ASSESSMENT OF RESIDUAL STRENGTH OF NORMAL CONCRETE AT ELEVATED TEMPERATURES AFTER HOT AND NORMAL WATER QUENCHING

Deepak N Nathe[1], Yogesh D Patil[1]

1. SVNIT, Surat, India

ABSTRACT. Nowadays concrete is a familiar material in nuclear plants, testing units of jets, bunkers, silos, etc. where it subjected to elevated temperatures. In this study, the effect of high temperature on the residual compressive strength of concrete considering the temperatures of 100^0C, 200^0C, 400^0C, 600^0C, and 800^0C for two hours of exposure has studied. Specimens subjected to regular water and hot water quenching for one hour after exposing to these temperatures. The changes in the properties like compressive strength, color change, mass loss after exposure, and microstructure by SEM images have studied. Reduction in residual compressive strength of concrete observed beyond 100^0C up to further increase in temperature to 800^0C. Residual strength after hot water quenching was 3-4% greater than that of after normal water quenching. No color change has been found up to 400^0C. However, it changes to light pink for further increase in temperatures. Mass loss in concrete substantially increases with the rise in temperatures. From SEM images it was observed that pore size in cement paste increases and CSH degrades with an increase in temperatures, that may be the reason for the decrement of residual strength.

Keywords: elevated temperatures; residual strength; water quenching, microstructure, mass loss

Mr Deepak N Nathe is a Research Scholar in Applied Mechanics Department, SVNIT, Surat, India. His research interest includes the performance of concrete at elevated temperatures.
Telephone with Country Code: +919765392989 Email Id:deepaknathe@gmail.com

Dr Yogesh D Patil, Assistant Professor in Applied Mechanics Department, SVNIT, Surat, India. His research area includes steel structures, utilization of waste materials in concrete, performance assessment of concrete structures.
Telephone with Country Code: +919998846518 Email Id:chipatil@yahoo.com

INTRODUCTION

Concrete is a most used material in the construction industry due to versatility, ease of construction and its durable properties. The infrastructure need of the world is growing tremendously, to meet this demand for material increasing enormously. The new advancement in concrete allows it for particular applications like aircraft engine test cells, turbojet runways, nuclear reactor vessels, and missile launching pads, which have to endure higher temperatures. Elevated temperatures also encountered in standard structures in cases of accidents like fire.

The actual behavior of the concrete exposed to high temperatures depends on many environmental factors such as the properties of materials building up the concrete, heating rate, maximum temperature at which it revealed to and the period of this exposure, cooling method after maximum temperature and loading level at the time of cooling. Concrete generally provides adequate fire resistance for most applications. However, the strength and durability properties of concrete are significantly affected when subjected to elevated temperatures due to chemical and physical changes.[1]

At present, a significant number of Research and Development works dealing with the concrete subjected to high temperatures are available in the literature. From the previous research, the effect of temperature on the concrete regarding exposure time, the rate of heating, mechanical properties, morphology and reviews related to this study examined.

From the literature, it found that the factors that can influence the strength of concrete at elevated temperatures. Some of the critical factors that affect concrete performance are water binder ratio, aggregate type, the age of specimens, the rate of heating and duration of heat, loading during temperature exposure, cooling of samples, cement blend, moisture content.

In addition to the above, experiments have shown that the method of testing, duration of heating, size and shape and the loaded condition, size, and shape of aggregate have a significant effect on the change of strength with temperature.

NEED FOR THE PRESENT STUDY

Structural properties of concrete changes after exposure to elevated temperatures. These observations are based on a literature review concerning time-temperature curves. The question of whether to retain or demolish the structure after it has been subjected to high temperatures will be based on an assessment of structural properties, in addition to economic considerations. In the normal circumstances during the accidental fire, the structure will be subjected to very high temperature for a short duration. The laboratory studies based on the standard time-temperature curves approximately simulate conditions of fire. However, when the temperature is sustained for an extended period as narrated in the introduction, the reliable research results on the effect of sustained elevated temperature on concrete is limited and warrants a detailed study. Examination of structures after it has been subjected to continuous high heat show extensive cracking, spalling, excessive bending deformation especially in flexural members such as beams and slabs and column. These clearly indicate that there is a change in structural properties. The behavior of structural members may differ from the original after the exposure. The features of the concrete after it has been subjected to sustained elevated temperature have to be adequately assessed so that the prediction of the behavior can be made scientifically. In the circumstances mentioned above, it was felt necessary to study the changes in the properties of concrete after it has been subjected to sustained elevated temperature.[2]

EXPERIMENTAL PROGRAM

Materials

Cement

Cement (OPC 53 grade) conforming to IS 269: 1976 and blended cement conforming to IS 1489: 1991 were used for casting the specimens.

Aggregates

Aggregates are the main components of the concrete which significantly influences the strength, density and other properties of the concrete. Different types of aggregates were used in this work.
Fine Aggregate: The fine aggregate used this study was locally supplied and confirmed to grading Zone-I as per IS: 383-1970.
Coarse Aggregate: Locally available coarse aggregate is having a maximum size of (10-20mm) used in this work.

Plasticizer

Emce Plast BV Plasticizers was used as directed by the manufacturer to improve the workability of the fresh concrete mix.

Water

Drinking water was used throughout the casting and curing of the concrete specimens.

Material Proportioning

Table 1 Mix proportions for concrete

CEMENT (kg/mm^3)	FINE AGGREGATES (SAND) (kg/mm^3)	COARSE AGGREGATE (20 mm)	COARSE AGGREGATE (10 mm)	WATER	ADMIXTURE
408	672	730	487	163	4
1	**1.64**	**1.78**	**1.19**	**0.4**	**0.01**

Experimental Methodology

Elevated temperature test

A PID controlled radiant electrical furnace was applied to heating specimens from ambient temperature (25^0C) to 200, 400, 600, and 800^0C respectively, at an average heating rate of 10 ^{0}C /min. According to the literature, the specimens were held at the target temperature for two h to ensure a uniform temperature throughout each sample. Power was turned off, and the examples were taken out and suddenly quenched in regular water and hot water for one hour afterward kept for cooling in ambient temperature for 24 hours. Note that the moisture in the tested specimens was allowed to escape freely from the furnace during the heating process. For each quenching type, two cubics (150 x150 x 150 mm) samples were placed in the furnace at each target temperature. All the samples stored in the furnace were in the same condition to have a uniform temperature. The layout of the furnace confirming to ISO curve and as per ASTM E119 [3] with the samples is shown in Fig.1.

Water quenching

According to literature, cubes after heating to target temperature for two hours, quenched suddenly in regular water at ambient temperature as shown in fig. 4 and hot water at 70^0C as shown in fig.2 for one hour. After quenching, specimens are drowned out and allowed to cool for 24 hours.

Figure 1 Furnace used for testing cubes at elevated temperatures

Figure 2 Normal and hot water quenching

Compressive strength

A Compression testing machine was used to determine the compressive strength of specimens before and after heating to target temperatures of each sample. The compressive strength of 150 mm × 150 mm × 150 mm sized cube-shaped samples determined according to BIS: 516 -1959, R 2004[4]. The compressive strength test conducted in digital uniaxial hydraulic compression testing machine of capacity 3000 kN. The compressive load applied at a rate specified by BIS: 516 -1959, R 2004 until the specimen broke down and sustained no greater load. The compressive strength of the sample calculated by dividing the maximum load supported by the sample during the test by the resisting area.

RESULTS AND DISCUSSIONS

Results of visual inspection on specimens

Change in color observed after exposure to various temperatures. The changes that occurred were mainly, change in color and surface cracking and microstructure.
Visual examination of the test specimens confirmed that the color change of concrete is gradual as shown in Table 2.

Table 2 Change in colour after exposure to elevated temperatures

TEMPERATURE	ROOM	100°C	200°C	400°C	600°C	800°C
COLOR	Grey	Grey	Grey	Light Grey	Light Pink	Light Pink

The residual compressive strength of concrete

From the results, it is observed that the reduction in the residual compressive strength after normal water quenching is 2-3 % greater than the decrease in strength in hot water quenching. Subsequently, the residual strength of concrete reduces by 33% at 600^{0}C in normal water quenching however 28% at 600^{0}C in hot water quenching. Results of residual compressive strength are tabulated in table 3 and represented in figure 3.

Mass loss

Figure 4 presents the mass loss evolutions concrete obtained from cubic specimens after exposure to high temperatures. Note that the ratio of mass loss equals the mass loss divided by its initial mass. As illustrated in Figure 4, the mass loss of the concrete at higher temperatures is higher than that of the lower temperatures. Loss of mass in concrete is observed 2.67%,4.59%, 7.14%, 10.24%, and 18.02% after exposure to the temperatures 100^{0}C,200^{0}C,400^{0}C,600^{0}C, and 800^{0}C respectively.

Table 3 Residual compressive strength after exposure to elevated temperatures

TEMPERATURE	AVERAGE COMPRESSIVE STRENGTH (N/mm^2) AFTER NORMAL WATER QUENCHING	% VARIATION IN RESIDUAL COMPRESSIVE STRENGTH(NORMAL WATER QUENCHING)	AVERAGE COMPRESSIVE STRENGTH (N/mm^2) AFTER HOT WATER QUENCHING	% VARIATION IN RESIDUAL COMPRESSIVE STRENGTH(HOT WATER QUENCHING)
Room	**37.74**	100	37.74	**100**
100°c	**35.88**	95.07	36.75	**97.37**
200°c	**33.35**	88.36	34.10	**90.35**
400°c	**31.59**	79.49	32.91	**82.81**
600°c	**26.86**	67.58	26.95	**71.40**
800°c	**--**	--	--	**---**

Figure 3 Graph of residual compressive strength vs. temperature

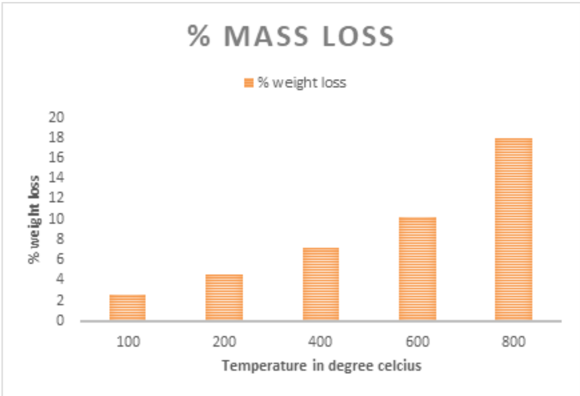
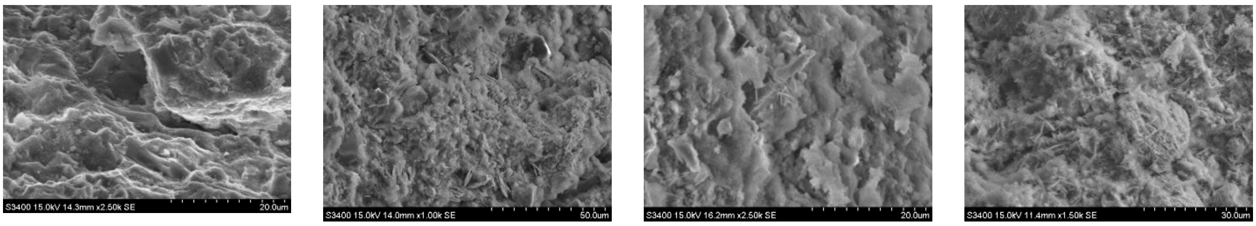


Figure 4 % Mass loss after exposure to elevated temperatures

SEM analysis

The internal structure of the concrete has a robust determining influence on the properties of the concrete. The Scanning Electron Microscopy (SEM) which show the magnified internal structure of the concrete play a crucial role in understanding the internal structure. This internal structure of the concrete is altered by various factors namely the types of cement, water-cement ratio in the mix, kind of mixing, type of mineral admixture used, curing time, etc. The SEM images of the concrete specimens were obtained after age of 28 days before and after exposure to the temperatures 200^0C, 400^0C, 600^0C, and 800^0C in order to study the microstructure of concrete and are shown in fig. 13, fig.14, fig15, and fig.16 shows the SEM images of reference concrete and the concrete specimens after exposure to elevated temperatures. The sample for SEM analysis is taken after exposure of target temperature for 2h and regular water quenching for 1h. from the SEM images; it observed that the concrete exposed to higher temperatures the pore size increases. Microcracks can be seen in the pictures at 400, 600, and 800^0C which might be the reason for strength reduction.



At room temperature 200°C 400°C 600°C

Figure 5 SEM images after exposure to elevated temperatures

CONCLUDING REMARKS

1. From the visual inspection, it can found that there is no color change up to 200^0C. Change in color observed after 400^0C. At 1000^0C the tone of concrete change to white grey.
2. It is observed from this study that the residual compressive strength of concrete decreases as temperature increases.
3. As compared to regular water quenching the residual compressive strength after hot water quenching, additionally increases by 2-3% due to less thermal shock effect.
4. From SEM analysis, it observed that the size of pores formed after exposure to higher temperatures increases and that may be the reason to decrease the compressive strength.
5. There is significant mass loss observed in concrete, and it rises to 18% at 800^0C from 2% at 100^0C.

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REFERENCES

1 B. JEYAPRABHA, G. ELANGOVAN, AND P. PRAKASH, Effects of elevated temperature and water quenching on strength and microstructure of mortars with river sand substitutes, Constr. Build. Mater., vol. 114, pp. 688–698, 2016.

2 STUDIES ON POST PEAK FLEXURAL STRENGTH OF CONCRETE UNDER, vol. 3, no. 3, pp. 133–141, 2014.

3 AMERICAN SOCIETY FOR TESTING AND MATERIALS, ‘Standard Test Methods for FireTests of Building Construction and Materials’, ASTM E 119. 1988

4 BIS: 516 -1959, “IS 516 -1959: Method of Tests for Strength of Concrete,” no. IS 516-1959, p. BIS: 383-1970, R1997, 2004.