# Cementing Efficiency of Low Calcium Fly Ash in Fly Ash Concretes

T. D. Gunneswara Rao, Mudimby Andal

***Abstract*—**Research on the utilization of fly ash will no longer refer the fly ash as a waste material of thermal power plants. Use of fly ash in concrete making, makes the concrete economical as well as durable. The fly ash is being added to the concrete in three ways namely, as partial replacement to cement, as partial replacement to fine aggregates and as admixture. Addition of fly ash to the concrete in any one of the form mentioned above, makes the concrete more workable and durable than the conventional concrete. Studies on fly ash as partial replacement to cement gained momentum as such replacement makes the concrete economical. In the present study, an attempt has been made to understand the effects of fly ash on the workability characteristics and strength aspects of fly ash concretes. In India major number of thermal power plants is producing low calcium fly ash. Hence in the present investigation low calcium fly ash has been used. Fly ash in concrete was considered for the partial replacement of cement. The percentage replacement of cement by fly ash varied from 0% to 40% at regular intervals of 10%. More over the fine aggregate to coarse aggregate ratio also has been varied as 1:1, 1:2 and 1:3. The workability tests revealed that up to 30% replacement of cement by fly ash in concrete mixes water demand for reduces, beyond 30% replacement of cement by fly ash demanded more water content for constant workability.

***Keywords*—**Cementing Efficiency, Compressive Strength, Low Calcium Fly Ash, Workability.

## I. Introduction

WITH the increase in industrial growth, the Indian society is experiencing a boom in industrial and consumer goods production. To sustain the growth rate, infrastructure needs to be strengthened and expanded. As a result the construction activity has risen up, demanding for the higher production of cement. Any eco-friendly measure in saving the cement quantity in the construction field is highly appreciated and use of fly ash in concrete is one of the best alternatives. In India around 100 million tons of fly ash is being produced every year, by the thermal power plants, and the disposal of which is becoming a major problem. The fly ash ponds developing around the thermal power plants are causing adverse impacts on the environment like health hazards, soil sickness etc. Studies on fly ash utilization in concretes indicated that, fly ash is a good pozzolanic material, hence can be used in the concrete making.

Fly ash has been classified as Class C fly ash and Class F fly ash. Class C fly ashes contain more calcium oxide (greater than 10%) compared to Class F fly ashes. High calcium fly ashes possess self hardening properties while the low calcium fly ashes possess less or no self hardening properties. The fly ash collected from the cyclonic separator is relatively coarser than the fly ash collected from the electrostatic precipitator.

## II. Review of Literature

Malhotra V. M. [1] based on his experimental results concluded that fly ash may be expected to influence the rate of hardening of cement. Low calcium Fly ashes tend to reduce the retard the setting time of the cement. More over it was also concluded that fly ash cement mortars contain less water, which will influence the stiffness of the mortar. Experiments conducted at CANMET proved that the ashes significantly increases both initial setting time and final setting time.

Helmuth [2] suggested that water reduction caused by fly ash was the result of an absorption and dispersion process very much like that of organic water-reduction admixtures.

Smith [3] proposed a factor called cementing efficiency 'k' such that a mass of 'f' fly ash is equivalent to a mass 'kf' of cement in terms of strength development. Based on his experiments the k-factor was found to be 0.25 for 25%flyash as CRM.

Ganesh Babu and Siva Nageswara Rao [4] reported that contribution of fly ash is not a constant determined solely by its physical and chemical properties, but also vary depending upon the type of cement, water/cement ratio etc,.

Bharat Kumar et al. [5] proposed a methodology for the concrete mix design, using cement replacing materials (CRM). The Cementing efficiency factor of CRM, including fly ash, was used to arrive at the economical mixes.

## III. Methodology

The literature reported on the utilization of fly ash in concrete mixes indicated that the fly ash addition to the conventional concrete mixes improves the workability of the mix and the compressive strength of the mix. However, the effect of partial replacement of cement by fly ash for different fine aggregate to coarse aggregate ratios was not reported. The fine aggregate to coarse aggregate ratio may affect the percentage replacement cement by fly ash. This is because fly ash particles may act as some part of the fine aggregates also. Thus in the present investigation an attempt has been made to assess the effect of fine aggregate to coarse aggregate ratio on the water demand characteristics and compressive strength characteristics of fly concretes. The workability (slump) of all mixes considered in the investigation was maintained constant between 45mm - 50mm. The cement has been replaced by fly

Dr.T.D.Gunneswara Rao is with National Institute of Technology, Warangal-506004, India (Phone: +91 870 246 2139; Email: tdgtdg@gmail.com, tdg@nitw.ac.in).

Dr. Mudimby Andal is with Civil Engineering Department of Kakatiya Institute of Technology and Science, Erragattugutta, Warangal-506 015, India (e-mail: andaltippabhotla@gmail.com).

ash up to 40%. Three fine aggregate to coarse aggregate ratios were considered. They are 1:1, 1:2 and 1:3. 20mm size hard granite aggregate has been used. The water binder ratio (w/(c+f)) was varied as 0.5 and 0.6.

*Designation of specimen* **-** Symbol 'A' and 'B' were used to distinguish water / (cement + fly ash) ratio of corresponding mixes as 0.5 and 0.6 respectively. The first suffix of the symbol (1, 2, and 3) represents the fine aggregate to coarse aggregate ratio (1:1, 1:2, and 1:3 respectively). Second suffix (1, 2, 3, 4, and 5) represents the percentage replacement of cement by fly ash (0%, 10%, 20%, 30%, and 40% respectively). Thus a symbol of the cube say A34 represents a mix with water / (cement + fly ash) ratio 0.5, Coarse Aggregate / fine aggregate ratio 3 and percentage of cement replaced by fly ash is 30%.

## IV. Materials

### *A. Cement*

The ordinary Portland cement of 43 Grade is used for the production of concrete. Consistency, specific gravity and fineness as percentage retained on 90microns sieve were found to be 30%, 3.10 and 4.3% respectively.

### *B. Fine Aggregate*

The fine Aggregate used in this investigation has a fineness modulus of 2.67. The specific gravity and unit weight are found to be 2.30 and 1510kg/cu.m. respectively. The sieve analysis revealed that the fine aggregate falls in the Zone II of IS 383:1972. The fineness modulus of the fine aggregate is found be 2.68.

### C. *Coarse Aggregate*

The nominal maximum size of the coarse aggregate is of 20mm. The Specific gravity and fineness modulus of the Coarse Aggregate was 2.78 and 6.89 respectively.

### *D. Fly Ash*

The Fly Ash obtained from N.T.P.C. Ramagundam plant is used. The Fly Ash looks like cement in appearance, however when magnified fly ash particles appear as spherical, where as cement appears angular. The fly ash used in this investigation has a specific gravity of 2.12.

## V. Experimental Program

The experimental program was designed to evaluate the effectiveness of fly ash as CRM in improving workability and strength of concrete. The water required for each variation was found keeping the constant workability. Trial mixes were cast for all variations considered in the investigation such that all mixes give a slump in the range of 45mm-50mm. In each and every trial mix coarse aggregate and fine aggregates in the desired proportion were mixed well. Binder (Water + Cement + Fly ash) in the pre-defined proportion was added to the aggregate in sufficient quantity so as to obtain mix of desired slump (45-50mm). Then with this finalized mix cubes were cast. The materials were mixed in an electrically operated mixing machine. The running speed of the mixer is 15 revolutions per minute. For obtaining uniform mix the drum was allowed to rotate for about 25-30 revolutions. The water, Cement, Fly ash, Fine aggregate and Coarse Aggregate requirement for Cubic Meter of Concrete were evaluated and are presented in Table I. The compressive strength of concrete with varying fine aggregate to coarse aggregate ratio was also studied. For each mix, 5 cubes were cast for evaluating the compressive strength. The average compressive strength of five specimens was considered to be the compressive strength of the respective mix. The compression test has been conducted after 90 days of curing.

TABLE I
Different Ingredients per Cubic Meter of Concrete and 90 days Compressive Strength

| Mix | Water | Cement | Fly ash | FA | CA | $f_c$ |
|---|---|---|---|---|---|---|
| A11 | 203.19 | 406.39 | 0 | 837.91 | 837.91 | 46.87 |
| A12 | 203.04 | 365.8 | 40.69 | 830.42 | 830.42 | 49.12 |
| A13 | 200.73 | 321.59 | 80.29 | 827.77 | 827.77 | 46.97 |
| A14 | 198.76 | 278.34 | 119.17 | 824.72 | 824.72 | 39.75 |
| A15 | 200.76 | 241 | 160.53 | 812.81 | 812.81 | 30.25 |
| A21 | 197.22 | 394.88 | 0 | 585.16 | 1170.33 | 45.40 |
| A22 | 191.08 | 344.21 | 38.39 | 588.95 | 1177.91 | 47.91 |
| A23 | 189.71 | 303.88 | 75.97 | 586.06 | 1172.11 | 46.20 |
| A24 | 188.09 | 263.32 | 112.85 | 583.72 | 1167.44 | 37.82 |
| A25 | 191.84 | 230.47 | 153.64 | 572.98 | 1145.96 | 28.82 |
| A31 | 193.43 | 386.86 | 0 | 450.34 | 1351.01 | 38.22 |
| A32 | 189.44 | 340.65 | 37.8 | 451.04 | 1353.13 | 43.50 |
| A33 | 187.18 | 299.4 | 74.96 | 449.75 | 1349.24 | 40.52 |
| A34 | 185.57 | 259.79 | 111.34 | 447.92 | 1343.75 | 33.47 |
| A35 | 190.43 | 228.85 | 152.43 | 438.49 | 1315.48 | 20.58 |
| B11 | 210.63 | 351.05 | 0 | 851.02 | 851.02 | 38.06 |
| B12 | 193.59 | 290.61 | 32.05 | 877.97 | 877.97 | 40.75 |
| B13 | 191.16 | 254.73 | 63.57 | 876.88 | 876.88 | 39.04 |
| B14 | 190.23 | 222.08 | 95.11 | 872.6 | 872.6 | 35.62 |
| B15 | 192.89 | 192.89 | 128.74 | 861.12 | 861.12 | 30.53 |
| B21 | 205.46 | 342.44 | 0 | 592.68 | 1185.36 | 33.50 |
| B22 | 187.1 | 280.64 | 31.33 | 613.06 | 1226.11 | 36.50 |
| B23 | 183.38 | 244.36 | 60.98 | 614.3 | 1228.61 | 35.45 |
| B24 | 182.21 | 212.57 | 91.1 | 611.89 | 1223.78 | 30.43 |
| B25 | 187.02 | 187.02 | 124.68 | 601.14 | 1202.28 | 28.04 |
| B31 | 204.13 | 340.51 | 0 | 453.15 | 1359.44 | 29.40 |
| B32 | 180.61 | 270.91 | 30.25 | 474.09 | 1422.27 | 32.82 |
| B33 | 176.23 | 235.12 | 58.89 | 475.68 | 1427.05 | 31.07 |
| B34 | 175.52 | 204.4 | 87.54 | 473.77 | 1421.32 | 26.63 |
| B35 | 179.15 | 179.15 | 119.58 | 466.77 | 1400.31 | 22.26 |

FA- Fine aggregate; CA – Coarse Aggregate; $f_c$- compressive Strength (MPa)

## VI. Results and Discussions

The water requirement for different proportions considered in this investigation is shown in Figs. 1 and 2. From these figures it can be observed that up to 30% replacement of cement by fly ash there is considerable decrease in the water requirement for given workability. Fly ash particles decreased the water content requirement in the concrete mix from workability point of view. This may be due to the reason that spherical particles of fly ash acted as ball bearings and allowed the coarse aggregates to roll one over other freely.

The decrease in water content is found to be more in the mixes with fine aggregates to coarse aggregates ratio of 1:3. The decrease in water content is observed to be less in the mixes with fine aggregates to coarse aggregates ratio of 1:1. From this observation it can be concluded that the mixes with higher fine aggregate to coarse aggregate ratio require less water from workability point of and water content can further be reduced with the addition of fly ash. The similar behavior was observed when the water to binder ratio is 0.6. Maximum decrease in water content requirement in case A11-A15 series of mixes was 2.18%, while the same in the case of A31-A35 series of mixes was found to be 4.06%. This infers that in mixes with higher coarse aggregate to fine aggregate ratio the effect of fly ash is pronounced. This may be due to the reason that fly ash particle would acted as a part of fine aggregate also.

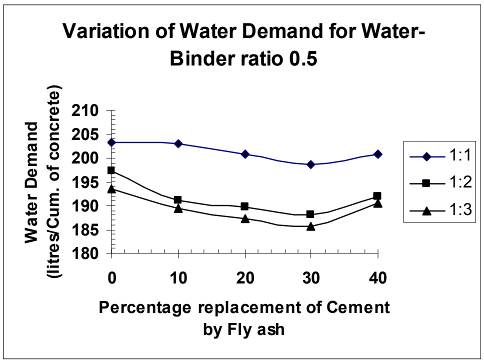


Fig. 1 Variation of water demand in fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

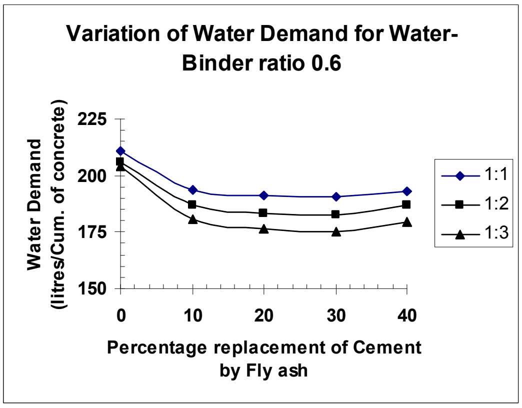


Fig. 2 Variation of water demand in fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

The variation of cement requirement in different mixes was presented in Figs. 3 and 4. From these variations it can be observed that cement requirement in fly ash concretes can be considerably reduced. However reduction in cement content at higher percentage replacements adversely affected the compressive strength. The variation of compressive strength of all mixes for different water to cementitious materials ratio was presented in Figs. 5 and 6. From these variations, it can be understood that 10% replacement of cement by fly ash improved the compressive strength of the matrix. Even at 20% replacement of cement by fly ash did not dropped the compressive strength of the matrix below the compressive strength of the conventional mix. But beyond 20% replacement of cement by fly ash has shown adverse effect on the compressive strength of the mix. The similar behavior was observed in case of the mixes with water to binder ratio 0.5 and 0.6. The maximum percentage increase in the compressive strength of A11-A15 series mixes was found to be 4.88%. In case of A31-A35 series mixes the maximum percentage improvement in the compressive strength was observed as 13.81%. From this observation it can be concluded that fly ash is more suitable in concrete mixes where the coarse aggregate to fine aggregate ratio is high (Under sanded mixes)

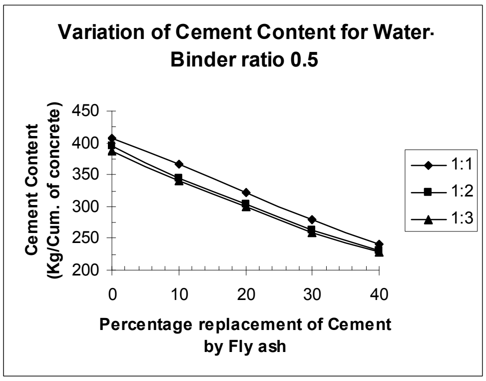


Fig. 3 Variation of cement content in fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

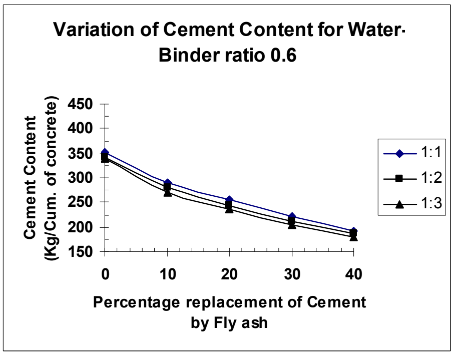


Fig. 4 Variation of cement content in fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

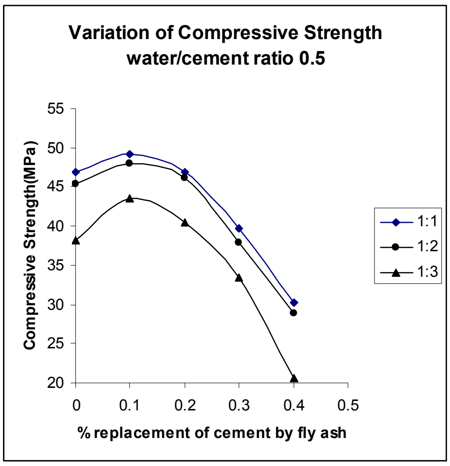


Fig. 5 Variation of Compressive strength of fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

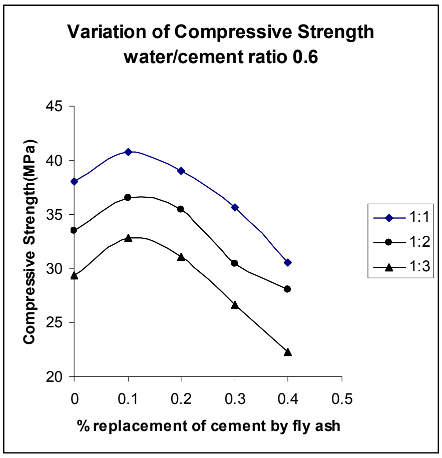


Fig. 6 Variation of Compressive strength of fly ash concrete for various FA:CA ratios at constant W/C ratio and slump

## VII. Cementing Efficiency of Fly Ash

In the present investigation cementing efficiency of fly ash was calculated for the three variations studied of fine aggregate to coarse aggregate ratio for the water binder ratio of 0.6. From Fig. 7, it can be found that when coarse aggregate to fine aggregate ratio is 1:1, 23% replacement of cement by fly ash is giving strength of conventional concrete without fly ash. Thus the corresponding cementing efficiency factor can be found as 1.00. The calculations for the k-factor were presented in Appendix-I. The k-factor for the remaining two series of mixes with water binder ratio of 0.6 is found to be 1.00. Thus the cementing efficiency factor is a useful parameter in the mix design of fly ash concretes. The German standards [6] value of k- factor was proposed as 0.3 for 10-25% replacement. The higher value of k-factor reported in this investigation may be because of higher reactivity of the fly ash. However some more confirmatory tests are needed to specify this value.

## VIII. Conclusion

Based on the tests conducted on the green as well as hardened low calcium fly ash concretes in this investigation, the following conclusions were drawn. The water binder ratio of the mixes was 0.5 and 0.6 in this investigation.

1. Replacement of cement by fly ash up to 10% increases the compressive strength of the mix.
2. Replacement of cement by fly ash up to 20% can be recommended without compromising on the compressive strength of conventional mix (without fly ash).
3. Replacement of cement by fly ash up to 30% decreases the water requirement of the matrix from workability point of view. It may be noted here that expectedly a reduction in water binder ratio causes increase in strength as seen from the higher strengths of fly ash concretes with water binder ratio 0.5 compared to those with water to binder ratio 0.6. This fact can be utilized to achieve desired strength levels in concretes with higher fly ash contents and any possible increased water demand can be accounted by using suitable super plasticizers at appropriate dosage level.

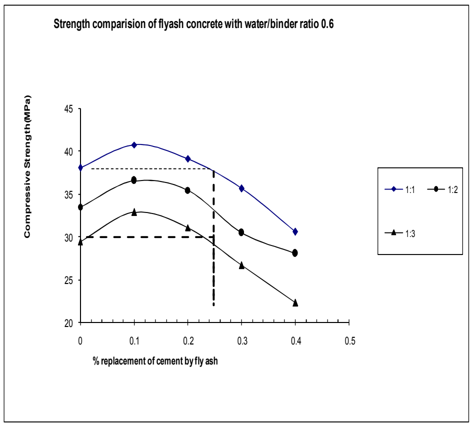


Fig. 7 Strength comparison of fly ash concrete with different percentage replacement of cement by fly ash for k-factor calculation

## Appendix

*Calculations for the Cementing Efficiency Factor of Fly Ash:*

B11-B15 series was considered for the demonstration. From Fig. 7 it was found that 23% replacement of cement by fly ash gives the 90-day compressive strength equal to that of the concrete mix without fly ash. From Table I, the materials required for the concrete mix without fly ash were

Cement = 351.05 kg; water = 210.63kg.

For 23% replacement of cement by fly ash quantities were calculated by linear interpolation (assumed).

Cement = 244.94 kg; water = 192.86kg. Fly ash = 73.03kg.

$$\left(\frac{w}{c}\right)_{no\_flyash} = \left(\frac{w}{c+kf}\right)_{23\%\_flyash}$$

$$\Rightarrow \left(\frac{210.63}{351.05}\right)_{no\_flyash} = \left(\frac{190.88}{244.94 + k(73.03)}\right)_{23\%\_flyash}$$

$$\Rightarrow k = 1.00$$

## ACKNOWLEDGMENT

Authors are highly thankful to the authorities of National Institute of Technology, Warangal, for providing necessary materials and equipment for conducting the experimental program.

## REFERENCES

[1] V. M. Malhotra, "CANMET Investigations dealing with high volume fly ash concrete", *Advances in Concrete Technology*, Canada Communication Group Publishing Co., Otowa,Canada,1992, pp 443-470
[2] R. H. Elmuth. "Fly ash in Cement and Concrete", *Portland cement Association*, 1987.
[3] I. A. Smith, "The design of fly ash concretes", *Proc Institute of Civil Engg*., vol.33, 1967, pp 769-790.
[4] K. Ganesh Babu and G. Siva Nageswara Rao, "Efficiency of fly ash in concrete", Cement and Concrete Composites, 15(1993) pp 223-229
[5] B.H. Bharat Kumar, R. Narayanan, B.K. Raghu Prasad and D.S. Ramachandra Murthy, "Mix proportioning of high performance Concrete", *Cement and Concrete Composites*, 23(2001) pp 71-80.
[6] DIN 1045. Belton und Stahlbeton, GMBH, Koln.

**Dr. T. D. Gunneswara Rao** born in Andhra Pradesh of India in 1966, Post Graduated in Structural Engineering in 1989 and Doctorate in Civil Engineering in 2003 at National Institute of Technology, Warangal, Andhra Pradesh, India.

He is working as Associate Professor in Civil Engineering at National Institute of Technology, Warangal, Andhra Pradesh, India. He has published technical papers in Magzine of Concrete Research, Cement and Concrete Research and Cement and Concrete Composites etc. He guided several post graduate dissertations and Six Doctoral thesis. His areas of research are Sustainable Construction Materials and Fracture Mechanics of Concrete Structures.

**Dr. Gunneswara Rao** is a member of Indian Concrete Institute and Institution of Engineers (India).

**Dr. Mudimby Andal** born in Andhra Pradesh of India in 1968, Post Graduated in Geotechnical Engineering in 2000 at National Institute of Technology, Warangal, Andhra Pradesh, India and Doctoral in Civil Engineering in Jawaharlal Nehru Technological University, Andhra Pradesh India.

She is working as Associate Professor in Civil Engineering at Kakatiya Institute of Technology and Science, Warangal, Andhra Pradesh, India. She has published technical papers in several International Conferences. Her areas of research are Sustainable Construction Materials and Geo-Environmental Engineering.

**Dr. Andal** is a member of Indian Society for Technical Education.