Influence of High Temperatures on Hvfa Concrete Columns - Ndt

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Abstract- Quality assurance of concrete structures subjected to elevated temperatures is enforcing challenge for the Structural Engineers. The standing specification scales among concrete strength and nondestructive testing measurements have been established under normal conditions is not suitable to concretes that have been exposed to higher temperatures. In addition to this "Fly ash concrete is increasingly used in the design of normal strength, high strength and elevated performance concretes" [1]. In this paper the authors exposed the influence of high temperatures on HVFA concrete columns for short durations of exposure. The columns are heated from 100oC to 800o C with the increments of 100o C and allowed to cool to room temperature by two methods one is by air cooling and other rapid cooling methods. All the column specimens were tested identically, pre heating and post heating for rebound hammer strength and material quality grading by NDT. The influence of elevated temperatures for short durations of exposure by air-cooling and water quenching methods has been studied and compared the results. The test results showed that the residual strength of HVFA concrete columns was comparable with control concrete columns.
Key words: HVFA concrete, NDT METHODS, Residual strength.

I. INTRODUCTION

Portland cement concrete is undergoing several modifications to suit to the ever changing construction needs. Accordingly testing of blended concretes at elevated temperatures is essential to examine their fire behaviour. Fly ash concrete is one among the blended concretes and finding upcoming applications in concrete industry due to its strength and durability properties. It has established itself as a potential construction material. It is used as partial replacement of cement and aggregate in cement-based materials [1]. Power industries are producing large volumes of fly ash in the world; therefore the large volumes of fly ash can be used in concrete as useful material by encouraging High Volume fly ash (HVFA) concrete. HVFA concrete is the concrete mix containing 50% or more than 50% of cement is replaced with fly ash. In this experimental study, HVFA concrete mix containing 50% of cement is replaced with fly ash in design mix has been used.

The column constitutes common structural member for any type of concrete construction. Hence the residual strength of heated columns has been selected for study. The residual strength of heated column is the ratio of the strength of heated column to that of the unheated column, expressed in percentage.

II. LITERATURE REVIEW

A. Ferhat Bing and RustemGul[2] tested the compressive strength of normal strength concrete at elevated temperatures up to 700◦c and "the effect of cooling regime were investigated and compared the result. Parameters are two mixtures with initial strengths of 20 and 35MPa were prepared, by using river sand, normal aggregate and Portland cement. Thirteen different temperature values were chosen from 50 to 700◦C. The specimens were heated for 3 h at each temperature. After heating, concretes were cooled to room temperature either in water rapidly and in laboratory conditions gradually. The residual strengths were determined by an axial compressive strength test. Strength and unit weight losses were compared with the initial values".

It was observed that concrete properties deteriorated with the heat however, a small increase in strength was observed from 50 to 100◦C. Strength loss was more significant on the specimens rapidly cooled in water. Both concrete mixtures lost a significant part of their initial strength when the temperature reached to 700◦C.Also Mahdi SalehEssa, Mohammed Mansour Kadhum[3]studied, some mechanical properties and deflection behavior of rectangular reinforced concrete rigid beams under the effect of fire flame exposure. The mix ratio is 1:1.2:2.7 as per British mix design. They investigated the compressive strength by two NDT tests, that is the rebound hammer test and ultrasonic pulse velocity test. Concluded that the ultrasonic pulse velocity test showed a response to the effect of fire, the reduction in U.P.V and rebound no was more for water quenched specimens than air cooled specimens at 400 Cº and 600 Cº. Also they mean this NDT test gives good predicted values for the residual compressive strength.

III. EXPERIMENTAL PROGRAMME

In this study the residual strengths of heated RC columns with HVFA concrete mix has been evaluated. The specimens are exposed to temperatures from 100°Cto 800°C with increments of 1000c for 1-hour duration and 2-hours durations. The heated specimens were brought to room temperature by air cooling and quick cooling methods.

3.1 Materials and mix design

Ordinary Portland Cement (OPC) 43grade is used in this experimental work. It was tested to have the properties of cement, specific gravity is 3.13, Fineness (as residue left on IS 90 micron sieve) is 91.8%, Standard Consistency 31%, Initial Setting Time 124 minutes, Final Setting Time 274 minutes. The coarse aggregate in concrete mix is saturated surface dried aggregate with specific gravity 2.78is used and locally available river bed sand conforming to Zone II of IS: 383-1970 [4] with specific gravity 2.66 is used as fine aggregate.

The grade of concrete used in this study is normal M20 grade. According to the guidelines of I.S10262-2009 [5] mix proportions are achieved for M20 grade. Targets mean strength of mix is 27.6 N/mm2. The cement content was optimised for the required target strength and workability of the mix. "HVFA concrete performed better than OPC concrete on optimizing the cement content in a mix, also it offers superior finish at later age strength" [7].

3.2 RC column details:

RC column was designed as per IS 456-2000[8]. A laboratory model column has been prepared by geometric analysis. The size of the model column was 1200 mm long and 150 x 150 mm in cross-section. The reinforcement detailing is as shown in Plate-1.

Plate-2

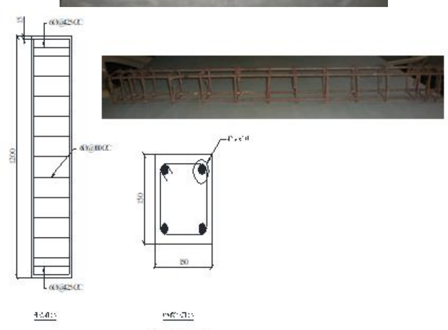


Plate-1 Reinforcement detailing of column

3.3 Casting and curing of Column Specimen

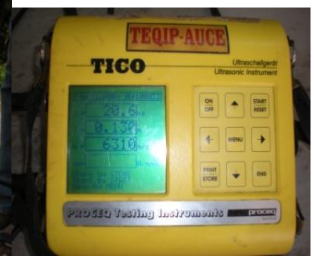
A total of 32 columns were cast and meant for high temperature exposure. One column has been caste on each batch of concrete mix. The ingredients of concrete are introduced into a drum type laboratory mixer, The total mixing was done for 2 minutes. After mixing, the concrete is filled into column moulds in three layers. The compaction has been done with 20mm needle vibrator. The specimens were marked and retained for a period of 24 hours on air drying. Then the specimens were demoulded, as well as cured in a curing tank with fresh water for a period of 28 days.

After 28 days of curing, the column specimens were stored under laboratory air-drying conditions prior to NDT test and temperature exposure. Each specimen was tested for compressive strength of concrete and the concrete quality grading using rebound hammer and ultrasonic pulse velocity meter respectively prior to exposure to fire. The testing has been done on two longitudinal side faces of the column by drawing a grid lines at 150 mm distance on two sides of column, leaving a concrete cover 20mm as shown in plate-2.

Rebound hammer is an equipment to determine the strength of material, shown in plate-3. It is surface hardness test. It measures the rebound of a spring loaded mass impacting the surface of the material. The equipment will hit the surface of material and it's dependent on the hardness of the material. When conducting the test, the equipment should be placed perpendicular to the surface. The surface must clean, clear, smooth, flat and non moist. The ultrasonic pulse velocity (UPV shown plate-4) technique is used to evaluate the quality grading of concrete structure. It measures concrete uniformity and evaluate the properties of concrete. In addition to this, UPV also measure the transit time, presence of voids, path length, perpendicular crack depth and elastic modulus.

Plate-3

Plate-4

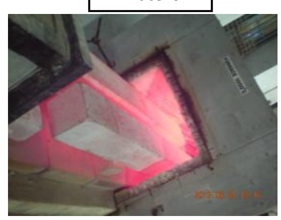


3.4 Temperature exposure and testing of specimens

All the 32 column specimens were exposed for fire in an electric furnace. The temperature exposure is from 100oC to800oC with increments of 100oC, in a furnace in accordance with ISO – 834 [9] as shown in plate-5. Two columns meant for each temperature. The exposure durations are 1-hour and 2-hour at all temperatures. Out of 32 specimens, 16 specimens are exposed to specified durations (one specimen for 1hr and 2hr) from which 8 specimens were air cooled at all temperature durations and other 8 specimens cooled by immediately water quenched, which is arranged nearby water tank. The specimens heated to temperature 800oC and removed from the furnace become red hot in colour shown plate-6. After cooling to room temperature again all the column specimens were tested identically for post fire residual strength of concrete with rebound hammer and quality grading of concrete with UPV meter are tested.

Plate-5

Plate-6



IV. ANALYSIS AND DISCUSSIONS:

In this investigation, the effect of temperature on residual strengths has been studied by NDT techniques and compared with the pre-fire strengths of respective columns.

Effect of temperature on probable rebound hammer compressive strength

The variation of percentage residual rebound hammer strengths with the increase in

Temperature has been plotted in Fig 1 to Fig 4.

HVFA concrete columns exposed to elevated temperatures100, 200, 300, 400, 500, 600, 700 and 800oC and brought to room temperature by air cooling method are retained the percentage variation of rebound hammer strengths 92, 90, 84, 84, 83, 73, 56, 50% for 1-hour duration and 90, 88, 83, 81, 80, 75, 47, 44% for 2-hour duration of exposure with respect to the unheated specimen strengths.

The water quenching method column specimens retained the residual rebound hammer strengths86.1, 89,81, 78, 73.1, 72, 71, 47% for 1-hour duration of exposure, 73, 89, 76, 86, 74, 71, 66, 44% for2-hours duration of exposure with respect to the unheated specimen strengths.

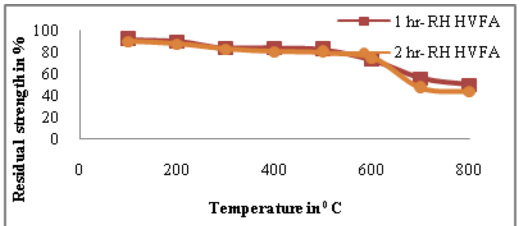


Fig 1 % variation of residual rebound hammer strengths -AC

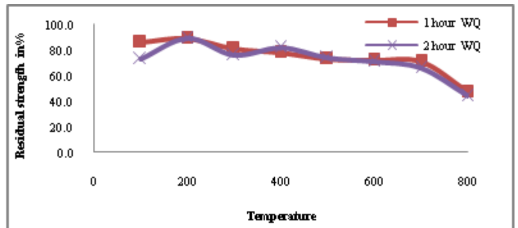


Fig 2 % variation of residual rebound hammer strengths -WQ

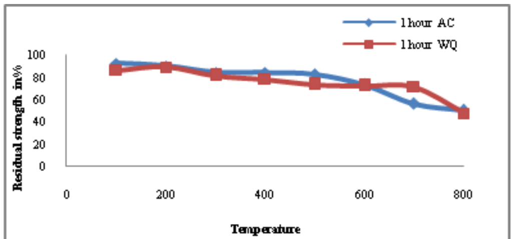


Fig 3 % variation of residual rebound hammer strength of HVFA concrete for 1 hour duration

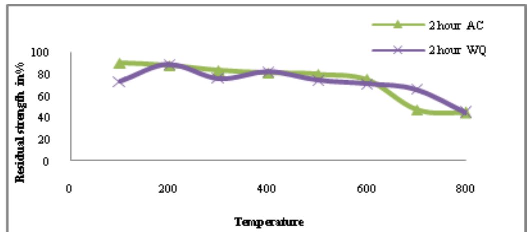


Fig 4 % variation of residual rebound hammer strength of HVFA concrete for 2hour duration

The test results shows that on increase of temperature the residual rebound hammer strength decreased gradually for air cooling method. However, for water quenching method on increase of temperature from 100oC to 200oC the strength increased slightly, on the evaporation of free water. Above 200oC temperature the strength decreased with the increase of temperature due to loss of water and bond between inter granular molecules.
Referring to fig 1 to fig 4 the effect of duration of exposure and method of cooling are insignificant in the variation of residual rebound hammer strength. Up to 700oC temperature the rebound hammer test results shows that the columns retained more than 50% of actual strengths of individual specimens. It can be noted from literature, loss in strength is more in case of quick cooling than in slow cooling for concrete specimens. Since the rebound hammer test is surface hardness test also the column specimens made with RCC the thermal shocks in quick cooling of HVFA concrete is less due to its water tightness and durability. The water-tightness is greatly influenced by the amount of mixing-water, type and amount of supplementary cementing materials, curing, and cracking resistance of concrete [10]. If proper curing is provided to High-volume fly ash concrete mixtures, it gives excellent water-tightness and durability. This is the reason, the strength reduction is insignificant on comparing the two methods of cooling of column specimens.

4.1 Effect of temperature on probable ultra pulse velocity
Referring to fig 5 and fig 6 the variation of ultra pulse velocity with increase in temperature from 100oC to 800oC has been plotted. For air cooling method the % variation of residual UPV values are 101.21, 96, 88.5, 81.64, 52.07, 33.93, 33.81, 20.54 for 1 hour duration of exposure and 97.03, 95.35, 86.13, 71.49, 47.36, 29.68, 14.55, 13.46% for 2 hour duration of exposure with respect to the unheated specimens of UPV.
The water quenching method column specimens retained the percentage variation of ultra pulse velocity 95.1, 97.84, 90, 86.5, 80.93, 64.19, 55.49, 45.87% for 1-hour duration and 95.38, 90.86, 81.3, 77.16, 71, 60.7, 43.2, 45.12% for 2-hours duration of exposure with respect to the UPV of the unheated specimens.
The ultra pulse velocity shows that on increase of temperature in both types of cooling methods, concrete quality grading deteriorated gradually. As per IS 13311-1992 part 1 table -2 [11], concrete quality grading at an exposure of 100oC and 200oC is good. The quality grading is moderate at 300oC and 400oC temperatures. Above 400oC temperature concrete quality grading is poor for 1 hour and 2 hour durations of exposure. It shows again the duration of exposure is insignificant for UPVs as rebound hammer strengths.
Referring fig 7 and fig8 concrete quality grading of water quenching method specimens are slightly better results than aircooled columns.This may be due to theevaporation of free water in the internal core of air cooled specimens at higher temperatures, hence loosees integrity. Hence the path length is long reduced the pulse velocity in air cooling method.

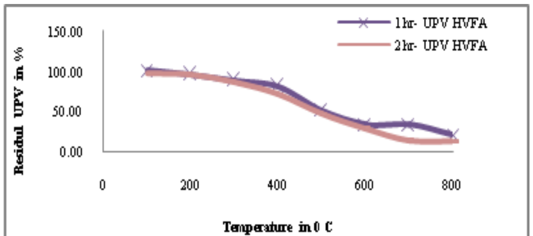


Fig 5 % variation of residual UPV values AC

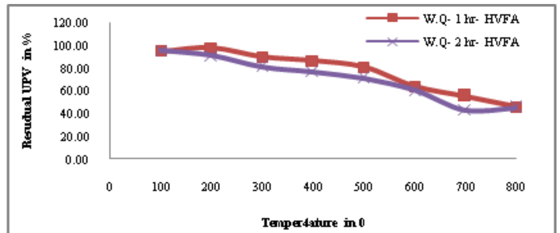


Fig 6 % Variation of residual UPV values -WQ

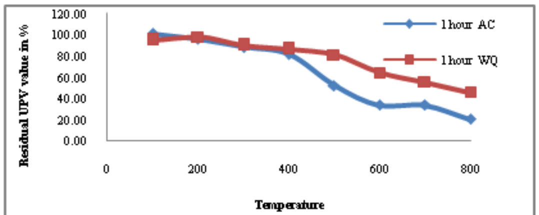


Fig 7 % variation of residual UPV values of HVFA concrete columns for 1 hour duration

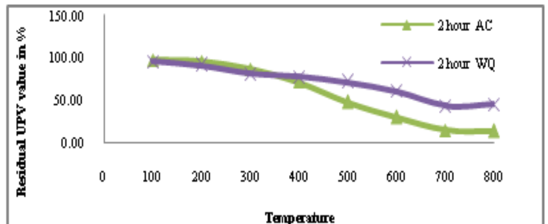


Fig 8 % variation of residual UPV values of HVFA concrete columns for 2 hour duration

V. CORRELATION

Reffering to fig9 to fig12 shows the correlation between the rebound hammer strength and ultra pulse velocityes of column specimens. The quality grading is poor for the temperature exposures above 400oC. The correlation between rebound hammer and ultra pulse velocity is maintained with temperature gradient for both methods of cooling of specimens.

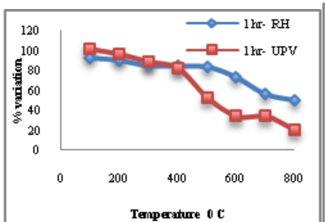


Fig 9 correlation between RH strength and UPV -AC

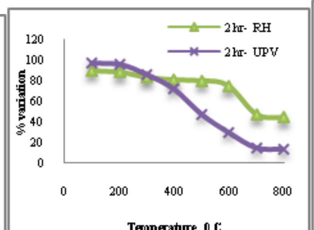


Fig 10 correlation between RH strength and UPV -AC

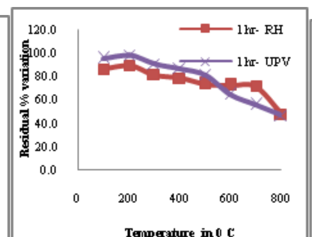


Fig 11 Corrlation between RH and UPV -WQ

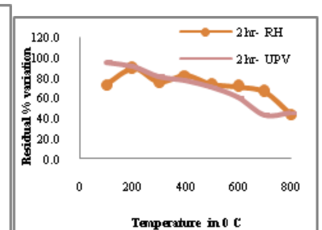


Fig 12 Corrlation between RH and UPV -WQ

VI. CONCLUSIONS

In this investigation, 32 no s of RCC columns (1200X150X150mm size) were caste with M20 grade HVFA concrete and the specimen columns were exposed to temperatures from 100 to 800oC.

The following conclusions have been drawn from this investigation.

1. The compressive strengths of all heated columns were lower than the respective un- heated specimens.
2. The concrete when exposed to temperatures between 700°C and 800°Cbecame red hot in colour. These columns turned smoke gray in colour after cooling them to room temperature.
3. Rebound hammer test illustrate the residual strengths of RC columns exposed upto 500°C were carried 70% strength of companion columns, beyond 500°C temperature the columns retained about 50% strengths.
4. The Concrete quality grading up to 400°C is considerable for M20 grade concrete .
5. Beyond 400°C temperature, the concrete necessary to carry out further NDT test.
6. There is no significant change in residual strength between 1-hour and 2- hour duration of exposure.
7. This non-destructive testing gives good predicted values for the residual strength and quality grading. It can be concluded that the decrease in the rebound number with the increase in fire temperature can be attributed to the fact that fire causes damage to the surface of concrete rather than to concrete core of the member.
8. The correlation between Rebound hammer strength and UPV is clear and considerable.

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