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TECHNICAL NOTE

COMPARATIVE STUDY ON PHYSICAL AND MECHANICAL PROPERTIES OF HIGH SLUMP AND ZERO SLUMP HIGH VOLUME FLY ASH CONCRETE (HVFAC)

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ABSTRACT

An experimental investigation was carried out to compare the compressive strength of zero slump and high slump concrete with high volume fly ash. 40% to 70% replacements of OPC (by weight) with class F fly ash have been incorporated. Superplasticizer was added at 1% of binder (cement + fly ash) to the zero slump mixture to get a slump in the range of 140 to 180mm and cubes were cast without compaction. The results showed that the apparent porosity and water absorption were higher for zero slump concrete than high slump concrete. Zero slump concrete showed better compressive strengths than superplasticized concrete with 40 to 60% fly ash addition for all curing times tested (3,7 and 28 days). Ultrasonic pulse velocity results categorized all mixes as of 'EXCELLENT' concrete quality. Based on the present experimental investigation, it can be concluded that high volume fly ash concrete is suitable for general construction applications.

KEYWORDS: HVFAC, Roller Compaction, High Slump, Zero Slump, Compressive Strength, Apparent Porosity.

INTRODUCTION

Thermal power plant ash generation in India has increased from about 40 million tonnes during 1993-1994 (Manz, 1997), to 112 million tonnes during 2005-06 (Kumar et al. 2011) and is expected to be in the range of 175 million tonnes per year by 2012, on account of the proposal to double the power generation (Joshi and Lothia, 1997). This may create a serious problem of disposal in relation to environmental pollution and health hazards.

There were numerous studies on the strength characteristics of concrete containing fly ash in different proportions (Tangtermsirikul *et al*., 2004, Kokubu *et al*., 1996, Atis, 2005 and Cheng *et al*., 2000). Concrete mixtures containing more than 50% fly ash by mass of cementitious material with a low water content (w/cm < 0.4) is termed as high volume fly ash concrete (Reiner and Rens, 2006). However, there is very little study regarding the strengths of high volume fly ash concrete with/without any superplasticizer particularly using Indian fly ash. Thus, the aim of this work is to make a suitable high volume fly ash mix without superplasticizer suitable for road construction that supposed to be compacted by suitable roller. A comparison has been made with the low slump fly ash concrete with high slump fly ash concrete using superplasticizer.

MATERIALS AND METHODS

Materials

Class F Fly ash was collected from National Thermal Power Corporation, Farakkha, West Bengal, India. The cement used was Ordinary Portland Cement (OPC) of Grade- 43. The chemical composition of fly ash and cement is given in Table 1.

Fine aggregate used was river sand having specific gravity of 2.5 and fineness modulus of 2.65. Figure 1 shows the results of sieve analysis report of the river sand and fly ash. The particle size distribution of the sand indicates that it falls in Zone-II, as per IS; 383-1970 classifications. Crushed, angular, graded coarse aggregates of size 12 mm and 16 mm were used in the investigation. Figure 2 represents the grading of coarse aggregate. The specific gravity and the water absorption of the coarse aggregates were 2.85 and 0.9%, respectively. Potable water was used for casting and curing. Polycarboxylic ether based high range water reducing admixtures (superplasticizer) were incorporated for high slump fly ash concrete. The properties of the superplasticizer are given in Table 2.

Table 1. Chemical properties of fly ash and ordinary Portland cement

COMPONENTS	***Fly Ash***	***OPC***
SiO_2	64.58	18.62
Al_2O_3	25.89	4.75
Fe_2O_3	5.27	3.02
CaO	0.59	61.42
MgO	0.26	3.21
Na_2O	0.027	1.51
K_2O	0.041	1.42
SO_4	0.31	2.29
Loss on Ignition	2.40	3.55
Specific Gravity, G_s (g cm^{-3})	2.42	3.11

Table 2. Typical properties of superplasticizer

Properties	***Value***
pH	7 ± 1
Relative Density	1.09 ± 0.01 at 25^{O}C
Solid Content	not less than 30% by weight
Chloride ion Content	< 0.2%

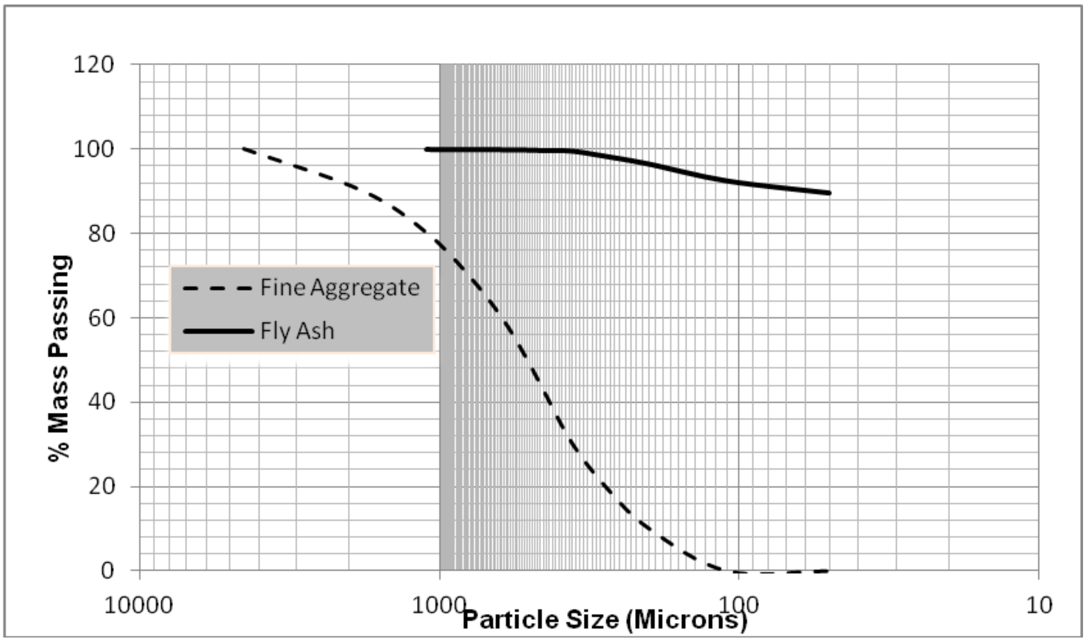

Figure 1. Particle size distributions of fine aggregate (sand) and fly ash

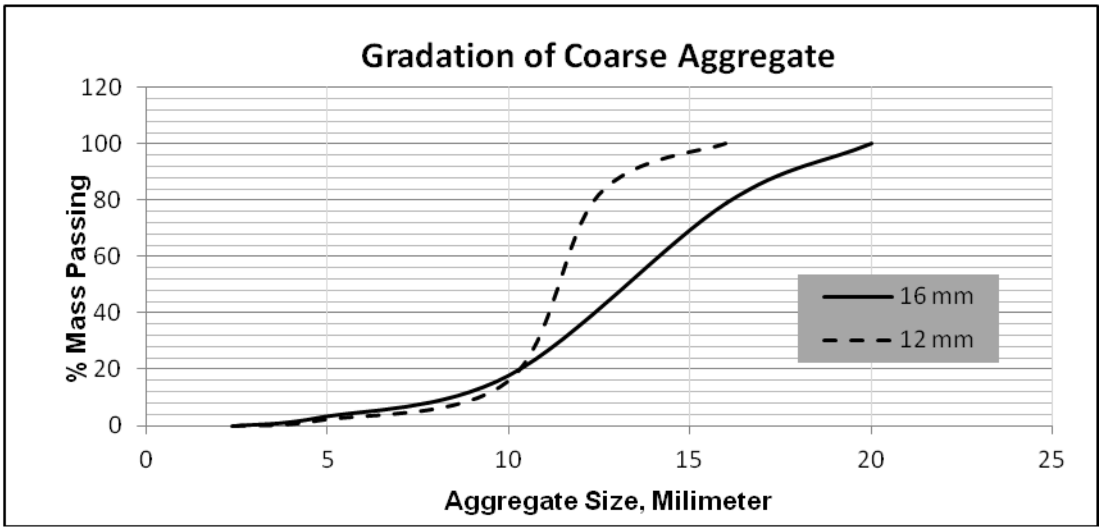

Figure 2. Gradation of coarse aggregate

Mixture Proportions

Table 3 shows the mixture proportions of different mixes using fly ash. The mixture proportions were made after several trials in the laboratory. The replacement of cement by fly ash was made (by weight) with 40, 50, 60 and 70% and designated as F40, F50, F60 and F70 respectively. The water to binder ratio for the above mixes was fixed at 0.35 to make zero slump fly ash concrete.

A separate set of concrete mixes was made with addition of superplasticizer and designated as F40S, F50S, F60S and F70S respectively. The dose of superplasticizer was kept as 1% to achieve a slump in the range of 140 to 180 mm. A control mix (F0S) with superplasticizer was also made without any fly ash.

Table 3. Mixture proportions for a cubic-meter of concrete

Components	***Mix Designation***								
	F0S	**F40**	**F50**	**F60**	**F70**	**F40S**	**F50S**	**F60S**	**F70S**
Cement (kg)	400	240	200	160	120	240	200	160	120
Fly Ash (kg)	0	160	200	240	280	160	200	240	280
Aggregate-16 mm (kg)	695	695	695	695	695	695	695	695	695
Aggregate-12 mm (kg)	463	463	463	463	463	463	463	463	463
Sand (kg)	637	637	637	637	637	637	637	637	637
W/B Ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Superplasticizer (L)	4	0	0	0	0	4	4	4	4
Slump (mm)	140	0	0	0	0	180	170	150	140

Specimen Size and Curing

Specimen size for compressive strength test was taken as 100 mm X 100 mm X 100 mm. Zero slump concrete was compacted in three layers. Each layer was hammered over a wood plate with a weight of 0.6 kg for 12 to 15 times. Cubes with high slump concrete were compacted by vibration table. All the specimens were cured in potable water after removal of mould till testing.

RESULTS AND DISCUSSION

Fresh Concrete

It is noted that the slump value decreases with the increase of fly ash replacement from 40% to 70%. Generally, the addition of fly ash with superplasticizer increases the workability of concrete within a lower range of fly ash addition. Beyond an optimum range, the slump will definitely fall due to the higher surface area of fly ash in high volume fly ash concrete. As the specific gravity of fly ash is less than that of cement and the replacement of cement was made by weight, the specific surface areas of the mix remains higher with higher replacement ratios. For high slump concrete, similar results were noticed for a fixed amount of superplasticizer. It is evident that use of superplasticizer in the mix can convert zero slump concrete to high slump concrete.

Bulk Density, Porosity and Water Absorption

To determine the bulk density, apparent porosity and water absorption of the concrete specimens, three cubes from each series were kept in water for 7 days for water to penetrate the pores. Specimens were then suspended in water with a copper wire of 0.5 mm thickness to take the suspended weight (S1 W). The soaked weight (S2 W) was also recorded by carefully removing the surface water and copper wire. The specimens were then dried in hot air oven at 110^{O}C for 24 hours and their dry weight (DW) determined. The following equations were used to find out the bulk density, apparent porosity and water absorption of the specimens.

$$\text{Bulk Density}\left(\frac{gm}{cc}\right)=\frac{DW}{S2W\text{-}S1W} \quad (1)$$

$$\text{Apparent Porosity }(\%)=\frac{S2W\text{-}DW}{S2W\text{-}S1W}\times 100 \quad (2)$$

$$\text{Water Absorption }(\%)=\frac{S2W\text{-}DW}{DW}\times 100 \quad (3)$$

It is evident that the bulk density of the OPC concrete is higher compared to fly ash content specimens. This is because the specific gravity of fly ash is much lower compared to OPC (G_s of OPC- 3.11 g cm^{-3}, Fly ash- 2.42 g cm^{-3}). The value of bulk density is decreased with increasing fly ash content in the mix. The apparent porosity and water absorption generally decreases with the replacement of OPC by fly ash upto a certain limit (30-40% Max.). However at a higher replacement level, the trend is reversed as shown in the fig. 4 and fig 5.for short duration. Similar results were obtained for HVFA concrete of short duration by other researchers (Li, 2004 and Poon *et al*., 2000) Compared to high slump concrete specimens, zero slump specimens show higher % apparent porosity and water absorption values.

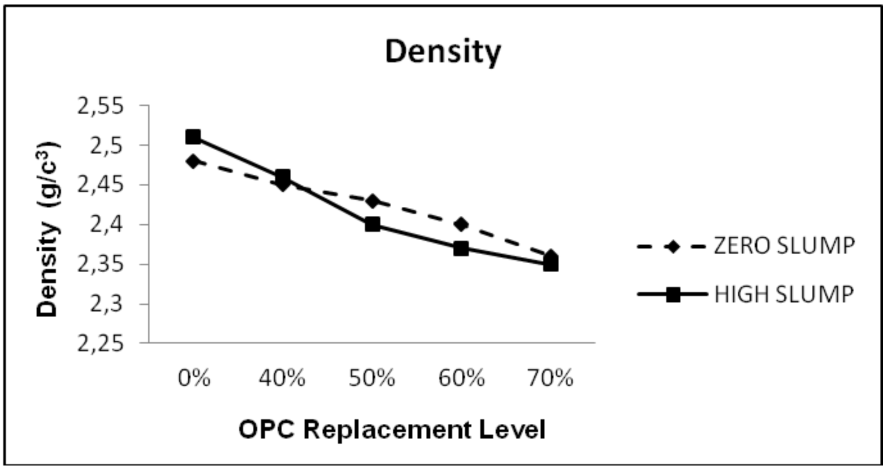

Figure 3. Bulk density of concrete specimens with OPC replacements

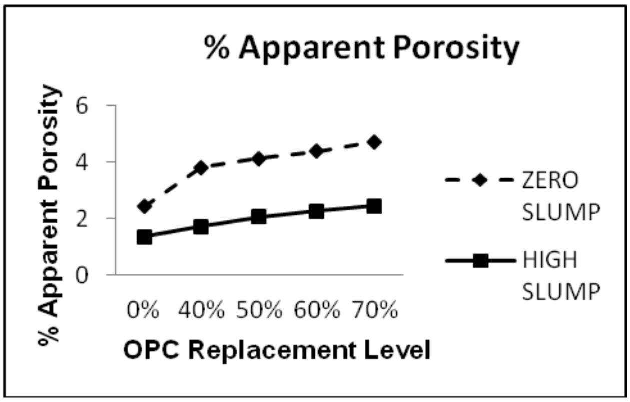

Figure 4. Apparent porosity of concrete specimens with OPC replacements

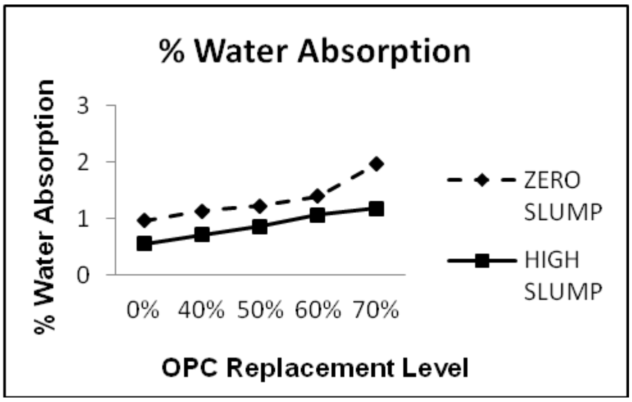

Figure 5. Water absorption of concrete specimens with OPC replacements

Ultrasonic Pulse Velocity

Table 4 represents the ultrasonic pulse velocity (UPV) result of concrete specimens after different OPC replacement. The test was conducted as per IS: 13311 (Part 1) – 1992. Results indicate that all concrete specimen's fall in 'EXCELLENT' category (pulse velocity above 4.5 km sec^{-1}, IS 13311,Part 1). It is evident from UPV results that on increasing the fly ash content the quality of the concrete begins to deteriorate. Compared to zero slump concrete specimens, the high slump concrete specimens shows better UPV test result.

Table 4. Ultrasonic pulse velocity test on samples (km sec^{-1})

F0S	F40	F50	F60	F70	F40S	F50S	F60S	F70S
5.17	4.75	4.67	4.62	4.58	4.89	4.78	4.67	4.59

Table 5. Compressive strength of the specimens at different curing times (MPa)

Mix Designation	*Compressive strength at different time interval (MPa)*				
	3 day	**7 day**	**7 day % strength gain w.r.t. 3 day**	**28 day**	**28 day % strength gain w.r.t. 7 day**
F0S	27.96	45.58	(63.02)	50.35	(10.46)
F40	22.05	28.20	(27.89)	43.65	(54.78)
F50	19.75	25.03	(26.73)	35.31	(41.07)
F60	13.92	20.89	(50.07)	31.40	(50.31)
F70	8.92	12.13	(35.99)	23.67	(95.13)
F40S	7.75	21.54	(177.94)	31.72	(47.26)
F50S	--	20.38	--	29.42	(44.35)
F60S	--	17.78	--	27.99	(57.42)
F70S	--	15.2	--	24.72	(62.63)

Compressive Strength

Table 5 shows the compressive strength of different mixes. It is obvious that the high range water reducing admixture delays the setting of concrete and thus the demoulding is not possible for specimens with superplasticizer particularly having fly ash replacement more than 50%. As a result the strength at 3 day is not reported for some mixes. Hence, strength gain in F50S, F60S and F70S could not be calculated. The % strength gain for 7 day has been calculated based on 3 day strength as well as 28 day strength gain has been calculated based on 7 day strength.

In the high slump concrete mixes (F40S, F50S, F60S and F70S) the percentage strength gain after 7 days is much higher than those after 28 days, which is almost similar to OPC concrete. The

similar, initial rate of % strength gain has been found from the data of other researchers (Bouzoubaa and Lachemi, 2001).On increasing the fly ash content, the 28-day strength gain seems to increase and is maximum in specimen of 70% fly ash content (F70S).
In the zero slump concrete mixes, the 28 day strength gain is much higher when compared to those of 7 day strength gain. Moreover, 28-day strength gain increased on increasing fly ash content in the batch and is maximum in F70 batch.

Environmental and Economical Benefit

Table 6 and Table 7 shows both the environmental and economical benefit for the high volume fly ash concrete. It is generally accepted that 1 tonnes of cement production releases 1 tonnes of carbon die oxide in the atmosphere. Based on this it may be concluded that high volume fly ash concrete will obviously reduce releases of CO_2 substantially. The price of OPC and fly ash is based on local price at Kolkata, India; the economical benefit of high volume fly ash concrete is established.

Table 6. Environmental benefit (CO_2 emission) of HVFA concrete

Sl. No.	Total Cement Production, Million Tonnes (2010) (Gjørv and Sakai, 2009)		Total CO_2 Emission, Million Tonnes		Utilization of Fly ash %	CO_2 Emission Reduced, Million Tonnes	
	East Asia	Total World	East Asia	Total World		East Asia	Total World
1	844.3	1946.1	844.3	1946.1	0	0	0
2					40	337.2	778.44
3					50	422.15	973.05
4					60	506.58	1167.66
5					70	591.01	1362.27

Table 7. Economical benefit of HVFA concrete.

Sl. No.	Price of OPC/ Tonnes	Price of Fly ash/ Tonnes	Fly used to make the binder (%)	OPC used to make the binder (%)	Actual Price of the Binder (Cementitious Materials)
1.	$ 140	$ 20	0	100	$ 140
2.			40	60	$ 92
3.			50	50	$ 80
4.			60	40	$ 68
5.			70	30	$ 56

CONCLUSIONS

Based on the present experimental investigation, it may be concluded that, increasing fly ash in concrete decreases the compressive strength at all ages and early strength gain is also reduced. The apparent porosity and water absorption is also increased with fly ash addition. The UPV results confirms that both in high slump and zero slump fly ash concrete, the overall quality of the concrete is gradually reduced with increase of fly ash content. Zero slump concrete shows higher compressive strength compare to workable concrete with superplasticizer up to 60% replacement with fly ash. The strength gain with time is higher compared to the OPC concrete at all replacement level of cement by fly ash and the optimum strength gain was noted at 70% replacement at 28 days. Although the experiment confirm the deterioration of concrete with higher OPC replacement by fly ash, It can be concluded that, the value of the mechanical and physical properties are well acceptable according to Indian standard as well as economical for general construction.

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