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Use of Parawada Fly Ash in Concrete as Partial Replacement of Cement

Dr. Narasinga Rao, B.N.D.[1], ME, PhD, FIE, FIGS and **AnanthaSairam, K.**[2]
1Professor & Head, 2 Graduate student
Department of Civil Engineering,
Anil Neerukonda Institute of Technology & Sciences,
Sangivalasa, Bheemunipatnam , Visakhapatnam, India

1. INTRODUCTION

Fly ash, the solid waste from thermal power plants and other industries using coal as fuel, has been a serious problem of environmental pollution for the last several decades across the world including in India (Vimal Kumar et al, 2005). Besides air pollution, the disposal of fly ash leads to pollution of land and ground water resources, and requires increasingly huge areas of valuable agricultural landsfor disposal (Sarat Kumar and Yudhbir, 2005). Utilization of fly ash for various civil engineering applications is therefore gaining attention of researchers and industries.

Though, a few decades before, the research on fly ash was limited to using it as an admixture in small proportions, the focus has now shifted to using fly ash in large volumes such as in concrete replacing the cement (Tomas, 2013; Rishabh Joshi, 2017; Saurav Kumar and Prashanth, 2016; and other studies cited later in this paper).

Using fly ash in concrete replacing the cement, on the one hand, causes dilution of cement and hence decreases the compressive strength. On the other hand, the free lime available in concrete initiates additional pozzolanic reactions with fly ash, adding to the strength, reducing the permeability of concrete and improving its resistance to acid attack and corrosion of steel.Use of fly ash in concrete, replacing the cement, would not only solve the pollution problem of fly ash but also decreases the overall cost of construction. Besides, it also leads to sustainable construction due to reduction in the use of cement which is the source of large CO_2 emissions during its production (Mehta, 1998)*.

There are several factors that influence the compressive strength of concrete, when cement is replaced with fly ash, such as type and % of fly ash, grade of concrete, grade of cement, w/cm ratio, mix proportion and mix design procedure as well as admixture used such as superplasticizer.

(Foot note: * As referenced in Mark and Kevin, 2006)

The characteristics of fly ash are found to vary widely from source to source and also at the same source from time to time (Yudhbir and Honjo, 1991; Winter and Clarke, 2002) and with collection point and variation in load generation (Lee et al, 1999). It is therefore not surprising that there is wide variation in the results of studies using fly ash in concrete replacing the cement.

For example, Kiran and Ratnam (2014) and Bansal et al (2015) reported that replacement of cement with fly ash, up to 23% and 30% respectively, increases the compressive strength of concrete relative to control concrete. Studies by Patil et al (2012), Jayesh Kumar et al (2012), Rishab Joshi (2017), Nagabhushana (2015) and Marthong and Agrawal (2012) indicate that the compressive strength of concrete decreases with increase in the fly ash content. Narasinga Rao (2016),Nagabhushana (2015),Wankhede and Fulari (2014), Arka et al (2014), Binod Kumar et al (2007), Dodson (1988) [#] and Helmuth (1987)[#] found that replacement of cement with fly ash increases the compressive strength of concrete when % of fly ash is low and further increase in fly ash decreases the compressive strength.

(Foot note: # As referenced in Toy Poole, 1995)

Studies on influence of fly ash on compressive strength and other properties of concrete using fly ash from each thermal power plant are highly needed today in order to enhance the use of fly ash concrete.Class F Fly ash is the most abundant in India, compared to Class C Fly ash. Narasinga Rao (2016) reported the effect of Class F Fly ash from NTPC, Parawada, on the properties of M25 concrete with a nominal mix of 1:1:2 without any admixture. From this study, it was found that Class F Fly ash from NTPC, Parawada can be used replacing up to about 50% cement, to produce M25 concrete of required target compressive strength.

The present study deals with the effect of the samefly ash on the properties of M25 concrete, using Mix design as per IS 10262, with Superplasticizer as admixture.

2. MATERIALS AND METHODS

The fly ash used in the study was collected from NTPC, Parawada, Visakhapatnam on December 5, 2016. Table 1 presents the chemical composition of fly ash. The specific gravity of the fly ash was 2.20.

Table1Chemical composition of fly ash

Chemical Compound	%
SiO_2	60.01
SiO_2+ Al_2O_3+ Fe_2O_3	94.48
Na_2O	0.24
CaO	8.7
MgO	0.20
SO_3	0.28
Loss on ignition	0.6

Concrete was prepared using 53 Grade Cement (OPC), 20mm aggregate, sand, Super Plasticizer,FosrocConplastSP430 and potable water. The specific gravity of cement is 3.10. The w/cm ratio was found out for control concrete (0% fly ash) for the desired slump of 50 mm by trials.

For each fly ash proportion, superplasticizer of 10 ml per kg of cement was added and different w/cm ratios were used to check for the slump value. Optimum w/cm ratio was determined from the considerations of desired slump and compressive strength of concrete. Then the Mix design was carried out for concrete as per IS: 10262-2009. A design mix of M25 was prepared with different w/cm ratios and hence different workability. The w/cm ratio corresponding to a workability of 50 mm was adopted for the mix. Table 2 presents the proportion of materials in concrete obtained from Mix design.

Cubes were prepared in cube moulds of 150mm size and prisms in moulds of 50mm×10mm×10mm size. The concrete was prepared by mixing ingredients in concrete mixer. After mixing the ingredients for 3 minutes, the fresh concrete was tested for workability by using slump cone apparatus. Compaction of concrete was done by placing the moulds on the vibration table and applying vibrations for 2 minutes. The concrete cubes were allowed to set for 24 hours and the moulds were dismantled and cubes were placed in curing tank.

Table 2Mix Proportions for Concrete

S. No.	% Fly ash*	Design Mix cm:fa:ca	w/cm ratio	Mix designation
1	0	1:1.358:1.910	0.35	CF0 (Control concrete)
2	25	1:1.409:1.937	0.33	CF25
3	50	1:1.329:1.827	0.32	CF50
4	75	1:1.119:1.538	0.30	CF75

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* % Fly ash = % of fly ash in total cementitious material (fly ash+cement)
cm= cementitious material=cement+fly ash
fa=fine aggregate; ca=coarse aggregate

To find out the compressive of concrete, cubes are cast with 0%, 25%, 50%, 75% replacement of cement by fly ash and their corresponding compressive strength was determined after 28 days curing. Each test was carried out on three identical concrete cube specimens. The average of the three values obtained from the three specimens for the given mix was adopted as its compressive strength. Similarly, the flexural strength test is carried out on three identical prisms for each mix.

3. RESULTS AND DISCUSSIONS

3.1 Influence % fly ash on Compressive strength

Table 3 presents the 28-day compressive strength of concrete at different % of fly ash. The compressive strength decreases with increase in % fly ash. The % variation in compressive strength with respect to that of control concrete is almost similar to the % fly ash itself, indicating a linear relationship between the two. The compressive strength decreases by about 50.4% when 50% of the cement is replaced with fly ash.

Table 3 Effect of fly ash on compressive strength of concrete

S. No	% Fly ash	% Cement	Compressive strength of Concrete (N/mm^2)	% Variation with control concrete
1	0	100	53.8	0
2	25	75	39.1	-27.3
3	50	50	26.7	-50.4
4	75	25	15.8	-70.5

Fig.1 presents the variation of compressive strength with % fly ash. The compressive strength varies almost linearly with % fly ash as indicated by Eq.(1) with a correlation coefficient (R^2) of 0.9953.

$$f_{ck} = 52.775 - [0.5048 \times (\%fa)] \qquad (1)$$

From Fig.1, the optimum fly ash for achieving a target compressive strength of 31.6 N/mm^2 (as per IS:456) for M25 concrete is found to be about 41%. We know that in case of M20 concrete the target strength is 26.6 N/mm^2, which may be achieved for the design mix adopted in the present study with a fly ash content of 48%, as shown by dashed lines in Fig.1. The variation of compressive strength with % fly ash obtained in this study are in line with those reported earlier by Narasinga Rao (2016), Wankhede and Fulari (2014), Nagabhushana (2015), Binod Kumar et al (2007) and Arka et al (2014).

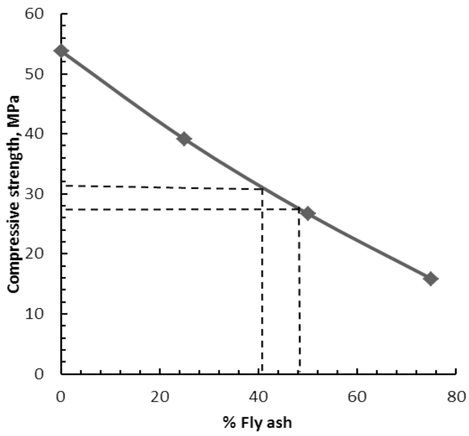

Fig.1 Variation of Compressive strength with % Fly ash

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3.2 Influence of % of fly ash on Flexural strength

Table 4 presents the flexural strength of concrete at different % of fly ash. The flexural strength decreases with increase in % fly ash, but the decrease is much less than that in compressive strength. Similar results were reported for flexural strength by Swapnil et al (2016) and Nagabhushana (2015). The flexural strength of concrete decreases only by 10.7% and 14.3% relative to that of control concrete, when the fly ash is 25% and 50% respectively. The flexural strength of concrete even with 75% fly ash is more than the design flexural strength of $0.7\sqrt{f_{ck}}$ (=3.5 $N/mm^2$for M25 concrete) recommended by IS:456.

Table 4 Effect of fly ash on flexural strength of concrete

S. No	% Fly ash	% Cement	Flexural strength of Concrete (N/mm^2)	% Variation with control concrete
1	0	100	5.6	0.0
2	25	75	5.0	-10.7
3	50	50	4.8	-14.3
4	75	25	3.8	-32.1

Fig.2 presents the variation of flexural strength with % fly ash. The relationship may be represented by linear relationship given by Eq.(2) with a correlation coefficient (R^2) of 0.93.

$$f_{cr} = 5.64 - [0.0224 \times (\%fa)] \quad (2)$$

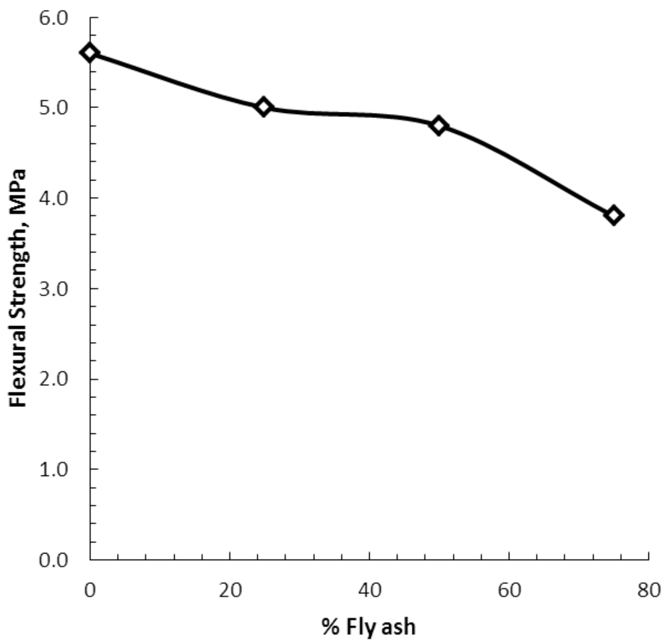

Fig.2 Variation of Flexural strength with % Fly ash

3.3 Workability and Initial Setting Time

It is already stated that the w/cm ratio for the concrete mix at each fly ash percentage was fixed by trial and error to have a workability of about 50 mm slump. The w/cm ratios so obtained and used are shown in Table 2. The actual workability of the concrete mix for the design mix are determined and shown in Table 5. Thus workability greater than the target workability of 50 mm slump have been achieved for the each of the given % of fly ash.

Table 5 Workability and Initial Setting time

S. No	% Fly ash	Workability (Slump, mm)	Initial Setting Time (min)	% Variation with control concrete
1	0	58	40	0
2	25	55	90	125%
3	50	53	120	200%
4	75	56	180	350%

Table 5 also presents the initial setting time for the design mix at each % of fly ash. It can be observed from Table 5 that increase in fly ash percentage increases the initial setting time considerably from 40 minutes at 0 % fly ash to 90 minutes at 25% and 120 minutes at 50% fly ash. The retardation of setting of fly ash mixed cement occurs due to longer hydration time necessary for the hydration products of cement grains to make interconnections because of dilution of cement with fly ash. Similar results are obtained by Rishab Joshi (2017) and Aman et al (2013).

The mechanism of interaction of fly ash in the concrete mix has been discussed by Narasinga Rao (2016) and therefore does not need elaboration here. The trend in the results obtained in the present study is similar to the study reported by Narasinga Rao (2016), where a nominal mix of 1:1:2 was used instead of design mix and a fixed w/cm ratio of 0.35 was used without admixture. We know that fly ash contributes additional strength by its pozzolanic reaction with excess lime which is released during the hydration of cement.

4. CONCLUSIONS

The following conclusions may be drawn based on the results obtained in this study and their discussion:

1) The compressive strength decreases with increase in % fly ash with an approximate linear relationship between the two.
2) The flexural strength decreases with increase in % fly ash, but the decrease is much less than that in compressive strength.
3) Increase in fly ash percentage increases the initial setting time considerably from 40 minutes at 0 % fly ash to 90 minutes at 25% and 120 minutes at 50% fly ash.
4) Optimum % of Parawada fly ash to replace cement is 41% for M25 concrete and is 48% for M20 concrete with a workability of about 50 mm slump.

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