STRENGTH CHARACTERISTICS OF FLY ASH CONCRETE WITH SAME WORKABILITY

A. Krishna Rao[1], D. Rupesh Kumar[2]

[1]*Assistant Professor, Department of Civil Engineering, CMR Institute of Technology, Hyderabad-504110, T.S., India*
[2]*Associate Professor, Department of Civil Engineering, University College of Engineering (A), Osmania University, Hyderabad-500007, T.S., India*

Abstract

For making high strength concrete, cement can be replaced by fly ash (collected from Vijayawada Thermal Power Station) upto an extent of 50% without affecting either compressive strength or flexural strength. It is proposed to investigate the effect on strength of fly ash concrete when water-binder ratio changes with same workability as that of basic mix. The consistency of cement decreases with increase in fly ash percentage. But no definite pattern is noticed in respect of initial and final setting times, through in all cases. The water-binder ratio, for a compaction factor of 0.72, reduces from 0.370 for basic mix to 0.335 for mix with 50% replacement of fly ash. The average increment in compressive strength at 28 and 90 days is 7% and 2% respectively. However, the average increment in flexural strength at 28 and 90 days age is 8% and 19% respectively. Hence, for the fly ash concrete with same workability, the increase in compressive strength is very marginal (2%); however, the increase in flexural strength is commendable (19%) compared to the basic mix.

Keywords: *Replacement of cement, fly ash, high strength concrete, workability, water-binder ratio.*

---***---

1. INTRODUCTION

Cement is the back bone for global infrastructure development. It was estimated that global production of cement is about 4200 million metric tons in 2017. Production of every ton of cement emits carbon dioxide to the tune of about 0.87 ton. It can be said that 7% of the world's carbon dioxide emission is attributable to Portland cement industry. We cannot go on producing more and more cement because of the high consumption of natural resources like lime stone and also the environmental pollution it causes. There is a need to economize cement utilization and one of the practical solutions is to partially replace cement with pozzolanic materials. Pozzolona is a natural or artificial material containing silica in a reactive form. It is a siliceous and aluminous material, which in itself possesses little or no cementitious value but in finely divided form and in the presence of moisture chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

Pozzolanas can be categorized as natural and artificial. While diatomaceous earth materials possessed by calcinations of soils are natural pozzolans, blast furnace slag, rice husk ash, etc. are artificial pozzolans. During hydration of cement considerable quantities of calcium hydroxide is liberated which is useless from the point of view of strength or durability. If pozzolanic material is added to the cement, the silica present in pozzolana combines with $Ca(OH)_2$ liberated by hydrating cement in the presence of moisture to form stable calcium silicates which have cementitious properties. Since soluble $Ca(OH)_2$ is converted into insoluble cementitious products, the permeability of such concrete is improved. It is established that the best pozzolans in optimum proportions mixed with Portland cement improves many of the qualities of concrete such as: less heat of hydration and thermal shrinkage; increase of water tightness; reduction of alkali-aggregate reaction; improvement of resistance to attack by sulphate soils and sea water. The IS: 456: 2000 [1] permits the use of pozzolana as it improves extensibility and workability, its lower susceptibility to dissolution and leaching, its lower cost. The reactivity of pozzolana is made use of to obtain cementitious properties in three forms viz, (i) Pozzolana as a part replacement of ordinary Portland cement; (ii) Pozzolana as a fine aggregate; and (iii) Pozzolana as an admixture.

IS 456: 2000 permits the use of the following pozzolanic materials: (i) Fly ash confirming to Part 1 of IS: 3812-1981 [2]; (ii) Silica fume confirming to a standard approved by the deciding authority; (iii) Fly ash giving required performance and uniformity characteristics; (iv) Metakaoline having fineness between 700 to 900 m^2/kg; (v) Ground granulated blast furnace slag.

Vipul and Pawan [3] proved for M40 grade that replacing cement by fly ash and lime up to 75% gives about 40.78% cost benefit compared to that of original mix cost. According to Padhye and Deo [4] with increase of fly ash there is steep increase in strength from 7 to 28 days and the variation in early strength is more than the variation in later strength. Thus, fly ash has an adverse effect on early strength of concrete. The strength increases with increasing amount of fly ash up to an optimum value, beyond which strength starts to decrease with further addition of fly ash. Oner, Akyuz and Yildz [5] stated that the optimum value of fly ash replacement for the four test groups is about 40% of cement. Gopalakrishnan *et al*. [6] studied the effect of different percentages (0, 15, 20, 25 and 30%) of replacement of cement with fly ash and concluded that cement can be replaced upto 25%. Rehi and Garg [7] replaced 20% of cement by weight with 27.5% fly ash and reported that the 28 day compressive strength is 109 to 123% of standard mix. Mehta [8] reported that for 25 MPa concrete, the cement content can be reduced from 307 kg/m^3 to 154 kg/m^3 by suitable adjustment in fine and coarse aggregate and reducing water-binder ratio from 0.58 to 0.38. Langley and Leaman [9] shown that the high volume fly ash concrete was having low permeability, low tendency for crack formation, propagation and resistance to freezing and thawing. Kiattikomal *et al.* [10] has studied that the fineness, not the chemical compositions, has the significant effect on compressive strength of mortar. The mortars with finer fly ashes gained higher compressive strength than those with the coarser ones. Naik and Singh [11] shown that the times of setting were generally delayed up to a certain level (60%) of cement replacement with fly ash, beyond this level, rapid setting occurred. Dunstun's [12] investigations on high fly ash content concrete (HFCC) show that a durable concrete exhibits increase in compressive strength beyond 28 days, little evidence of carbonation, low to average permeability, and resistance to chloride penetration. In this respect, it is significant that at the marine exposure sites, the chloride concentrations decrease significantly with depth. Strength and workability are two most important factors in the design of concrete mix. Most of the research done in the past on strength of concrete with partial replacement of cement by fly ash is keeping same water-binder ratio irrespective of the quantum of replacement of cement by fly ash. Hence, in this paper, it is proposed to investigate the effect on high strength concrete with cement partially replaced by fly ash when water-binder ratio adopted is such that the workability is same as that of basic mix.

2. EXPERIMENTAL PROGRAM

2.1 Materials used in Manufacture of Fly Ash Concrete

2.1.1 Cement

Ordinary Portland cement of 53 grade is used in the study. The fineness of cement is 2.5% and satisfied as per the IS: 12269-1987 [13] and the specific gravity of the cement is 3.15. The expansion of cement is 0.5 mm. The 7, 28 and 90 days compressive strength on cement mortar is 41.45 N/mm^2, 49.69 N/mm^2 and 51.11 N/mm^2 respectively. The standard consistency is 30%, initial and final setting times are 130 min and 239 min respectively.

2.1.2 Aggregate

River sand is used as fine aggregate with the following properties: Specific gravity is 2.62, fineness modulus is 2.0865, loose and rodded bulk density is 1.5325 gm/cm^3 and 1.7210 gm/cm^3, moisture content is 0.1%. For coarse aggregate the maximum size is 20 mm, specific gravity is 2.6251, fineness modulus is 6.5675, moisture content is 0.1%, loose and rodded bulk densities are 1.4481 gm/cm^3 and 1.656 gm/cm^3 respectively and satisfied as per the IS: 383-1970 [14].

2.1.3 Fly Ash

The composition of fly ash (collected from Vijayawada Thermal Power Station): SiO_2 is 61.32%, Al_2O_3 is 26.30%, Fe_2O_3 and Fe_3O_4 is 6.95%, CaO is 2.41 %, Na_2O is 1.02%. Its specific gravity is 2.0325 and bulk density is 0.8434 g/cm^3.

2.1.4 Cement and Fly Ash

The properties of mortar with partial replacement of cement by fly ash are shown in Table 1.

2.2 Water-Binder Ratio for Fly Ash Concretes for same Workability as that of basic Mix

The compaction factor for basic mix is 0.72 and w/c (water-cement ratio) is 0.37. For the concretes with partial replacement of cement by fly ash, the water-binder ratio for same compaction factor is determined by trial and error method and the results are given in Table 2.

2.3 Mix Design

M50 mix design is prepared using the Entroy and Shacklocks method (using references Shetty [15] and IS: 456 – 2000). The mix proportion for the basic mix is 1: 0.94:2.36:0.37 and compaction factor is 0.72. 54 cubes are casted and cured for 7, 28 and 90 days; 36 beams are casted and cured for 28 and 90 days.

2.4 Testing of Specimens

The concrete cube specimens are capped at both ends to ensure smooth surfaces and tested for compressive strength at the age of 7, 28 and 90 days. The reported results are the average of three concrete samples. The flexural strengths of concrete are reported at 28 and 90 days.

3. RESULTS AND DISCUSSIONS

Table 1 gives the properties of mortar with partial replacement of cement by fly ash and also expressed as a percentage of strength of basic mix. The results show that for cement partially replaced with fly ash, compressive strength of mortar cubes reduces at 7 and 28 days compared to that of the basic mix. However, the compressive strength increases marginally at 90 days as compared to the basic mix. Hence, this fly ash can be used for manufacturing the high strength fly ash concrete. The consistency of cement decreases with increase in fly ash percentage. But no definite pattern is noticed in respect of initial and final setting times, through in all cases. However, these are confirming as per IS: 4031(Part 5):1988 [16].

The results of compressive strength and flexural strengths of fly ash concrete are given in Table 2 and also expressed in the water-binder ratio reduces as the percentage of replacement of fly ash increases from 0 to 50%.

The water-binder ratio, for a compaction factor of 0.72, reduces from 0.370 for basic mix to 0.335 for mix with 50% replacement of fly ash. With decrease in water-binder ratio the compressive and flexural strengths increases. Therefore, for correct comparison of strength of concrete with and without fly ash, the water-binder ratio adopted should not be the same; but, it should be based on the criteria of same workability.

At 7 days age, the compressive strength of concrete with 20% replacement of fly ash is higher than that of the basic mix, whereas with 10% replacement, it is 3.5% less. For replacements beyond 20% the compressive strength is much less. At 28 days age, the compressive strength of concrete with replacement of fly ash even upto 50% is not less than terms of percentages in parenthesis. The experimental results show that for same workability as that of basic mix, that of the basic mix (except for a small decline of 1.57% for 10% replacement). For 30% and 40% replacements, it is in fact higher by about 13% and 16% respectively. The average increment in compressive strength at 28 days is 7%. At 90 days age, the compressive strength of concrete with replacement up to 50% is not less than that of the basic mix (except for a small decline of 0.58% for 40% replacement). The average increment in compressive strength at 90 days is just 2%. The flexural strength of concrete at 28 and 90 days is highest at 30% replacement of fly ash. The average increment in flexural strength at 28 and 90 days age is 8% and 19% respectively.

From the above discussions it is seen that for the fly ash concrete with same workability, the increase in compressive strength is very marginal (2%); however, the increase in flexural strength is commendable (19%) compared to the basic mix.

Table 1: Properties of mortar with partial replacement of cement by fly ash

% of cement replaced by fly ash	Normal consistency (%)	Initial setting time (min)	Final setting time (min)	Compressive strength (N/mm^2)		
				7 days	28 days	90 days
0	30.00	130	239	41.45 (100.00)	49.69 (100.00)	51.11 (100.00)
10	29.25	111	210	38.67 (93.29)	44.99 (90.54)	53.78 (105.22)
20	29.00	115	250	37.35 (90.10)	46.39 (93.37)	53.43 (104.53)
30	28.50	118	225	33.98 (81.90)	42.58 (85.71)	51.20 (100.17)
40	28.00	119	230	29.06 (70.11)	43.79 (88.12)	53.46 (104.60)
50	27.75	125	247	27.22 (65.69)	42.38 (85.29)	50.20 (98.21)

Table 2: Compressive and flexural strength test results of concrete

S. No.	% of replacement of cement by fly ash	Water-binder ratio	Compressive strength (N/mm^2)			Flexural strength (N/mm^2)	
			7 days	28 days	90 days	28 days	90 days
1	0	0.3700	46.85 (100.00)	54.76 (100.00)	65.52 (100.00)	6.984 (100.00)	7.045 (100.00)
2	10	0.3625	45.24 (96.56)	53.90 (98.43)	67.63 (103.22)	7.265 (104.20)	8.654 (122.84)
3	20	0.3500	50.04 (106.80)	58.62 (107.00)	68.20 (104.09)	7.209 (103.22)	8.083 (114.73)
4	30	0.3400	43.45 (92.74)	61.87 (112.98)	66.17 (100.99)	8.130 (116.20)	8.610 (122.21)
5	40	0.3375	38.42 (82.00)	63.91 (116.71)	65.14 (99.42)	7.513 (107.54)	8.184 (116.16)
6	50	0.3350	33.98 (72.53)	55.83 (101.95)	67.19 (102.55)	7.693 (110.15)	8.457 (120.04)

4. CONCLUSION

For making high strength concrete, cement can be replaced by fly ash (collected from Vijayawada Thermal Power Station) up to an extent of 50% without affecting either compressive strength or flexural strength. For cement partially replaced with fly ash, compressive strength of mortar cubes reduces at 7 and 28 days, but increases marginally at 90 days as compared to the basic mix. Hence, this fly ash can be used for manufacturing the high strength fly ash concrete.

The water-binder ratio, for a compaction factor of 0.72, reduces from 0.370 for basic mix to 0.335 for mix with 50% replacement of fly ash. With decrease in water-binder ratio the compressive and flexural strengths increases. Therefore, for correct comparison of strength of concrete with and without fly ash, the water-binder ratio adopted should not be the same; but, it should be based on the criteria of same workability.

The consistency of cement decreases with increase in fly ash percentage; but, no definite pattern is noticed in respect of initial and final setting times, through in all cases. The average increment in compressive strength at 28 and 90 days is 7% and 2% respectively. However, the average increment in flexural strength at 28 and 90 days age is 8% and 19% respectively. Hence, for the fly ash concrete with same workability, the increase in compressive strength is very marginal (2%); however, the increase in flexural strength is commendable (19%) compared to the basic mix.

ACKNOWLEDGEMENTS

The authors of the present paper work would like to acknowledge CMR Institute of Technology, Hyderabad, Telangana, for providing the laboratory facilities during the research work.

REFERENCES

[1] IS: 456–2000, Code of Practice for Plain and Reinforced Concrete, BIS, New Delhi.
[2] IS: 3812-1981, Specifications of Fly ash use as Pozzolana and admixture, BIS, New Delhi
[3] Vipul Naidu, P., and Pawan Kumar Pandey (2014). "Replacement of cement in concrete." *International Journal of Environmental Research and Development*, 4(1), 91-98.
[4] Padhye, D., and Deo, N.S. (2016). "Cement replacement by fly ash in concrete." *International Journal of Engineering Research*, 5, 60-62.
[5] Oner, A., Akyuzb, S., and Yildiz R. (2005). "An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete." *Cement and Concrete Research*, 35, 1165–1171.
[6] Gopalakrishnan, S., Rajamane, N.P, Neela Megam, M., Peter, J.A., and Dattatreya, J.K. (2001). "Effect of partial replacement of cement with fly ash on the strength and durability of HPC." *The Indian Concrete Journal*, 75(5), 335-341.
[7] Rehi. S.S., and Garg. S.K., "Use of fly ash in concrete technology." *National workshop on utilization of Fly ash organized by Central building research institute, Roorkee*. May 19-20, 1988, 117-125.
[8] Kumar Mehta, "Preening of the concrete industry for sustainable development". *Concrete International (Originally presented as the Tuthill Commemorative lecture at the Fall 2001 ACI convention, Dallas, Texas)*, July 2002, 23-28.
[9] Langely, W.S., and Leaman, G.H. (1992). "Development of high strength concrete incorporating a large percent of fly ash and super plasticizer." *ASTM Journal*, *Cement Concrete and Aggregates*, 4, 45-58.
[10] Kraiwood Kiattikomal, Chai Jaturapitakkul, Smith Songpiriyskij, and Seksun Chutubtim (2001). "A study of ground coarse fly ashes with different fineness from various sources as pozzolanic materials." *Cement and Concrete composite*, 23, 335-343.
[11] Tarun Naik, R., and Shiw Singh, S. (1997). "Influence of Fly ash on setting and hardening characteristics of concrete systems." *ACI Materials Journal*, 355-360.
[12] Dunstun, M.R.H. (1992). "Investigation into the long term in-situ performance of high fly ash content concrete used for structural applications." *ACI SP*, 132, 1-20.
[13] IS: 12269-1987, Grade Ordinary Portland Cement Specifications, BIS. New Delhi.
[14] IS: 383-1970, Specification for Coarse and Fine Aggregates from Natural Sources for Concrete, BIS, New Delhi.
[15] Shetty, M.S. (2009). *Concrete Technology*, S. Chand and Company Ltd., New Delhi.
[16] IS: 4031 (Part 5):1988 Methods of physical tests for hydraulic cement: Determination of initial and final setting times.

BIOGRAPHIES

A. Krishna Rao has over 12 years of teaching experience; published 2 research papers and is a Ph.D. scholar at University College of Engineering, Osmania University, Hyderabad, Telangana, India

Dr. D. Rupesh Kumar has vast administrative experience; published 24 research papers; conducted 2 international conferences / 10 workshops; attended 32 workshops; visited 2 countries, delivered 8 guest lectures; edited 2 books; guiding 9 Ph.D. scholars; guided 27 M.E. projects; completed 430 consultancy projects.