Performance of Concrete Under Elevated Temperatures for Varying Composition of Fly Ash

*** Abhishek Rana**

Abstract

Fly ash, a by-product generated by the combustion of coal has been broadly used in concrete applications over the last half century. Fly ash is typically used as either an additive or as a cement replacement. In this study the effect of variation in percentage of fly ash over the compressive strength and also the change in compressive strength for the same mixes of different grade of concrete (M20, M30, and M35) when exposed to different elevated temperatures was studied. Various percentages of fly ash are 20%, 30%, and 40% and the different intensities of temperature are taken as 600°C, 800°C, and 1000°C at which concrete cubes are tested for compressive strength.

From the study it is concluded that the compressive strength of concrete reduces with the increase in fly ash content and as the exposure temperature of fire is increased the compressive strength of concrete decreases. However, the dip is comparatively less steep with fly ash content 20% - 30% and the results of 20% are slightly better at 800°C.

Keywords: Concrete, fly-ash, temperature

I. INTRODUCTION

The extensive use of concrete as a structural material for high-rise buildings, nuclear reactors, pressure vessels, storage tanks for hot crude oil & hot water and coal gasification & liquefaction vessels increases the risk of concrete being exposed to elevated temperatures. Concrete is most suitable to resist high temperatures because of its low thermal conductivity and high specific gravity. The applications of such concretes are increasing day by day due to their superior structural performance, environmental friendliness, and energy conserving implications. Mechanical properties like strength, modulus of elasticity, colour etc., are affected by exposure to high temperature . Concrete is made with partial replacement of cement by additives such as fly ash, silica fume, metakaolin, finely grounded pumice(FGP), group granulated blast furnace slag (GGBS), polypropylene fibre (PP fibre), palm oil fuel ash (POFA), Portland pozzolana cement (PPC), rice husk ash (RHA) which provide higher fire resistance. This concrete plays a very important role in the present day durable concrete construction utilizing the mineral and chemical admixtures with low water cement ratio and high strength aggregates. These materials can also improve the durability of concrete and the rate of gain in strength and can also reduce the rate of liberation of heat, which is beneficial for mass concrete. There are changes in the properties of concretes, particularly in the range of 100–300 °C. Above 300°C, there is decrease in mechanical characteristics. As the concrete is used for special purpose, the risk of exposing it to high temperature also increases. To be able to predict the response of structure after exposure to high temperature, it is essential that the strength properties of concrete subjected to high temperature be clearly understood.

II. LITERATURE REVIEW

Wong conducted an experimental study on the basic damage mechanisms of concrete under fire attacks, and then the experimental study of the residual compressive strength and durability properties of normal and high strength concrete made of materials available in Hong Kong after exposure to high temperatures up to 800°C. Results of the research conducted show:

1) The three causes of deterioration of the performance of concrete under temperature attacks are thermal mismatch, decomposition of hydrates, and pore pressure. However, it is difficult to identify/quantify the contribution of each cause to thermal damage because they have cross-effects upon each other.

2) Concretes with mineral admixtures showed better performance at elevated temperatures than the pure OPC concretes except the mixes containing 10% CSF. This better performance was due to the reaction of these

* A. Rana is Assistant Professor with Department of Civil Engineering, Shri Venkateshwara University, Gajraula, Uttar Pradesh, India - 244236. E-mail : rana.abhishek90@yahoo.com

mineral admixtures with free lime, which enhances strength and durability both at normal and high temperatures by reducing free lime content.

3) The exposure of concrete to 600°C resulted in better strength and durability recovery than that of the concrete exposed to 800°C. The reason is that the decomposition of the structure of the CSH gel started at about 550°C. This indicates that during a fire, if the temperature of the concrete can be kept below 600°C, the concrete can recover its original strength and durability properties with proper re-curing alone without the need of special repairs.

A great deal of research has been done on the fire resistance of concrete, since HSC is a relatively new type of concrete**.** Knowledge about the performance of HSC especially the one with blended cement subjected to fire is limited in comparison to Normal Strength Concrete (NSC). The behaviour of HSC differs from that of NSC under the same temperature exposure. A recent review of fire performance of HSC identifies that HSC differs from NSC with respect to relative strength loss and the occurrence of explosive spalling in HSC. An attempt has been made in this work to study the effect of elevated temperatures (upto 950°C) on compressive strength of HSC of M60 grade using fly ash based Pozzolona Portland Cement. High strength concrete cube specimens were exposed to different temperatures of 50°C to 950°C in intervals of 50°C for different durations of 1, 2, and 3 hours. After exposing the specimens to elevated temperatures, they were tested for their compressive strength in hot state. Then effect of elevated temperatures on compressive strength of HSC was assessed.

It was noticed that upto 400°C, no change in colour of concrete was observed. Beyond 400°C change in colour of concrete to light pink shade was observed and at 800°C, the concrete after exposure to temperature was found to be red hot and concrete looked slightly pink even after cooling. It was also concluded that increase in compressive strength gradually takes place in the temperature range of 200°C. Increase in compressive strength is nominal within the temperature range 250°C to 350°C. The concrete retains its original strength upto a temperature of 400°C for all durations of exposure. The rate of decrease in compressive strength is gradual in the range 400°C to 700°C. The rate of decrease in compressive strength is faster in the temperature range 800°C to 950°C.

Research by Jatale, Tiwari, and Khandelwal dealt with the effect on strength and mechanical properties of cement concrete by using fly ash. The utilization of fly-ash in concrete as partial replacement of cement is gaining immense importance today mainly on account of the improvement in the long term durability of concrete combined with ecological benefits. Technological improvements in thermal power plant operations and fly-ash collection systems have resulted in improving the consistency of fly-ash. Based on the studies conducted by authors following conclusion are drawn on fly ash concrete. Use of fly ash improves the workability of concrete. This phenomenon can be used either for the unit water content of mix or to reduce the admixture dosage.

Usually, use of fly ash slightly retards the setting time of concrete, but it is compensated by reduction in the admixture dosage to maintain the same workability.

Bleeding in fly ash concrete is significantly reduced and other properties like cohesiveness, pumping characteristics, and surface finish are improved. As the fly ash content increases, there is reduction in the strength of concrete. This reduction is more at earlier ages as compared to later ages. This is expected as the secondary hydration as the pozzolanic action is slower at initial stage for fly ash concrete. Rate of strength development at various ages is related to the W/Cm and percentages of fly ash in the concrete mix. Modulus of elasticity of fly ash concrete also reduces with the increase in fly ash percentage for a given W/Cm.

Shrinkage of fly ash concrete mix is similar to control concrete mix. Fly ash concrete is more durable as compared to OPC concrete. Significant reduction in RCPT values at 56 days and 90 days indicates much lower permeability of fly ash concrete as compared to OPC concrete.

Mundle had proposed that the variation of compressive strength, performance are some of the important parameters to be investigated when concrete structures are subjected to temperatures. In this study it was observed that the compressive strength is increased after 24 hours of exposure to an elevated temperature up to 200°C after which compressive strength of concrete decreases with increasing temperature after the peak point. It is also noticed this peak value is obtained due to the evaporation of free water inside the concrete.

III. MATERIALS USED

Fly Ash

The fly ash word sounds its own definition i.e. material which flies along with gases and ash, which is a residue of burnt material. This name is used for residue of coal which is used as pulverization fuel for generation of electricity in thermal power stations. In present life style, electricity has become one of the most important parts of human life. For generation of electricity, coal has continued been used as a major source of fuel in many countries in the world including India. In the process of electricity generation, a large quantity of fly ash is produced and it becomes available as a by-product of coal-based power stations.

Types of Fly Ash

Different types of fly ash available are classified according to the type of coal used for production. These are:

1) Class F is produced from bituminous coal.

2) Class C is produced by burning lignite and sub bituminous coal.

Class F- Produced from bituminous coal

Class F fly ash is designated in ASTM C 618 and originates from anthracite and bituminous coals. It consists mainly of alumina and silica and has a higher loss of ignition than Class C fly ash. Class F fly ash also has a lower calcium content than Class C fly ash.

Cement

Cement is a binder substance which on reacting with water leads to hydration. It hardens and binds two substances together. Two types of cement are:

1) Ordinary Portland Cement (OPC): OPC is obtained by adding raw materials like calcareous materials and argillaceous materials. Ordinary Portland cement comes in three grades: OPC-53, OPC-43, and OPC-33. The 43-grade OPC is most popular and its production is about 50% of the total production of cement.

2) Portland Pozzolona Cement (PPC): PPC is obtained by adding pozzolanic materials like fly ash, volcanic ashes, shales, tuffs, etc.

IV. METHODOLOGY

The methodology adopted involved an extensive literature survey on the various works being done in the field of fly ash blended cements. This study investigated the use of fly ash in various replacements of Portland cement in concrete mix design. Concrete cubes were prepared by using fly ash replacement of 0%, 20%, 30%, and 40% of Portland cement by weight. This was done for mix designs M20, M30, and M35. Then test for compressive strength was conducted for cubes, comparative study was analyzed for the same proportion of different grade of concrete. Also, after exposing to temperature with different intensities 600°C, 800°C, and 1000°C comparative study for compressive strength is done at the same proportion for different grades of concrete.

V. RESULTS AND DISCUSSION

At the same proportion of fly ash with different grades of concrete, compressive strength test is performed on the cube specimen. The cube specimens were tested at normal conditions and after exposure to temperature and comparative study of the results were done. After exposing cubes to different elevated temperatures 600°C, 800°C, and 1000°C, comparison of compressive strength was done for different grades of concrete with the same proportion of fly ash.

TABLE I.

Test results of comparison of different grades with same percentage of fly ash at different temperatures

(a) Average Compressive Strength (N/mm²) of Fly ash mix at different temperatures (°C)

Grade	0% Fly ash				20% Fly ash			
	27°C	600°C	800°C	1000°C	27°C	600°C	800°C	1000°C
M20	27.07	22.97	21.05	19.15	25.32	22.09	20.77	18.25
M30	38.39	35.18	32.08	27.09	35.01	33.17	30.11	26.35
M35	43.27	40.76	37.27	32.58	41.04	38.33	36.22	31.91

(b) Average Compressive Strength (N/mm²) of Fly ash mix at different temperatures (°C)

Grade	30% Fly ash				40% Fly ash			
	27°C	600°C	800°C	1000°C	27°C	600°C	800°C	1000°C
M20	23.31	20.56	17.47	14.11	21.89	18.49	15.19	13.04
M30	32.21	29.81	27.06	24.14	30.9	27.09	23.14	19.08
M35	39.13	36.3	33	28.98	36.95	34.13	30.15	24.99

VI. CONCLUSION

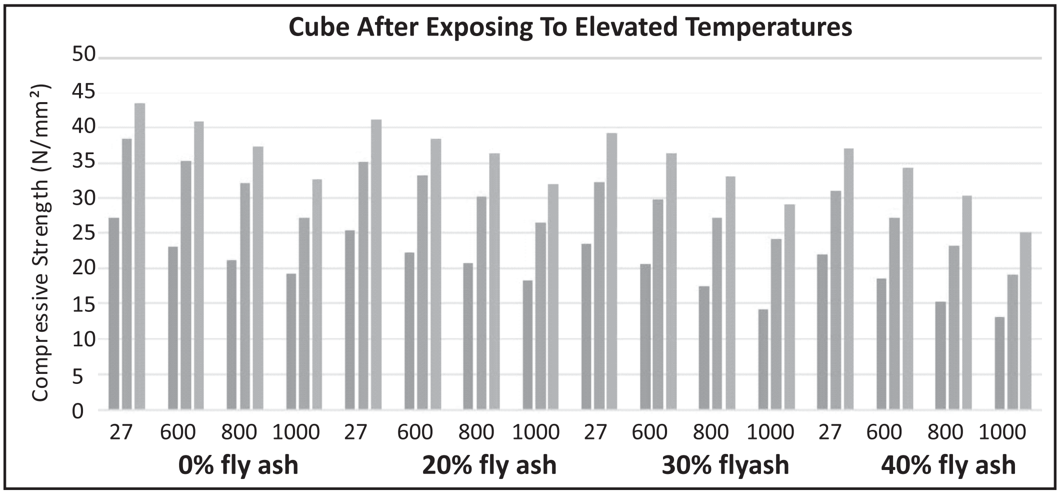
The following conclusions can be drawn from the present study:

❖ The compressive strength of concrete reduces with the increase in fly ash content.

❖ The workability of the mix increases with the increase in fly ash content even when the water cement ratio is kept constant.

❖ In general, as the exposure temperature is increased

Fig. 1. Graphical comparison of different grades with same percentage of fly ash at different temperatures



the compressive strength of concrete decreases. However, the dip is comparatively less steep with fly ash content 20% - 30% and the results of 20% being slightly better.

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About the Author

Abhishek Rana is Assistant Professor with Department of Civil Engineering, Shri Venkateshwara University, Uttar Pradesh, India.