCCB of 20% exhibited better thermal constancy; but the compressive strength was decreased by about 24% at temperature of 600°C compared to all the other specimens. It was concluded that the ternary concrete with 20% CWCCB and 30% fly ash is suggested for structural elements for thermal stability.

Venkateswara Rao, A and Srinivasa Rao, K. [15] studied the compressive strength of M30 grade of concrete replacing cement with 0, 30, 40 and 50% of fly ash, by casting 100mm cube specimens after curing for 28 days and exposed the specimens to various temperatures of 27, 100 to 500°C at intervals 100°C for 1h and 3h durations. The percentage loss of weight is also assessed by measuring the weight before and after exposure to the desired temperature and the loss of weight was assessed. It was reported that the compressive strength was improved up to 300°C beyond which, the compressive strength was decreased, and no visible cracks was observed up to 500°C. The workability and percentage weight loss and workability were increased with rise in temperature, duration of exposure and with rise in fly ash content.

Venkateswara Rao, A. and Srinivasa Rao, K. [16] have studied the compressive strength of M60 grade of concrete with fly ash of 0, 30, 40 and 50% at an age of 7, 28, 56 and 91 days exposing the specimens for 1h and 3h durations at various temperatures of 27, 100 to 500°C at intervals 100°C. The percentage loss of weight is also assessed. It was observed that the compressive strength and split tensile strength increase up to 300°C beyond which the compressive strength and split tensile strength were decreased and also reported that change of colour was observed at above 400°C, no visible cracks were observed up to 500°C. The workability, percentage weight loss was increased with rise in temperature, duration of exposure and with increase of fly ash content.

3.0 Experimental Program
3.1 Proportions for the mix.

The present experimental investigation involves casting of 100 mm cubes with mix proportions of 1:1.69: 2.626 (Cement: Fine Aggregate: Coarse aggregate) at 0.42 w/c ratio,
obtained from guidelines of IS: 10262-2009[4], IS: 456-2000[5] and after testing several trial mixes. Ordinary Portland cement of 53 grade, meeting the requirements of IS: 12269[6], fine aggregate meeting the requirements to zone-II, coarse aggregate conform to IS: 383[7] code provisions, super plasticizer SP 430 DIS were used for the present study and the compliance of workability for the mix was checked by the slump test.

### 3.2 Method of exposure and testing:
Cubes of 100 mm are cast and exposed to different temperatures to study the behaviour of different concrete mixes at high temperatures. The cubes are demoulded after lapse of 24 hours of casting and kept in clean water in a curing tank. After the desired period completed (7 or 28 days) of curing, the cubes are taken out from water and dried naturally at room temperature before keeping them for heating to the specified temperature and duration. Three cubes are tested for each parameter, average of the three values is considered as its strength in compression. Weights of cubes are measured before and after heating with digital balance and the values are recorded. Oven of maximum working temperature of 300°C is used to heat the specimens. While placing the cubes in oven, the temperature inside the oven is at room temperature. The temperature of oven was set to the desired temperature. After reaching the specified temperature, it is maintained stable throughout the exposed duration of 1h then the cubes are allowed to cool to room temperature by air cooling and after its weight is measured tested in 200 kN compression testing machine as per stipulations of IS 516-1959[8]. Fig. 1 shows cube specimens during casting and testing.

![Cube specimens during casting and testing](image-url)
4. Results and discussions:

The data obtained from the test results at age of 7 days and 28 days are presented in the Table 1 and Table 2 respectively. The variation compressive strength and weight of specimen with temperature at 7 and 28 days for M45 grade is represented graphically in Fig. 2 and Fig.3 respectively. The test results of the percentage weight loss and the compressive strength at age of 7 days and 28 days are shown in Table1 and Table 2 respectively. The specimen identification is given as first S refers to Specimen, R - room temperature, second, T1 - T6 is temperatures 50 -300, last number 1- age of 7 days and 2- age of 28 days. The Test results of the study are shown in table 1 at age of 7 days and in Table 2 at age of 28 days. The variations of loss of weight and the variation of compressive strength of concrete at different temperatures are presented graphically in Fig. 3 and Fig. 4 respectively. The weight loss increased as the temperature rise starting from 50°C at interval of 50°C up to 300°C. The weight loss was increased from 0.43 at 50°C to 4.67% at 300°C, compared to the control mix (at room temperature of 27°C), no loss in weight is observed, at age of 28 days, but for 7 days the loss of weight changed from 0.41 at 50°C to 5.02% at 300°C.

But at the at 7 days, for the same temperature, the increase of compressive strength was 13.8% at 200°C compared to that of at room temperature, beyond 200 °C it was decreased and at 300°C it decreased to 4.2% and at age of 28 days the increase at 200°C was 12.5 % compared to that at room temperature and beyond which it was decreased and the increase at 300°C was 2.4%. The results at age of 7 and 28 days are tabulated in detail and are shown in Tables 1 and 2 respectively.

Table 1: Effect of temperature on Percentage loss of weight and compressive strength at age of 7 days

| Sl. No | Specimen Identification | Temp. °C | Weight of specimen | Average % loss of weight | Density of specimen | Average density of specimen | Compressive strength Before heating | After heating | Individul | Average |
|--------|-------------------------|----------|--------------------|-------------------------|---------------------|-----------------------------|------------------------------------|--------------|-----------|---------|
| 1      | SRT 1                   | 27       | 8.581              | 8.581                   | 2559.56             |                             | 36                                 |              |           |         |
|        |                         |          | 8.604              | 8.604                   | 2566.37             |                             | 34.9                               | 35.5         |           |         |
|        |                         |          | 8.591              | 8.591                   | 2562.52             |                             | 35.6                               |              |           |         |
|        |                         |          | 8.591              | 8.55                    | 2549.4              |                             | 36.8                               |              |           |         |
| 2      | ST1 1                   | 50       | 8.598              | 8.565                   | 2553.5              |                             | 36.3                               | 36.5         |           |         |
|        |                         |          | 8.590              | 8.557                   | 2551.5              |                             | 36.5                               |              |           |         |
| Sl.No | Specimen Identification | Temperature, °C | Weight of specimen Before heating | Weight of specimen After heating | Average percentage weight loss | Density of specimen Before heating | Density of specimen After heating | Compressive strength Before heating | Compressive strength After heating | Compressive strength Average |
|-------|---------------------------|-----------------|-----------------------------------|-------------------------------|-------------------------------|-----------------------------------|-----------------------------------|-----------------------------|-------------------------------|-----------------------------|
| 1     | ST1 2                     | 27              | 8.602                             | 8.596                         | 0.63                          | 2540.59                           | 2540.59                           | 37.6                        | 37.6                          | 37.7                        |
| 2     | ST2 2                     | 50              | 8.592                             | 8.551                         | 0.63                          | 2540.59                           | 2540.59                           | 37.6                        | 37.6                          | 37.6                        |
| 3     | ST3 2                     | 100             | 8.599                             | 8.542                         | 0.63                          | 2540.59                           | 2514.52                           | 40                          | 40                            | 40                          |
| 4     | ST4 2                     | 150             | 8.601                             | 8.458                         | 1.69                          | 2523.11                           | 2519.75                           | 38.5                        | 38.4                          | 38.5                        |
| 5     | ST5 2                     | 200             | 8.596                             | 8.453                         | 1.69                          | 2521.63                           | 2506.52                           | 38.5                        | 38.5                          | 38.5                        |
| 6     | ST6 2                     | 250             | 8.591                             | 8.402                         | 1.69                          | 2506.52                           | 2472.74                           | 38.5                        | 38.5                          | 38.5                        |

Table 2: Effect of temperature on Percentage loss of weight and compressive strength at age of 28 days
Fig. 2: Deviation of loss of weight with temperature at different ages of 7 and 28 days
Reason for the variation of the presented results might be due to the fast loss of humidity that prevents prolonged hydration process leading to the improved strength. The other probable reason for the strength loss is the damage of vigorous strength generating ingredients such as the cement and aggregates. Another cause postulated for the results found in this study is that the rapid change in temperature causes the fast change in stress-strain relation by that of lesser temperatures. Elastic modulus and strength in compression decreased with improved warp of the material of concrete. The effect of spalling and cracking are accelerated, hence falling of the concrete strength at elevated temperature.

5. Conclusions

1. With rise of temperature the compressive strength of concrete reduced because fast lack of moisture in the Calcium hydroxide presented in the cement and generate additional water vapor thus leads to rise in strength.

2. The loss of humidity due to increase of temperature reduces the weight of the specimen with increase of temperature. The necessity of the present study is to collect statistical data for M45 grade concrete; which does not provide from the earlier works to design structural members.

3. The suggested design for 28 days for M45 grade concrete investigated strength reduction at 27°C is of 53.47% and reduction of weight is of 4.67% are significant.
4. From the observations, it is the fact that further exploration is needed to recognize the behaviour of concrete at high temperatures to steer suitable design services are needed for structural applications in areas, like nuclear reactor vessels and buildings subjected to fire accidents and pavements of Aircrafts etc where the structural elements are exposed to high temperatures.

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