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Effect of Fly Ash Additive on Concrete Properties

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ABSTRACT

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. Three grades of ordinary Portland cement (OPC) namely: 33, 43 and 53 as classified by Bureau of Indian Standard (BIS) are commonly used in construction industry. This paper reports a comparative study on effects of concrete properties when OPC of varying grades were partially replaced by fly ash. The main variable investigated in this study is variation of fly ash dosage of 10%, 20%, 30% and 40%. The compressive strength, durability and shrinkage of concrete were mainly studied. Test results shows that, inclusion of fly ash generally improves the concrete properties upto certain percent of replacement in all grades of OPC.

Keywords - Fly ash, ordinary Portland cement (OPC), partial replacement.

1. INTRODUCTION

The use of bituminous or sub-bituminous coal increasing day by day as large number of thermal power plants are being constructed, leading to increase of the production of fly ash. Fly ash is the finely divided residue, resulting from the combustion of ground or powdered coal and transported by the flue gases of boilers fired by the pulverized coal. It's available in large quantities as a waste product from a thermal power and industrial plants. The amount of ash contained in coal or lignite burned in power plant can vary greatly depending on the source of coal. The fine particles of fly ash by virtue of their lightness become air borne and create health problems to all living being. Its indiscriminate disposal requires a large volume of land, water and energy. Fly ash as a siliceous or aluminous, it poses pozzolanic properties when used in concrete as a partial replacement of cement. Use of such an industrial waste has many advantages such as it improves the performance of concrete exposed to sulphate environment, deterioration caused by alkali-aggregate interaction etc. Hungry Horse dam in America completed in 1954 contains over 2.3 million m^3 of concrete and a total of 120,000 tons of fly ash. In India, Rehand dam can be quoted as an example for which fly ash has been used for mass concreting [Shetty,2005]. In recent times, used of fly ash in concrete has grown so much that it has become a common ingredient in concrete. Thus, Bureau of Indian Standard (BIS) [IS 10262-2009] on concrete mix proportions has already incorporated fly ash for making high strength and high performance concrete.

The properties of fly ash contribute to strength gain and improved durability when used with Portland cement. India has vast resource of fly ash generation all across the country. This material if segregated, collected and used properly can resolved the major problems of fly ash disposal and reducing the use of cement, which consumes lot of energy and natural resources. Different grades of ordinary Portland cement (OPC) are available depending on the respective country codal classification. Bureau of Indian Standard (BIS) normally classify three grades of OPC namely: 33, 43 and 53, which are commonly used in construction industry.

A wealth experimental study to evaluate the behavior of concrete properties both in plastic and hardened states with the inclusion of fly are available in the technical literature [Naik and Ramme (1990), Mullick (2005), Shi Cong et al. (2008)]. However, no record could be found where comparative studies on the effect of concrete properties when cement of varying grades were partially replaced by fly ash are addressed together. Thus, the present is to investigate the improvement of concrete properties when OPC of varying grades were partially replaced by fly ash. The long-term contributions to strength gain and improvement in durability are the main objectives of this study.

2. SOURCES OF FLY ASH AND IT USE IN CONSTRUCTION INDUSTRY

ASTM broadly classifies two classes of fly ash i.e. class F and class C. Class F fly ash is usually produced by burning anthracite or bituminous coal, while class C fly ash is normally produced by burning sub-bituminous coal or lignite. The separation of fly ash into two classes reflects differences in composition, which affect cementitious and pozzolanic properties. Class C fly ash usually has cemetitious properties in addition to pozzolanic properties, while class F fly ash is rarely cementitious when mixed with water alone [Shetty 2005].

Fly ash has been used for various works and its utility is ever increasing with new avenues opening for different works. Guidelines regarding utilization of fly ash are available in IS 10153 [1982]. To name few of its uses such as; pozzolana cement, cement fly ash concrete, precast building blocks, light weight aggregate, fly ash cellular concrete, fly ash building bricks, partial replacement of fine aggregate in concrete and mortar, high strength concrete etc.

3. EXPERIMENTAL PROGRAM

Experimental investigations are carried out on mortar cubes, concrete cubes and beams specimens. The mix was designed for target cube strength of 30 MPa at 28 days with water-cement ratio of 0.38. Cement of various grade were partially replaced with fly ash by weight (10%, 20%, 30% and 40%). A simple method of mix proportioning using fly ash (i.e. fly ash as part replacement of cement by weight) has been adopted.

3.1 Ingredients

Various grades of ordinary Portland cement (OPC) classified by BIS namely: 33, 43 and 53 conforming to standard codal provision [IS 269-1989, IS 8112-1989 and IS 12269-1987] were used.

Coarse aggregate from crushed basalt rock was use. Flakiness and Elongation Index were maintained well below 15%. River sand was used as fine aggregate. Material used have been tested as per relevant codal provision [IS 2386 (I, III), 1963].

Fly ash used in this study was obtained from Obra Thermal Power Plants, India. This fly ash conforms to the requirement of IS 3812 (Part I) [2003] and also ASTM C-618 type F [1878]. Test results of fly ash are summarized in Table 1.

3.2 Casting, curing and testing of specimen samples

Twelve cubes of sizes 150x150x150 mm were cast per variety of sample per each grades of cement for strength test. Cube strength was examined at different age's i.e. 7, 28, 56 and 90 days.

Five un-reinforced beams of sizes 150 x150x1000 mm per each grade of cement were cast to measure the shrinkage. Shrinkage test of beam after 28 days of curing were done by measuring the change in length of the specimen at 7 days interval.

Six mortar cubes of 50x50x50 mm were cast per variety of the sample and per each grades of cement for durability test (sulphate resistance). The resistance to sulphate attack were evaluated by immersion of well-cured specimens after 28 days of curing in a standard sodium sulphate solution (Na_2SO_4) having concentration of 16 gm/l [Buenfeld and Newman, 1984]. The specimens were alternately wetting and drying at 7 days intervals and then determining the strength loss as a result of sulphate exposure for 28 days.

Table 1 Test results of fly ash

Descriptions	Test Value	Acceptable Value	
		IS3812-2003 (Part)	ASTM C-618 Type-F
Specific gravity	2.13	-	-
Initial setting time (min)	125	-	-
Final setting time (min)	300	-	-
Retained on 45 micron (%)	2.80	Max. 34.0	Max. 34.0
Specific gravity	330.0	Min. 320	-
Soundness (Lechatelier)	0.20	-	-
Water requirement (%)	98.0	-	Max. 105
Compressive strength (% of control)	7 days: 140.0 28 days: 142.5	-	Min. 75

3.3 Details of fly ash replacement

Fly ash has been added as percentage by weight of total cementitious material replacing cement by various percentages. Table 2 illustrates the detail of various percentages chosen.

Table 2 Details of proportions of cement and fly ash

Symbols	% of cement	% of fly ash
C100	100	0
F10	90	10
F20	80	20
F30	70	30
F40	60	40

4. RESULTS AND DISCUSSIONS

Various parameters which significantly affect the properties of hardened concrete with the inclusion of fly ash are discussed below.

4.1 Effect of fly ash on cementitious properties

The main physical properties of fly ash that influence the activity of fly ash with which it gain strength is its fineness. Fly ash reacts with $Ca(OH)_2$ released from the hydration of cement in the concrete and produces cementing materials. Fly ash is required to be equal or finer than cement for its good cementing efficiency. The fineness of 33, 43 and 53 cement grades OPC in this investigation are found to be 9, 8 and 6% residue on 90 micron sieve respectively. Fineness of fly ash obtained from Obra Thermal Power Plants (India) is found to be 6%. This show that fly ash is of finer size as comparable to cement particles and hence can be expected to have appreciable influence on the strength development on concrete.

The variation of normal consistency for different grades of cement using different percentage of fly ash as partial replacement by weight is shown in Fig. 1. The plot indicated that the water requirement for the paste increases approximately linearly for all grades of cement. The normal consistency of 43 and 53 grades cement are higher by 5 and 9% as compared to that of 33 grade cement. Further, the cement of 53 grades is finer as compared to 33 grades OPC; hence more water is required for wetting the particles, as the total surface area of the particle is increases.

The variation of initial setting time (IST) and final setting time (FST) for different grades of cement with fly ash content are approximately linear (Fig. 2). The increase in initial setting time for 33, 43 and 53 grade OPC using 40% replacement by fly ash is around 147, 140 and 139% while that of final setting time is about 92, 83 and 80% respectively. This shows that setting time decreases with the increase in grade of cement. The delays in setting times is due to the reducing the C_3S ($3CaO.SiO_2$) content and C3A ($3CaO.Al_2O_3$) and thus increasing the C_2S ($2CaO.SiO_2$) contents. Though, final setting time increases with inclusion of fly ash, the increase is of lesser magnitude as compared to the increase of initial setting time. The increase in setting times (both initial and final) is found to be more for 33 grade OPC and least for 53 grade OPC at each replacement level. This behaviour is due to the reason that 53 grade OPC is more fines, finer the cement, the higher is the rate of hydration as more surface area is available for chemical reaction. This results in early hardening and developement of strength. However, all grades of cement with each proportion fall within the specified limit [IS 269-1989, IS 8112-1989 and IS 12269-1987].

Expansion test were performed as per specification and the Le-Chatelier's expansion is measure. The variation with fly ash contents are shown in Fig. 3. Le-Chatelier's expansion without fly ash is 2.0, 2.2 mm and 2.3 mm for 33, 43 and 53 grades OPC, while for mixes with 40% fly as replacement is 0.9, 1.1 and 1.3 mm i.e. the increase in soundness is about 55, 50 and 44% respectively. Hence inclusion of fly ash increases the soundness of mixtures or decreases the Le-Chatelier's expansion because of decreasing in carbon and increasing in silica content. The increase in soundness in each proportion is found to be greater in 33 grades and least sound for 53 grades OPC. This show that 33 grade OPC contains less free lime to cause the expansion than the other. However, all grades of cement with each proportion fall within the specified limit [IS 269-1989, IS 8112-1989 and IS 12269-1987].

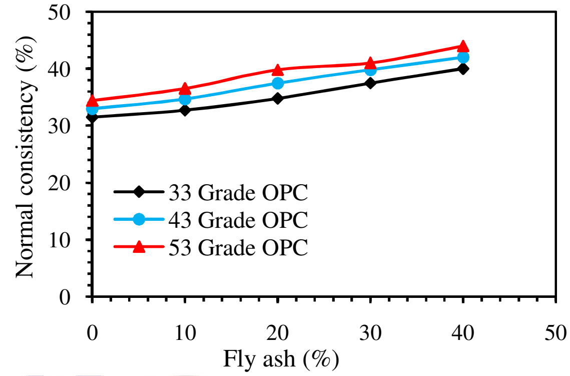

Fig. 1 Normal consistency with fly ash content

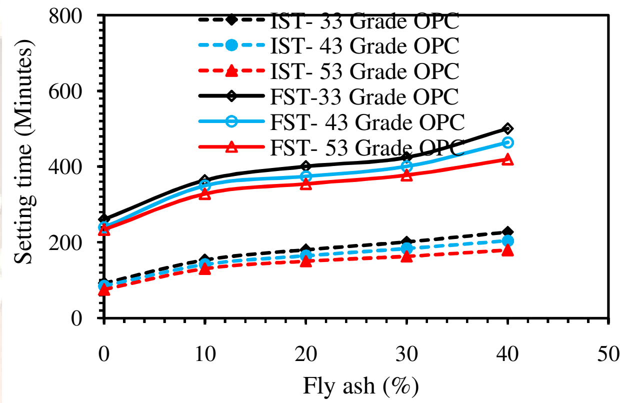

Fig. 2 Setting times with fly ash content

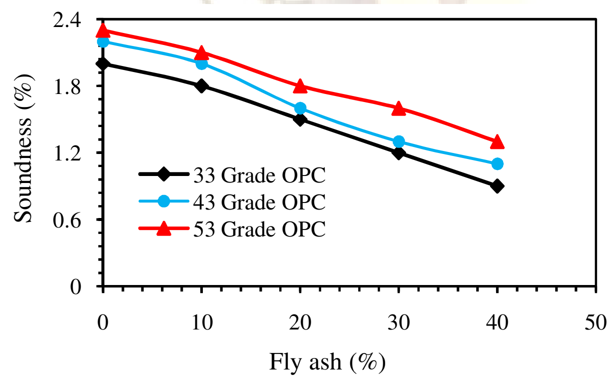

Fig. 3 Soundness with fly ash content

4.2 Effect of fly ash on concrete properties

4.2.1 Workability

Workability of concrete increased with the inclusion of fly ash in comparison to that of concrete with pure cement. The reason may be due to the increase of the paste volume that leads to the increase of plasticity and cohesion. Fly ash particles tend to coat and lubricate the aggregate particles. The spherical shape of the fly ash particles contributes to the workability of concrete by reducing the friction at the aggregate paste interface, producing a ball-bearing effect at the point of aggregate contact. The workability (slump) of concrete for 33, 43 and 53 grades OPC varies from 25, 20 and 16 mm for concrete containing 40% fly ash respectively. The higher value of slump is obtained for concrete with cement of 33 grades and lowest for 53 grade cement. This behavior may be because the higher the grade of cement the more fine it is. Finer cement requires more water to wet the surface particles.

4.2.2 Compressive strength

Variation of cubes strength at different ages of 7, 28, 56 and 90 days with different grades of cement and various percentage of fly ash as partial replacement by weight is shown in Fig. 4 to 6. The plot shows that the strength of concrete decreases with increase of fly ash contents at the early ages for all three grades of cement. The inclusion of fly ash about 40% replacements causes a reduction of 7 days strength about 55, 51 and 50% respectively as compared to that of concrete with pure cement. The 28 days cube strength at 40% replacement also decreases in strength about 42, 38 and 37% respectively as compared to that of concrete with pure cement. Similarly, at 40% replacement the strength reduction for 56 days is about 37, 32 and 30% respectively. At this age, the reduction in strength is lower as compared to that of 7 and 28 days. The rate of strength gained at this age over that of 28 days is about 8, 9 and 10% for pure cement to 17, 21 and 22% for 40% fly ash content. However, the rate of strength gained over that of 28 days being maximum for 20% fly ash replacement. Similarly, the 90 days cube strength reduction for sample containing 40% fly ash is still lower to 33, 26 and 21% respectively for 33, 43 and 53 grades concrete. The reduction in 90 days strength is smaller as compared to 7, 28 and 56 days strength. This shows that strength of fly ash concrete increases with age. Further, it is also observed that at the age of 90 days the rate of strength gain for 33, 43 and 53 grades concrete is increased and being maximum up to 20% fly ash replacement (Fig. 7). The rate of strength gain is up to 39, 41 and 41 % respectively over that of 28 days strength with a small difference of 4.62, 2.5 and 1.98 MPa as compared to the pure cement concrete. This shows that fly ash have an effect of delayed hardening on strength gain of concrete.

For concrete at 90 days the 10, 20, 30 and 40% replacement by fly ash causes a reduction in strength of about 11, 10, 21 and 32% for 33 grades cement while for 43 and 53 grades are 7, 5, 16, 26 and 6, 4, 15, 24% respectively. This indicates that replacement by fly ash for 43 and 53 grades cement is seems to be better in term of ultimate strength reduction and strength gain than that of 33 grade OPC. However, in all grades of cement the replacement upto 20% fly ash has lesser effect on the strength at the later age.

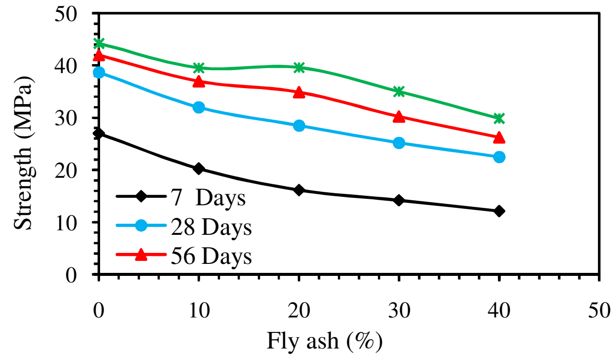

Fig. 4 Compressive strength of 33 grade OPC

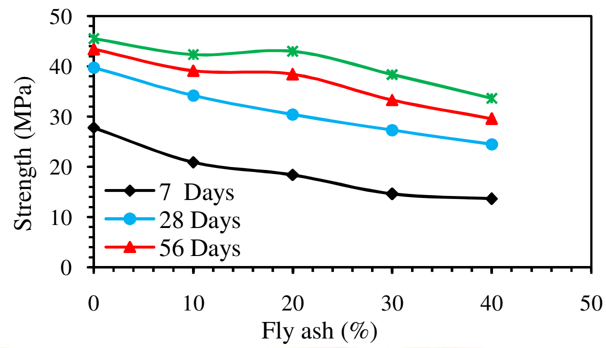

Fig. 5 Compressive strength of 43 grade OPC

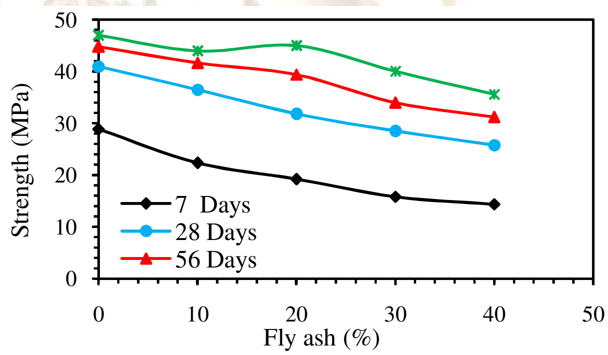

Fig. 6 Compressive strength of 53 grade OPC

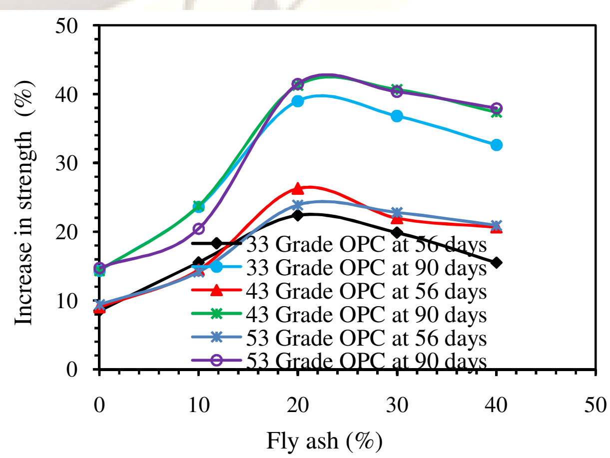

Fig. 7 Percentage increase in 56 and 90 days strength over 28 days

4.2.3 Durability

Salt concentration of sea water varies from 0.58 to 4.0 g/l with an average of 2 g/l [Buenfeld and Newman, 1984]. In this study, the enhanced sulphate salt concentration as high as eight times that of average salt concentration of sea water was considered. Fig. 8 shows the variation in compressive strength with fly ash content for 28 days exposed in sulphate solution and tap-water. The figure demonstrates that, for each grades of cement the strength of ordinary cube and that replaced by fly ash immersed in sulphate solution have less compressive strength than the corresponding referral cubes immersed in tap-water. The strength was found less as fly ash contents is increase in both cases. Though, the strength exposed to sulphate solution decreases at each proportion of replacement as compared to cube strength exposed in tap-water, the decrease in strength is found to be more for ordinary cube than that of cubes containing fly ash. This loss of strength for ordinary cube may be due to the presence of sulphate salts in OPC which leads to the formation of complex expansive salts i.e. ettringite [Mehta, 1986]. This might have been accompanied by leaching of salts from inside pores. The formation of ettringite results in increased in volume and cause disruption of concrete. The decrease in cube strength exposed in sulphate solution over that exposed in tap-water are about 8% for ordinary cubes and that of 40% fly ash content are about 5% for all grades of OPC. Thus, it shows that addition of fly ash as partial replacement of cement improves the durability when exposed to sulphate environment. Cement paste containing fly ash favored the formation of expansive salts. Addition of fly ash to cement converts the leachable calcium hydroxide into insoluble non-leachable cementitious products. The increase in sulphate resistance may be due to the contained reaction of fly ash with hydroxides in concrete to form additional calcium silicate hydrate (C-S-H), which fills in capillary pores in the cement paste, reducing permeability and the ingress of sulphate solution. Comparing all the three grades of OPC, the strength loss seem to be betters for 53 grade OPC (Fig. 9) as compared to the other two grades.

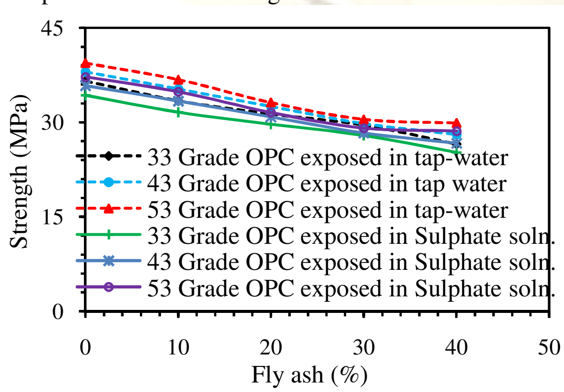

Fig. 8 Compressive strength under different environment

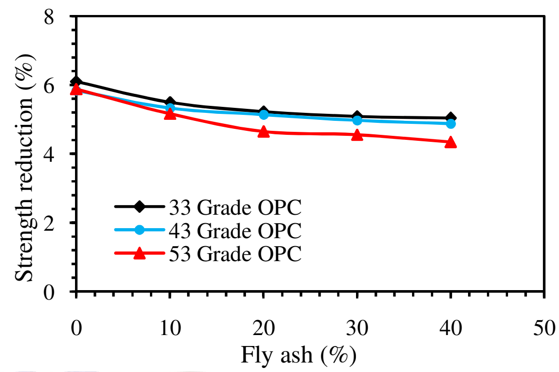

Fig. 9 Reduction in strength exposed in sulphate solution

4.2.4 Shrinkage

In general, the shrinkage is decreases in fly ash concrete due to the reduction in water demand and production of finer paste structure, which restrict the loss of pore water within the paste, which helps in the reduction of shrinkage. However, it has been observed in this study that the shrinkage of specimens with 40% fly ash content measured at the age of 90 days found to be same for pure and fly ash concrete at each proportion with a minimal change in length. Hence, it may be concluded that influence of fly ash on shrinkage is negligible.

5. CONCLUSIONS

From the experimental work carried out and the analysis of the results following conclusions seem to be valid with respect to the utilization of fly ash.

1) Normal consistency increases with increase in the grade of cement and fly ash content.
2) Setting time and soundness decreases with the increase in grade of cement.
3) Use of fly ash improves the workability of concrete and workability increases with the decreases in the grade of cement.
4) Bleeding in fly ash concrete is significantly reduced and other properties like cohesiveness, pumping characteristics and surface finish are improved.
5) Compressive strength of concrete increases with grade of cement. As the fly ash contents increases in all grades of OPC there is reduction in the strength of concrete. This is expected, as the secondary hydration due to pozzolanic action is slower at initial stage for fly ash concrete. The reduction is more at earlier ages as compared to later ages. The rate of strength gain of concrete with age is almost similar in all the three grades OPC. Concrete with 20% fly ash content closer to that of ordinary concrete at the age of 90 days.
6) In all grades OPC, fly ash concrete is more durable as compared to OPC concrete and fly ash upto 40% replacement increase with grade of cement.

7) Shrinkage of fly ash concrete is similar to the pure cement concrete in all grades of OPC.

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