Effect of High Temperature on Fly Ash Concrete

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Abstract-
In this experimental study, an attempt has been made to determine the behaviour of Multi-blended Ordinary Portland Cement concrete with 10% and 20% fly ash of M30 grade of concrete at higher temperatures ranging from 100^{0}C to 600^{0}C. The specimens after single cycle of heating and cooling were tested for their residual compressive strength.. The changes in physical state were also studied by measuring UPV. The cubes casted of conventional and with 10% and 20% fly ash of M30 grade of concrete after exposure to higher temperatures are showing gradual decrease up to 300^{0}C and drastic retardation in the compressive strength and pulse velocity at higher temperatures beyond 500^{0}C. It is observed from the results that cubes with higher concentrations of fly ash show higher rates of decrease in compressive strength, pulse velocity and much lower concentrations, i.e. dehydration and complete decomposition of cement hydration compounds like CSH, CH etc.

Keywords: *concrete, fly Ash, high temperature, multiblended concrete, fire damage, residual strength, compressive strength, pulse velocity.*

I. INTRODUCTION

Concretes containing mineral admixtures are used extensively throughout the world for their good performance and for ecological and economic reason. Pozzolanic concretes are used wide throughout the world and theapplications of such concretes are increasing day by day attributable to their superior structural performance, environmental friendliness, and energy conserving implications.

For the most part cement is associated as a brilliant insulating material, yet there is serious harm or maybe sudden failure at high temperatures. At high temperatures, chemical change of the gel happens bringing on shortcoming in the matrix bonding, resulting in reduction in strength of fly ash concrete. The effect of high temperature on concrete containing ash or natural pozzolans has not been investigated very well. There are changes in the properties of concretes, particularly in temp. ranging from 100–300°C. Above 300°C, there is decrease in mechanical characteristics. However, there is a decrease in strength attributable to the range of heat condition tested, and thetype of constituent materials of concrete used. The behaviour of concrete subjected to high temperatures is a results of many factors; like heating rate, peak temperatures, dehydration of C–S–H gel, phase transformations, and thermal incompatibility between aggregates and cement paste.

A. *Effect of Temperature on Concrete:*

Damage Mechanisms of Concrete under Fire

The effects of high temperatures on Ordinary cement concrete have also been studied since the past decade. Although there are significant differences between ordinary and fly ash concretes in fire performance, their thermal damages (crack formation, explosive spalling, and degradation of mechanical/durability properties) are almost similar and mainly arise from (i) thermal mismatch, (ii) decomposition of hydrates, and (iii) pore pressure.

After a fire, concrete structure requires damage assessment. The aim of a post-fire investigation is to determine the extent of the damage and the thickness of the degraded concrete. As the duration of the actual fire is limited and concrete structures are usually not completely destroyed in a fire, according to[1] most of the fire affected structures can be efficiently repaired. However the assessment of condition and safety analysis of the structure after the fire is necessary to make the right decision on a strategy of repair, strengthening of the structure as an alternative to demolition. Most of the in situ techniques usedto assess the condition of concrete after being exposed to fire are well-known methods, widely used to assess the properties of concrete in structures [1, 2, 3]. In case of fire damage, laboratory techniques are also used to examine concrete integrity. These tests require the sampling of material and laboratory testing. Recently, micro structural changes of heated cement pastes have been studied by neutron diffraction [Castellote et al.(2004)]. This research demonstrates the temperature at which the main products of hydration of Portland cement, including portlandite, ettringite, calcite, lime, larnite, and hydrated calcium silicate (C-S-H gel), are present. During heating, ettringite decomposes first, even before the temperature reaches 100^0 C. C-S-H gel dehydration is progressive and takes place from the very beginning of material heating. It is worth noting that the structure of the cement paste is partially damaged due to dehydration at the temperature of 105^0 C, which is standard for the drying of materials.

As soon as cement paste is heated to temperature of 50^0–550^0 C, the portlandite content rapidly drops, as it decomposes according to the following reaction:

$$Ca(OH)2 \rightarrow CaO + H2O \uparrow .$$

The portlandite decomposition reaction explains the observed increase in CaO content in cement paste at the temperature of approximately 550^0 C [5,7]. The CaO created in this reaction makes the elements made of the Portland cement practically redundant after cooling.

The dehydration process of the C-S-H gel reduces its volume, which in turn increases the porosity of the cement matrix. Moreover, during heating, the cement paste experiences a slight expansion up to temperature of approximately 200^0 C [5, 6, 8, 9] although the intense shrinkage begins as soon as this temperature is exceeded. This significantly contributes to the porosity evolution of the cement paste. Due to heating total pore volume increases, as does the average pore size.

There are several research fields in the fire sciences that use colourimetry and the physical phenomenon of the colour change of solids resulting from heating. In the wildfire literature (e.g. [10, 11]), it was reported that physical and chemical transformation so curing at the soil surface during a fire bring about colour changes. The maximum temperature and duration of exposure were estimated by colour analysis. In this research the CR-300 colorimeter was employed along with the Munsellcolour system to evaluate the changes of the chromas and hues of heated soils [10]. The changes in colour due to the exposure of building materials to heat are a well known phenomenon widely documented in the literature on the subject.

II. EXPERIMENTAL SETUP

The behavior of concrete under high temperature depends on the type of mix and ingredients used. Therefore, the preliminary properties of Ordinary Portland cement, fly ash, fine aggregates, coarse aggregates, admixture and mixing water are evaluated according to relevant codes. Care has been taken to ensure that the same type of OPC, fly ash, fine and coarse aggregates were used throughout this investigation.

Properties of Ingredients

A. ***Cement:*** Cement used was OPC 43 grade conforming to IS: 8112-1989.The chemical and physical properties of the cement were tested as per the IS: 4032-1985 & IS: 4031-1988 respectively.

B. ***Fine Aggregate:*** Fine aggregate used was locally procured badarpur sand. The fine aggregates was tested as per relevant IS 2386 (Part I to VII)-1963 and it confirmed to IS: 383-1970.

C. ***Coarse Aggregate***: The coarse aggregate was tested for its physical properties as per relevant IS 2386 (Part I to VII)-1963 and it confirmed to IS: 383-1970 for wearing as well as non wearing surfaces.

D. ***Superplasticizer:*** Sikament®-581, a concrete superplasticizer based on Sulphonated Naphthalene Polymer was used as a water-reducing admixture and to improve the workability of fly ash concrete. Sikament®-581 is non-toxic. Superplasticizer complies with ASTM C 494-81 Type G and IS 9103 – 1999 BS 5057 part III .

E. ***Water:*** According to proposals of IS: 456 (2000), Potable water was utilized for the concrete casting and curing of Specimens.

III. MIX DESIGN PROCEDURE

The concrete mix proportions were calculated as per IS 10262-2004. The trial mixes were performed to arrive at the required mix proportions for M30 grade of concrete. The normal mix proportion is given in Table 2. The fly ash is also added in 10% and 20% of replacement of cement in different mix proportions.

Table 1: Design mix

w/c ratio(Kg)	Cement content (Kg)	Water (Kg)	Sand (Kg)	Coarse aggregate(Kg)	Admixture (Kg)	% of admixture (Kg)
0.462	380	175.6	712.22	1124.44	5.13	1.35

A. *Specimens Setup*

The cube specimens of size 150 mm x150 mm x150 mm were cast as per procedure laid down in IS: 516 -1959 (Reaffirmed 2004) for each mix of concrete to determine the compressive strength. These specimens were air dried for 24 hr before they were cured for 28days for performing compressive strength test. Fig. 1 & 2 shows the mixing and casting of cubes in laboratory.

Fig 1: Mixing of Multiblended Concrete

Fig 2: Casting of Cubes

B. Curing of the Specimens

The specimens were removed from the moulds after 24 hr from the time of adding the water to the ingredients. The specimens then marked for identification. These specimens were then stored in water for the required period of curing.

C. Ultrasonic pulse velocity

It is non- destructive testing technique to calculate the quality of concrete matrix of casted samples. The air-dried pre- and post-fired concrete cubes were assessed for their physical deterioration by ultrasonic pulse velocity (UPV) measurement by cross-probing method using portable ultrasonic non-destructive digital indicator tester as per IS:13311Part I (1992).

Fig 3: UPV Testing of Cubes

D. Compressive strength

Compressive strength of a material is defined as the value of uni-axial compressive stress reached when the material fails completely. The fired cubes after cooling to ambient temperature were immersed in water for 48 h before testing for compressive strength. The cube specimens of size 150 mm x 150 mm x 150 mm are then tested in accordance with IS: 516 – 1969.

Fig 4: Compressive Strength Testing of Cubes

IV. RESULTS AND DISCUSSION

This paper presents the results of the investigation of the cement concrete behaviour at a high temperature from room temperature to 600^0C.There are many ways to evaluate the deterioration. However, in this paper, compressive strength and ultrasonic pulse velocity tests are taken in to account for evaluate the deterioration of concrete exposed to high temperature.

A. Pulse Velocity

UPV measurement was carried out for different concrete cubes of different mix proportions (with OPC, 10% flyash and 20% flyash) after 28days of curing period as have been discussed. The results are represented graphically in figure 5. Test results shows that till 200^0C, degradation increase with the increasing amount of fly ash as the permeability of the cubes is decreased with increase in flyash, hence higher pore pressure and between $400\text{-}600^0$C, OPC shows the highest degradation as comparative of 10 & 20% fly ash because maximum decomposition and transformations of bonds causing maximum air voids.

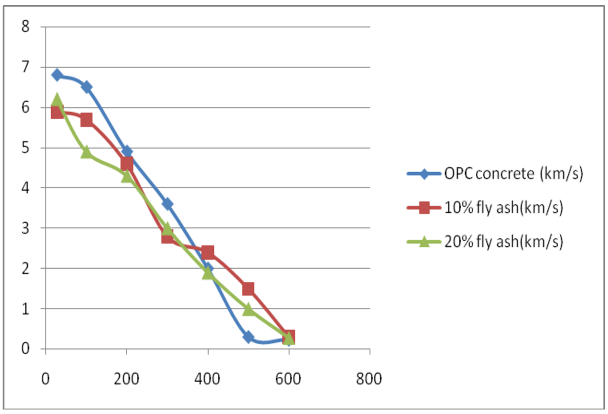

Fig. 5: Comparison in Ultrasonic Pulse Velocity with Temperature at 28 days

B. Compressive Strength

Percentage loss of Compressive Strength is represented in Table 1 of OPC, 10% and 20% flyash cubes.

Table 2: Percentage of C.S. After Exposing to Elevated Temperatures

Temp. (^{0}C)	%age loss of C .S.	%age loss of C .S.	%age loss of C .S.
27	--------	-------	------
100	5.3	5.95	6.3
200	10.35	11.9	16.46
300	25.42	28.3	30.8
400	35.43	36.92	39.62
500	42.96	46.19	48.92
600	60.1	65.12	68.89

For both Ordinary and Fly Ash concretes the gradual decrease in compressive strength observed with the temperature increase ranging from 100^{0}C to 600^{0}C.In the above graph it can been seen that the percentage loss of compressive strength ranges from 0% at room temperature, 5.3% at 100^{0}C , 10.35% at 200^{0}C, 25.42% at 300^{0}C, 35.43% at 400^{0}C, 42.96% at 500^{0}C, 60.10% at 600^{0}C in case of conventional concrete samples.

0% at room temperature, 5.95% at 100^{0}C , 11.90% at 200^{0}C, 28.30% at 300^{0}C, 36.92% at 400^{0}C, 46.19% at 500^{0}C, 65.12% at 600^{0}C in case of 10% fly ash concrete samples.

0% at room temperature, 6.3% at 100^{0}C , 16.46% at 200^{0}C, 30.80% at 300^{0}C, 39.62% at 400^{0}C, 48.92% at 500^{0}C, 68.89% at 600^{0}C in case of 20% fly ash concrete samples.

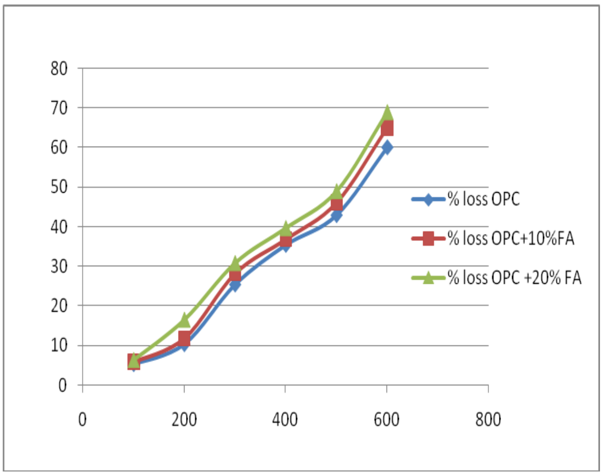

Fig. 6: Comparison of Percentage Loss of Concrete Cubes After Curing Period of 28days

V. CONCLUSIONS

1. Drastic reduction in compressive strength occurred at temperature beyond 400^{0}C because complete decomposition of portlandite and variation of thermal expansion between coarse aggregate and cement mortar.
2. Percentage loss of compressive strength is higher with increase amount of fly ash in concrete samples i.e. for 20% fly ash concrete. . This is due to high impermeability and moisture gained in longer curing period resulting in high pore pressure, but low initial strength gain.
3. The Pulse velocity reduced quite rapidly at temperatures 300^{0}C after 28 days curing and falls below 1 km/sec for temperatures beyond 500^{0}C. The reduction in pulse velocity is due to loss of free, capillary and bound water evaporation and dehydration on heating.
4. Pulse velocity is higher in higher concentration of concrete samples representing the better quality of concrete. This is caused because the matrix inside the cubes is more intact i.e. it has less number of air voids because of the finer particles of fly ash than cement.

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