Experimental Study on Use of Fly Ash in Concrete

Khushal Chandra Kesharwani[1], Amit Kumar Biswas[1], Anesh Chaurasiya[1], Ahsan Rabbani[2]

[1]*Graduate Student, Dept. of Civil Engineering, Kalinga University, Raipur, (C.G), India.*
[2]*Assistant Professor, Dept. of Civil Engineering, Kalinga University, Raipur, (C.G), India.*

Abstract - *Fly ash utilization in concrete as partial replacement of cement is gaining importance day by day. Technological improvements in thermal power plant operations as well as collection systems of fly ash improved the quality of fly ash. To study the use of fly ash in concrete, cement is replaced partially by fly ash in concrete. In this experimental work concrete mix prepared with replacement of fly ash by 0%, 25%, 50%, 75% and 100%. Effect of fly ash on workability, setting time, compressive strength and water content are studied. To study the impact of partial replacement of cement by fly ash on the properties of concrete, experiments were conducted on different concrete mixes.*

Key Words: Fly Ash, Concrete, Workability, Strength, Curing.

1. INTRODUCTION

Pozzolans are materials which have little or no inherent cementitious properties, but which develop cementitious properties in the presence of calcium hydroxide (lime) and water. Such materials usually derived from natural deposits. Many modern pozzolans still derive from natural deposits, but the bulk of pozzolana derive from the combustion of powdered coal during electric power generation. This product is commonly called fly ash. There are currently three classes of pozzolana defined by the ASTM: Class N, Class C, and Class F. Class N are natural pozzolans: calcined shale, calcined volcanic ash, etc. Class F is fly ash nominally produced from anthracite, bituminous, and some sub-bituminous coals. Class C is nominally produced from fly ash derived from combustion of lignite and some sub-bituminous coals. Total USA production of Fly ash in 1983 was 52.4 million tons, of which 3.6 million tons was used in cement and concrete products [6]. An additional 5.3 million tons was used for other things, such as mud stabilization, agriculture, and raw material for cement manufacture, the remainder going to landfills [1].

The components of the concrete are fine aggregate (FA), coarse aggregate (CA), cement and water. The vital environmental problems related with cement production is releasing of CO_2, one of the major greenhouse gas which causes Global Warming. Keeping this ill effect of cement, various replacements include fly ash, ground granulated blast furnace slag, rice husk and silica fume is used. Fly ash is a much cheaper material than Portland cement, so that large replacements can result in significant economic savings. [2] estimated that a 25 percent savings in materials cost was realized in the construction of the Upper Stillwater Dam through use of large amounts of fly ash.

1.1 Effects of Large Quantities of Fly Ash on Properties of Fresh Concrete

1.1.1 Time of Setting

Setting is defined as the onset of rigidity in fresh concrete. Although specific events are defined, i.e. initial and final setting. Portland cement is the principal active ingredient in concrete that causes setting. Fly ash usually has a tendency to retard the time of setting of cement relative to similar concrete made without fly ash. [8] examined the effect of 35 to 55 percent (by mass) of Class C fly ash on time of setting. Initial time of setting increased about 1hr for each 10 percent increase in fly ash content. [9] Reported increases in time of setting from a few minutes to a few hours. The effect was most pronounced in high-replacement concretes made with Class C fly ashes. [10] investigated two Class F fly ashes used at 60 percent (by mass) of total cementitious material at a w/c of 0.31. They found that initial time of setting was not changed relative to control, but the final time of setting ranged from 8 to 11hr. [7] found that 37 percent Class F fly ash (by mass) caused a maximum delay in time of setting of 3 hr.

1.1.2 Workability, Water Requirement, and Bleeding

Water required for constant workability is usually lower for fly ash containing mixtures, but the amount of water reduction varies among fly ashes. At conventional replacement levels, Class C ashes tend to affect greater water reduction than the Class F ashes. [9] Used a troweling test and found a general improvement in workability with increasing fly ash contents. [4] Found that workability of a 50 percent (mass) replacement improved when measured by the Veebe test, for eight fly ashes studied. [5] Found a reduction of water demand with increasing fly ash content for both 0.5 and 0.8 w/c mixtures.

1.2 Effects of Large Quantities of Fly Ash on Properties of Hardened Concrete

1.2.1 Strength

Strength is one of the properties of concrete in which fly ash has a notable effect, but the size of the effect is strongly dependent on the w/c. When fly ash used as a replacement for Portland cement, reductions in early strength relative to the pure Portland-cement concrete are common. In the case of high replacements, the ultimate strength may not exceed 70 percent of the control mixture [5]. Fly ash reacts with calcium ion in the pore solution of concrete and water to form hydration products (CSH) that contribute to strength. [3] Investigated the relationships between w/c and strength change with the substitution of large quantities of fly ash.

1.2.2 Curing

From strength-development studies that concrete containing fly ash require longer moist curing than pure cement concretes [5]. [11] Confirmed this at the microstructural level. He looked at the pozzolanic action, as measured by lime consumption and microstructure refinement. He found that fly ash-containing pastes (30 percent) were more sensitive to relative humidity than pure cement pastes.

1.3 Physical Characteristics

The physical characteristics of fly ash like fineness, particle shape and size, density and colour mainly depend on the type of collection system and the combustion temperature of the pulverised coal. The physical properties of fly ash have a greater influence on the performance of fresh concrete such as workability, bleeding, segregation etc. The fineness of the fly ash influences pozzolanic activity and workability of concrete. It observed that the fineness of fly ash was the most significant parameter influencing the suitability of fly ash for applications in concrete. Physical Requirements of fly ash as per BIS is shown in Table-1 and as per ASTM is shown in Table- 2.

Table -1: Physical Requirements of fly ash as per (BIS)

SN.	Characteristics	Requirements (Siliceous and Calcareous Fly ash)
1	Fineness- Specific surface in m^2/kg, (Min.)	320
2	Particle retained- on 45-micron IS sieve in % (Max.)	34
3	Lime reactivity- in N/mm^2, (Min.)	4.5
4	Compressive strength-at 28 days in N/mm^2, (Min.)	Not less than 80% of the strength of plain cement mortar cubes
5	Soundness by auto clave test- Expansion in % (Max.)	0.8

Table -2: Physical Requirements of fly ash as per (ASTM)

Sl No.	Characteristics	Requirements (Siliceous and Calcareous Fly ash)
1	Particle retained- on 45-micron IS sieve in % (Max.)	34
2	Water requirement- in % on control, (Max.)	105
3	Strength Activity index –with Portland cement at 7 and 28 days, in %, (Min.)	75
4	Soundness by auto clave test- Expansion in % (Max.)	0.8

1.4 Chemical characteristics

Fly ash is a fine particulate material with the main chemical constituents being SiO_2, Al_2O_3, Fe_2O_3 and CaO. These chemicals are responsible for its pozzolanic activity. The general variation in three principal constituents will be as follows: SiO_2 (25-60%), Al_2O_3 (10-30%) and Fe_2O_3 (5-25%).

Table -3: Chemical Requirements of Fly Ash (As per BIS)

SN.	Characrteistics	Requirements	
		Siliceous Fly Ash	Calcareous Fly Ash
1	$SiO_2+Al_2O_3+Fe_2O_3$ (% by mass, Min.)	70	50
2	SiO_2 (% by mass, Min.)	35	25
3	Reactive silica (% by mass, Min.)	20	20
4	MgO (% by mass, Max.)	5	5
5	SO_3 (% by mass, Max.)	3	3
6	Na_2O (% by mass, Max.)	1.5	1.5
7	Total Chlorides (% by mass, Max.)	0.05	0.05
8	Loss on Ignition (% by mass, Max.)	5	5

Table -4: Chemical Requirements of Fly Ash (As per ASTM)

SN.	Characteristics	Requirements	
		Siliceous Fly Ash	Calcareous Fly Ash
1	$SiO_2+Al_2O_3+Fe_2O_3$ (% by mass, Min.)	70	50
2	Moisture Content (% by mass, Max.)	3	3
3	SO_3 (% by mass, Max.)	5	5
4	Loss on Ignition (% by mass, Max.)	6	6

2. MATERIALS USED

The various material used in this research work are cement, coarse aggregate, fine aggregate, super plasticiser, water and fly ash. The cement used was OPC of 43 grade. Size of coarse aggregate used are of 20mm and 10mm. To increase the fluidity of the concrete super plasticisers are used. For mixing and curing of concrete portable water is used. Fly ash is taken from Palod a village in Naya Raipur.

2.1 Test on ingredient of Fly ash concrete

2.1.1 Particle size distribution of Fly Ash

Sieve analysis is done to determine the particle size distribution. One kg of dry fly ash sample is taken and placed on the topmost sieve of the sieve shaker having different sizes of brass sieves. Place the pan on the bottom and cover on the top of the sieve shaker. Start it for shaking for 10 to 15 minutes. After complete shaking stop the sieve shaker and weight the material retained on each sieve.

Table -5: Weight retained on each sieve

SN.	Sieve Size (mm)	Weight Retained (gram)	% weight retained	Cumulative % weight retained	% Finer
1	4.75	45	4.5	4.5	95.5
2	2.36	65	6.5	11.0	89.0
3	1.18	84	8.4	19.4	80.6
4	0.600	95	9.5	28.9	71.1
5	0.300	123	12.3	41.2	58.8
6	0.150	205	20.5	61.7	38.3
7	0.075	383	38.3	100	00.0

2.1.2 Specific Gravity

The test is useful to know how much heavy the material relative to water. After receiving the Fly Ash sample, it is dried in an oven at a temperature of 105 to 115^{0}C for a period of 16 to 24 hours. Average specific gravity of fly ash is 1.87.

Table -6: Specific gravity using Density bottle method

SN.	Observation Number	1	2	3
1	Weight of Bottle (W_1)	594.2	594.2	594.2
2	Weight of Bottle and Soil (W_2)	744.2	744.2	744.2
3	Weight of Bottle, Soil and Water (W_3)	1552.6	1550.1	1553.3
4	Weight of Bottle and Water (W_4)	1482.0	1482.0	1482.0
	Specific gravity	1.89	1.83	1.90

2.2 MIX PROPORTION

To achieve target strength mix design of concrete is required. In this work concrete of grade M20 prepared by replacing the cement with fly ash. M20 mix design prepared using the following guidelines. Figure 1 shows checking slump value in concrete.

Figure- 1: Measure of slump value in concrete.

Concrete mix Design data required

I. Data required for concrete

a. Characteristic compressive strength at 28-day grade designation: M20
b. Nominal aggregate size (maximum) used: 20 mm
c. Shape of coarse aggregate used: Circular
d. Workability requirement (slump): 40-70 mm
e. Quality control checking : as per IS:456
f. Type of exposure: Mild (as per IS: 456)
g. Type of cement: OPC grade 43
h. Method of concrete placing: by hand

II. Concrete ingredient data

a. Specific gravity of cement used: 3.10
b. Specific gravity of fine aggregate (FA): 2.52
c. Specific gravity of coarse aggregate (CA): 2.71

Concrete Mix Design Procedure (M20 Grade concrete)

Step 1: Target Strength determination

$$F_{target} = f_{ck} + 1.65 \times S = 20 + 1.65 \times 4.0 = 26.6\ N/mm^2$$

Where,

S = standard deviation in N/mm^2 = 4 (From IS 10262-2009 Table no. 1)

f_{ck} = Characteristic Compression Strength at 28 days.

Step 2: Water/cement ratio selection

Water Cement Ratio 1200/2000 = 0.6 is mix concrete design as per Indian Standards

From IS 456 Table no. 5

Maximum water-cement ratio used= 0.55

Adopting water-cement ratio as 0.5.

Step 3: Water content selection
From IS 10262 (2009) Table no. 2, Maximum water content required for 20 mm nominal maximum size of aggregate = 186 Kg.

Step 4: Selection of cement content

W/C = 0.5

Therefore water content (correct) = 191.6kg/m^3

Cement content = 2* 191.6= 383.2 kg/m^3

From IS 456 Table no. 5,

Minimum cement content required (Type of exposure condition mild) = 300 kg/m^3

383.2 kg/m^3 > 300 kg/m^3 (OK)

As per clause 8.2.4.2 of IS: 456

Maximum cement content required = 450 kg/m^3

(As per IS: 456 clause 8.2.4.2)

Step 5: Calculation of coarse Aggregate proportion

From IS 10262 (2009) Table no. 3

For size of aggregate (max.) = 20 mm, and w/c = 0.5

Coarse aggregate volume per unit volume of total aggregate = 0.62

3. CONCLUSIONS

From the result of this study, it can be conclude that cement replacement by fly ash is useful in lower grades of cement such as M20. It can be stated that at 25% of replacement of cement by fly ash there is considerable increase in strength properties.

- Incorporation of fly ash in concrete can save the coal and thermal industry disposal cost and produce a “greener” concrete for construction.
- With the use of mineral admixture the cost is considerably reduced due to no use of mechanical vibrators plus viscosity modifying admixtures also avoided.
- The strength of concrete decreases with increases in percentage of fly ash first and again increases as the percentage of fly ash increases.

REFERENCES

[1] Diamond, S. (1984). "The utilization of fly ash," Cement and Concrete Research 14, 455-462.

[2] Dolen, T. P. (1987). "Performance of fly ash in roller compacted concrete at upper stillwater dam." Proceedings: Eighth International Ash Utilization Symposium.

[3] Dunstan, M. R. H. (1983). "Development of high fly ash concrete." Proceedings Inst. Civil Engineers, 74, 495-513.

[4] Joshi, R. C, Day, R. L., Langan, B. W., and Ward, M. A. (1987). "Strength and durability of concrete with high proportions of fly ash and other mineral admixtures," Durability of Building Materials 4, 253-270.

[5] Mather, B. (1956). "The partial replacement of portland cement in concrete," in Cement and Concrete, 37-73.

[6] Mehta, P. K. (1985). "Influence of fly ash characteristics on the strength of portland-fly ash mixtures," Cement and Concrete Research 15, 669-674.

[7] Mukherjee, P. K., Loughborough, M. T., and Malhotra, V. M. (1982). "Development of high-strength concrete incorporating a large percentage of fly ash and superplasticizers," Cement, Concrete, and Aggregates 4(2).

[8] Naik, T. R. (1987). "Setting and hardening of high fly ash content concrete," Paper presented at American Coal Ash 8th International Coal Ash Utilization Symposium.

[9] Ravina, D., and Mehta, P. K. (1986). "Properties of fresh concrete containing large amounts of fly ash," Cement and Concrete Research 16, 227-238.

[10] Sivasundaram, V., Carette, G. G., and Malhotra, V. M. (1990). "Long term strength development of high-volume fly ash concrete," Cement and Concrete Composites 12, 263-270

[11] Thomas, M. D. A. (1989). "The effect of curing on the hydration and pore structure of hardened cement paste containing pulverized fuel ash," Advances in Cement Research
2, 181-188.

BIOGRAPHIES

Mr. Khushal Chandra Kesharwani completed B Tech in Civil Engineering from Kalinga University Raipur. Currently he is working in his own firm.

Mr. Amit Kumar Biswas completed B Tech in Civil Engineering from Kalinga University Raipur. Currently he is working in his own firm.

Mr. Anesh Chaurasiya completed B Tech in Civil Engineering from Kalinga University Raipur. Currently he is working in Housing Board Abhanpur Raipur as a Junior Engineer.