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INVESTIGATIONS ON HIGH VOLUME FLY ASH CONCRETE

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ABSTRACT: Cement is the most cost- and energy-intensive component of concrete. The unit cost of concrete can be reduced by partial replacement of cement with fly ash. Fly ash is the by product of the combustion of pulverized coal and is collected by mechanical and electrostatic separators from the fuel gases of power plants where coal is used as a fuel. The disposal of fly ash is one of the major issues for environmentalists as dumping of fly ash as a waste material may cause severe environmental problems/hazards. More than 88 million tonnes of fly ash is generated in India each year. Most of the fly ash is of Class F type. The percentage utilization is around 10 to 15%. To increase its percentage utilization, an extensive investigation was carried out to use it in concrete. This article presents the results of an experimental investigation dealing with high volume fly ash (HVFA)concrete incorporating high volumes of Class F fly ash. Portland cement was replaced with high percentages (40%, and 50%) of Class F fly ash. M 30 is used as control mix(M1) with 0% fly ash. M2 and M3 contains Fly ash of 40 and 50%. Tests were performed for fresh concrete properties: slump, Compressive, splitting tensile, and flexural strengths were determined up to 7 and 28 days of testing. The workability of concrete measured from slump cone test. The slump value for control mix was obtained as 65mm. For M2 and M3 which contain Fly Ash in 40 and 50 % wt of Cement, the slump values obtained were 85 and 100 mm respectively. This shows that the addition of Fly Ash increase the workability of concrete without addition of water. This will have a positive impact on the strength of concrete. Test results indicated that the use of high volumes of Class F fly ash as a partial replacement of cement in concrete decreased its 28-day compressive, splitting tensile, and flexural strengths of the HVFA concrete. However the rate of strength development from 7 days to 28 days is very interesting and likely to continue beyond 28 days. Based on the test results, it was concluded that Class F fly ash can be suitably used up to 50% level of cement replacement in concrete for use in precast elements and reinforced cement concrete construction.

Key Words: Fly Ash, Admixture, Concrete, Strength, HVFA

I. INTRODUCTION

The study of high-volume fly ash concrete mixtures has become popular due to the potential of the material to provide significant environmental and economic benefits. By increasing the amount of fly ash introduced into concrete mixtures, less cement would be produced, which would decrease CO2 emissions, and less fly ash would be placed in landfills. The use of less cement, along with the sustainability benefits of HVFA concrete, would also decrease the amount of raw materials which would need to be extracted to produce Portland cement concrete. Immediate economic benefits occur because Portland cement is replaced with a less expensive by-product material. For properly designed HVFA mixtures, increased durability and long-term strengths would provide long-term economic benefits, because infrastructure components would have to be replaced less often. By being able to increase the incorporation of fly ash into concrete at 50 percent or greater replacements, substantial benefits could be obtained.

Concrete is the world's most consumed man-made material. To produce 1 ton of Portland cement, 1.5 tons of raw materials are needed. These materials include good quality limestone and clay. Therefore, to manufacture 1.5 billion tons of cement annually, at least 2.3 billion tons of raw materials are needed. Over 5-million BTU of energy is needed to produce one tone of cement. In the year 1914, India Cement Company Ltd started cement production in Porbandar with an output of 10,000 tons and a production of 1000 installed capacity. At the time of independence 1947, the installed capacity of cement plants in India was approximately 4.5 million tons and actual production around 3.2 million tons per year. The partial deep control in 1982 prompted various industrial houses to set a setup new cement plants in the country, capacity was nearly 30 million tons, which has now, increase to nearly 120 million tons during a period of 20 years. The full decontrol on cement industry in 1988 further provided momentum for the growth.

India is the second largest producer of cement on the globe after China. In total, India manufactures 251.2 Million Tons of cement per year. The cement industry in India has received a great impetus from a number of infrastructure projects taken up by the Government of India like road networks and housing facilities. While the Indian cement industry enjoys a phenomenal phase of growth, experts reveal that it is poised towards a highly prosperous future over the very recent years. The annual demand for cement in India is consistently growing at 8-10%. National Counsel for Applied Economic Research (NCAER) has estimated after an extensive study that the demand for cement in the country is expected to increase to 500 million tons by 2020. At the same time, the demand will be at 311.37 million tones if the projections of the road and housing segments are met in reality

The production of superior quality of Ordinary Portland Cement (OPC) in the country was primarily responsible for introducing the grading system in OPC by Bureau of Indian Standard (BIS) during 1986-87. The other varieties of structural cements, such as sulphate resisting Portland cement, Pozzolana cement and blast furnace slag cement found their way in the improve quality of prompted the structural engineers and major consumers to adopt higher grades of concretes in the construction work. This has been marked difference in the quality of concrete during this period primarily due to the availability of superior quality of cements in the market. The trend is continuing more and more varieties of cements are coming to the markets which help to the consumers to make appropriated grade quality of concrete to meet the specific construction requirement. The high performance fiber reinforced, polymer concrete composites and ready mixed concrete have been progressively introduced for specific applications.

Cement and steel are available in the free market and the durability of concrete was guaranteed and was unquestionable. The reinforced concrete has become a common building material because of its inherent strengths such as

- High strength and durability
- Easy design procedures to suit any type of aggressive environmental conditions.
- Modularity to required size and shape
- Resistance to fire.
- Flexibility to extend or reduce without serious efforts and side effects.
- Cracking and damage control.
- Easy maintenance.

With the advancement of technology and increased field of applications of concrete and mortars, the strength workability, durability and other characters of the ordinary concrete need modifications to make it more suitable by situations. Added to this is the necessity to combat the increasing cost and scarcity of cement. Under these circumstances the use of admixtures is found to be an important alternative solution.

The use of Pozzolana materials in cement concrete paved a solution for

- Modifying the properties of the concrete
- Controlling the concrete production cost
- To overcome the scarcity of cement
- The economic advantages disposal of industrial wastes

In the past continuous efforts were made to produce different kinds of cement, suitable for different situations by changing oxide composition and fineness of grinding. With the extensive use of cement, for widely varying conditions, the types of cement that could be made only by varying the relative proportions of the oxide compositions were not found to be sufficient. Recourses have been taken to add one or two more new materials, known as additives, to the clinker at the time of grinding, or to the use of entirely different basic raw materials in the manufacture of cement. The use of additives, changing chemical composition, and use of different raw materials have resulted in the availability of many types of cements to cater to the need of the construction industries for specific purposes.

The most important Pozzolana materials are Fly ash, silica fume and Metakaolin whose use in cement and concrete is thus likely to be a significant achievement in the development of concrete technology in the coming few decades. The trend is continuing and more and more varieties of cements are coming to the market which helps to consume to make appropriate grade and quality of concrete to meet the specific construction requirement. There has been a remarkable advance in the field of concrete technology also. The high Performance fiber reinforced, polymer concrete composites and ready mixed concrete have been progressively introduced for specific applications.

HIGH VOLUME FLY ASH CONCRETE

As per IS:456-2000, OPC can be replaced with Fly ash up to 35%. Fly ash content greater than 35% can be considered as high volume replacement or high blending. So any concrete with more than 35% Fly ash is called as High Volume Fly Ash (HVFA) concrete. High-volume fly ash concrete has emerged as construction material in its own right. This type of concrete normally contains more than 50% fly ash by mass of total cementitious materials. Many researchers have used high volumes of Class C and Class F fly ashes in concrete.

NEED FOR PRESENT INVESTIGATION

Incorporating fly ash in a concrete mixture provides benefits to both fresh and hardened properties of the concrete. Improvements in fresh properties include increased workability, increased pump ability, and reduced bleeding. Hardened concrete benefits could include greater long-term strength, decreased early-age temperature rise, and increased durability. The use of fly ash can also have negative effects on concrete mixtures. These commonly include decreased strengths at early ages, delayed setting times, loss of certain forms of durability, and lower later strengths. Also incompatibilities between constituents of the mixture can lead to detrimental effects on the properties of the concrete.

As the amount of fly ash used in a mixture increases, the degree and likelihood of the above-mentioned problems increases. Therefore, in high volume fly ash concrete, it is necessary to assess the degree to which these problems may occur and determine methods of mitigating these problems in order for HVFA concrete to be a viable construction material. Hence in the present work, HVFA is prepared and samples were tested to ascertain the properties in wet and hardened states.

II. MATERIALS AND METHODS

Experimental investigation was planned to provide sufficient information about the strength characteristics of HVFA concrete. This chapter describes the details of different materials used, different tests conducted and all the relevant information regarding experimental work. The results obtained from all the tests were presented in tables.

MATERIALS USED:

Cement: - OPC Cement of 53-grade was used. The Physical Properties of cement are shown in Table .1.

Table.1. Physical properties of Cement

S.NO	PROPERTY	VALUES
1	Fineness of Cement	225 m^2/kg
2	Specific Gravity	3.1
3	Normal Consistency	33 %
4	Setting Time i) Initial Setting time ii) Final setting time	45 mins 6 hours
5	Compressive Strength i) 3 days ii) 7 days iii) 28 days	32 N/mm^2 46 N/mm^2 53 N/mm^2

Coarse Aggregate: - Crushed granite metal with 50% passing 20mm and retained on 12.5mm sieve and 50% passing 12.5mm and retained on 10mm sieve was used. Specific gravity of coarse aggregate was 2.75.

Fine aggregate: - River sand from local sources was used as fine aggregate. The specific gravity of sand is 2.68. Other details are presented in Table 4.4 and 4.5.

Water: - Potable fresh water, which is free from concentration of acid and organic substances was used for mixing the concrete.

Fly ash: - Fly ash is generated as a by-product of combustion in coal-fired power plants, paper mills, and other coal burning factories. In the present research the Class F Fly ash used, is detained from 300 microns. The properties of Fly ash were shown in Table 2.

Table.2. Chemical properties of Fly ash

Sl. No	Constituents	Percentage
1.	SiO_2+Al_2O_3+Fe_2O_3	94.25
2.	Sulphur trioxide as SO_3	0.71
3.	Sodium oxide as Na_2O	0.26
4.	Loss On Ignition	0.38
5.	Silica as SiO_2	59.90
6.	Alumina as Al_2O_3	30.81
7.	Iron as Fe_2O_3	3.83
8.	Reactive SiO_2	30.01
9.	Calcium oxide as CaO	1.94
10.	Free CaO	Nil
11.	Reactive CaO	1.44
12	Chloride as Cl	0.009
13	Magnesium oxide as MgO	0.36
14	Manganese dioxide as MnO_2 (mg/Kg)	12.38
15	Potassium oxide as $K_2OP_2O_5$(mg/Kg)	0.031

MIX PROPORTIONS

For carrying out the experimental investigation, three mixes were prepared with designations as M1. M2, & M3. Mix design was done as per IS code method and M30 grade concrete is taken as control mix. Different percentages of the Fly ash are shown in the following Table.3.

Table.3. Mix designations

Mix Designation	Fly ash %
M1	0
M2	40
M3	50

Different ingredients used in the mixes are shown in the following Table 4.:

Table.4. Mix Ingredients

Mix Designation	M1	M2	M3
Flyash %	0	40	50
Cement in KG/M^3	400	240	200
Flyash inKG/M^3	0	160	200
Water inKG/M^3	164	160	160
Sand inKG/M^3	616	614	616
Coarse Aggretate inKG/M^3	1228	1224	1225

III. RESULTS AND DISCUSSION

The effect of addition of Fly ash and steel fibres at various percentages on workability, compressive strength, split tensile strength, and flexural strength has been discussed based on the results obtained.

WORKABILITY

Wet properties of the concrete mixes were tested, immediately after preparation of the mixes, and 'slump values' are presented in the following Table 5.

Table 5. Slump values

Slump values for different mixes	
Mix	**Slump in mm**
M1	65
M2	85
M3	100

The slump value for control mix was obtained as 65mm. For M2 and M3 which contain Fly Ash in 40 and 50 % wt of Cement, the slump values obtained were 85 and 100 mm respectively.

This shows that the addition of Fly Ash increase the workability of concrete without addition of water. This will have a positive impact on the strength of concrete.

COMPRESSIVE STRENGTH

Compressive strength obtained from testing of cube samples under compression testing machine were presented below:

Table 6. Compressive strength in MPA

Compressive strength in MPA		
Mix	7days	28days
M1(0% FA)	26.7	38.2
M2(40% FA)	18.0	27.7
M3(50% FA)	15.7	24.1

The variation of compressive strength with addition of fly ash is shown in the following Figure below:

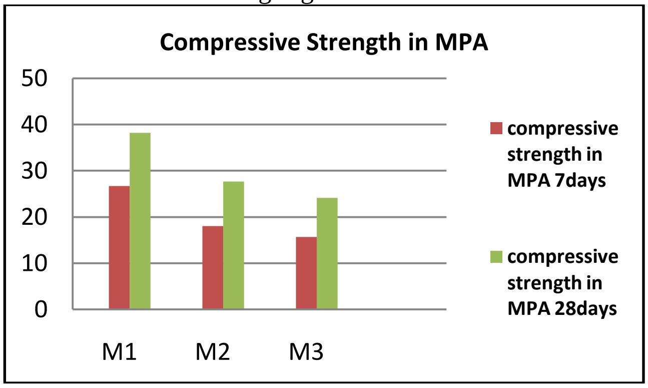

Figure 1 Variation of compressive strength for different mixes

Effect of addition of Fly ash on compressive strength:

Compressive strength of concrete mixtures was determined at the ages of 7 & 28 days. At 28 days, control mixture M-1 (0% fly ash) achieved compressive strength of 38.2 MPa, whereas mixtures M-2 (40% fly ash), M-3 (50% fly ash) achieved compressive strength of 27.7, and 24.1 MPa, respectively; a reduction of 27%, and 37%, respectively, in comparison with the strength of the control mixture M-1 (0% fly ash). From 7 days to 28 days strength gain in control mix is at the rate of 43%, where as in M2 mix and M3 mix it is 53.8% and 53.5% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete. Although at 28 days, the replacement of cement with fly ash decreased the compressive strength of concrete, but, even then, compressive strength result indicated that even mixture M-4 (50% fly ash) could be used for general concrete construction, and other mixtures M-2 (40% fly ash) could very well be used for structural concrete.

SPLIT TENSILE STRENGTH

Split tensile strength obtained from testing of Cylinders samples under compression testing machine were presented below:

Table 7. Split tensile strength in MPA

Split tensile strength in MPA		
Mix	**7days**	**28days**
M1(0% FA)	2.9	4.2
M2(40% FA)	1.9	3.1
M3(50% FA)	1.6	2.3

The variation of Split tensile strength with addition of fly ash is shown in the following Figure.

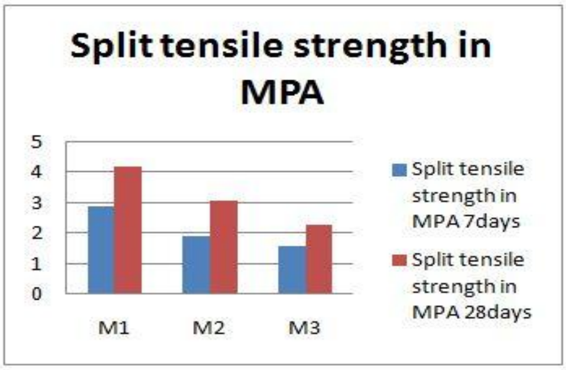

Figure 2 Variation of Split tensile strength for different mixes

Effect of addition of Fly ash on Split Tensile Strength:

Split tensile strength of concrete mixtures was determined at the ages of 7 & 28 days. At 28 days, control mixture M-1 (0% fly ash) achieved Split tensile strength of 4.2 MPa, whereas mixtures M-2 (40% fly ash), M-3 (50% fly ash) achieved Split tensile strength of 3.1, and 2.3 MPa, respectively; a reduction of 26%, and 45%, respectively, in comparison with the strength of the control mixture M-1 (0% fly ash). From 7 days to 28 days strength gain in control mix is at the rate of 45%, where as in M2 mix and M3 mix it is 63% and 44% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete with 40% addition of Fly Ash where as for with 50% addition of Fly Ash, it is not too low in comparison with control mix. Hence it can be concluded that long term strength development is possible in case of HVFA.

FLEXURAL STRENGTH

Flexural strength obtained from testing of cube samples under compression testing machine were presented below:

Table 8. Flexural strength in MPA

Flexural strength in MPA		
Mix	7days	28days
M1(0% FA)	3.9	5.5
M2(40% FA)	2.4	3.7
M3(50% FA)	1.9	2.8

The variation of Flexural strength with addition of fly ash is shown in the following Figure.

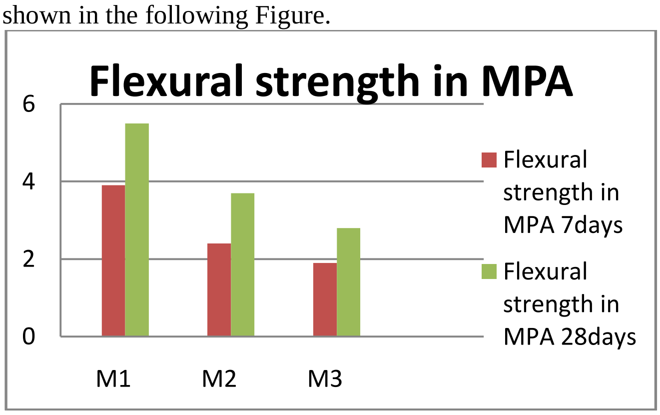

Figure 5.3 Variation of Flexural strength for different mixes

Effect of addition of Fly ash on Flexural Strength:
Flexural strength of concrete mixtures was determined at the ages of 7 & 28 days. At 28 days, control mixture M-1 (0% fly ash) achieved Split tensile strength of 5.5 MPa, whereas mixtures M-2 (40% fly ash), M-3 (50% fly ash) achieved Split tensile strength of 3.7, and 2.8 MPa, respectively; a reduction of 33%, and 49%, respectively, in comparison with the strength of the control mixture M-1 (0% fly ash). From 7 days to 28 days strength gain in control mix is at the rate of 41%, where as in M2 mix and M3 mix it is 54% and 47% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete with 40% addition of Fly Ash where as for with 50% addition of Fly Ash, it is 6% more in comparison with control mix. Hence it can be concluded that long term strength development is possible in case of HVFA.

IV. CONCLUSIONS

Results were analyzed to derive useful conclusions regarding the strength characteristics of high volume fly ash (HVFA) concrete. M30 concrete has been used as reference mix. The following conclusions may be drawn from the study on strength characteristics of high volume fly ash (HVFA)concrete

- The workability of concrete measured from slump cone test. The slump value for control mix was obtained as 65mm. For M2 and M3 which contain Fly Ash in 40 and 50 % wt of Cement, the slump values obtained were 85 and 100 mm respectively.
- This shows that the addition of Fly Ash increase the workability of concrete without addition of water. This will have a positive impact on the strength of concrete.
- The replacement of cement with three percentages of fly ash content reduced the compressive strength, splitting tensile strength, and flexural strength of concrete at the age of 28 days.
- However From 7 days to 28 days strength gain in control mix is at the rate of 43%, where as in M2 mix and M3 mix it is 53.8% and 53.5% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete.
- Similarly From 7 days to 28 days strength gain in control mix is at the rate of 45%, where as in M2 mix and M3 mix it is 63% and 44% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete with 40% addition of Fly Ash where as for with 50% addition of Fly Ash, it is not too low in comparison with control mix. Hence it can be concluded that long term strength development is possible in case of HVFA.
- From 7 days to 28 days strength gain in control mix is at the rate of 41%, where as in M2 mix and M3 mix it is 54% and 47% respectively. Hence it shows, with time the strength development is more with high volume fly ash (HVFA)concrete with 40% addition of Fly Ash where as for with 50% addition of Fly Ash, it is 6% more in comparison with control mix. Hence it can be concluded that long term strength development is possible in case of HVFA.
- Based on the test results, it was concluded that Class F fly ash can be suitably used up to 50% level of cement replacement in concrete for use in precast elements and reinforced cement concrete construction.

RECOMMENDATIONS FOR FUTURE INVESTIGATIONS

- Studies beyond 28 days strength could give better picture of strength development.
- Studies on the different proportions of Fly ash may be carried out.
- Mathematical / Empirical models can be developed for the Stress/Strain behavior of strength characteristics on HVFA concrete.

Durability studies such as resistance to Sulphate attack, Acid resistance etc., can be carried out on HVFA concrete.

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