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Feasibility Study on Concrete with High Volume Fly Ash

Vetturayasudharsanan Ramasamy[1]* and Balaji Govindan[2]

[1]Assistant Professor, Department of Civil Engineering, M.Kumarasamy College of Engineering, Karur,Tamil Nadu, India. Email: vetturayasudharsananr.civil@mkce.ac.in
[2]Assistant Professor, Department of Civil Engineering, M.Kumarasamy College of Engineering, Karur,Tamil Nadu, India. Email: in balajig.civil@mkce.ac.in
*Corresponding Author

Abstract— This study mainly inspects the production of durable and environment friendly concrete by utilizing Fly Ash [FA]. This fly ash is the byproduct occurred from the coal based thermal power plants as cementitious material. High Volume Fly Ash [HVFA] Concrete is topic of discussion as it utilises FA as cement replacement to greater extent [more than 40%replacement]. Owing to their pozzolanic properties, FA is examined as partial replacement of cement with varying proportions [40%, 45% and 50%by weight] in this study as HVFA concrete. The grade of concrete adopted to observe the performance of HVFA concrete is M30 and were tested for analyzing their strengths-compressive ability, strength on the flexural capacity and their split tensile strength, after curing the molded samples 7 days,28 days and 90 days respectively.

Key Words— Coal Ash, Environmentally friendly, Cement Replacement.

I. INTRODUCTION

Concrete is observed as the second major material consumed per capita in the world after water ,by approximately consuming 560 kg per person in a year. The prime component of this concrete is Portland cement depletes the environment by consuming the natural resources for their production and by emitting 5-7% of carbon [1 ton of CO2 for 1 ton of cement produced]. Being major element in achieving the strength of the concrete, various researches have done to investigate the results in replacement of this cement, either fully or partially or by adopting the alkali activated binders or commonly known as geopolymers. Hence, there is need to implement the replacement of cement for providing greener and sustainable environment with the properties matching to the conventional cements. The material used for cement replacement mainly focused on utilizing waste from industries with alkali-based minerals such as silica fumes, fly ash, mine tailings, furnace slag, etc. One such industrial waste which contains excellent pozzolanic properties is fly ash. Fly ash is considered as waste, just because they are obtained as the byproduct from coal based thermal power plants. The disposal and handling this fly ash is nuisance due to their nature of chemical composition and particle fineness. Thus, utilizing fly ash in construction sector will be beneficial way to both environment and in economic aspect.

The composition of this obtained fly ash differs on the variety of coal used and the design of boilers, but they typically contain silica and alumina in greater amounts, favouring the replacement of cement. Due to varied chemical composition, standards were created to meet the requirements to be used an alternative of Portland cement-ASTM C618-12, “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.” This standard classifies the fly ash obtained into two acceptable classes which can be used in concrete - Class F Fly Ash have properties of puzzolan and Class C Fly Ash have the properties of both pozzolan and cement. Apart from having pros on economic and environmental aspects, using FA in concrete has other advantages also. The usage of FA improves the pump ability of concrete by reducing the friction between pump line and concrete due to their spherical nature. In addition to this, fly ash reaction with CaOH forms calcium aluminate and calcium silicate hydrate reduces the leaching of CaOH, providing increased life and durability of concrete. Due to their physical nature, fly ash provides greater workability of concrete with lower water-cement ratio when compared to traditional cement binder. Besides all these benefits, utilizing fly ash reduces the heat of hydration process than conventional cement, which reduces cracks and their formation.

II. MATERIALS USED

A. Cement

The modernization of the construction industry offers a variety of cements, out of which OPC-Ordinary Portland Cement is popularly available in market. The OPC used in this study is grade 53 and confines to specifications of IS 8112:1989. The OPC used is examined for their physical properties and are listed in Table 1.

Table 1. Characteristics of the physical properties of OPC

Physical Properties of cement	Results
Fineness	6.69

Consistency	26%
Specific Gravity	3.76
Setting Time [Initial]	25 minutes
Setting Time [Final]	11 hours

B. Fly Ash

The Fly Ash utilized in this study belongs to fly ash of Class C type and purchased from Mettur Thermal Power Station, TamilNadu, India. The properties of their chemical and physical nature is examined and are tabulated in Table 2 and Table 3 respectively.

Table 2. Physical properties of fly ash

Properties	**Values**
Specific Gravity	1.9 - 2.0
Bulk Density	1.2 g/cm^3
Fineness	2000 - 2200 cm^2/g
Moisture	Nil
Colour	Whitish grey to grey with slight black fines

Figure 1. Fly Ash

Table 3. Chemical composition of fly ash

Properties	**Percent by weight**
Silica dioxide	55.3
Aluminate	25.6
Ferric Oxide	5.2
Oxides of Magnesium & Calcium	7.0
Sulphur	0.5
Magnesium	3.2
Oxides of alkali metals	2.5
Loss of Ignition [LOI]	1.9

To ensure the particle uniformity and particle fineness, sieve analysis is conducted to calculate the fineness of the fly ash used in this study and their percentage finer are tabulated in Table 4.

Table 3. Results of sieve analysis

Sieve Size as per IS specifications [in microns]	**Percentage Finer**
600	98.2
300	96.5
150	72.3
75	25
<75	0

C. Coarse Aggregate

The coarse aggregate size adopted in this study of HVFA concrete is 20 mm and they were tested for their properties- specific gravity, test for their shapes, etc. and their results are enumerated in Table 4.

Table 4. Test results for Coarse aggregate

Test Conducted	**Results**
Water Absorption	0.7 %
Specific Gravity	2.76
Elongation Index	11.38%

Flakiness Index	16.1%
Crushing value	21.33%
Impact value	10.94

D. Fine Aggregate

Fine aggregate is the prime component present in huge quantities in concrete. River sand, which is a naturally available fine aggregate is used passing through a sieve of 4.75 mm. The fine aggregate used is as per the IS 383 and confines to Zone II. The material property tests such as Specific gravity, Water absorption ratio and Bulk Density were conducted, and the results are given in Table 5.

Table 5. Test results of Fine Aggregate

Test Conducted	**Result**
Bulk Density	1.2
Water Absorption	1 %
Specific Gravity	2.68

E. Water

Water is a necessary element which induces chemical reaction which leads to hydration product when it gets reacted with cement, forming gel-the calcium silicate hydrate gel in the concrete. The binding action of the gel-like formation from the hydration of the cement maintains the strength of the concrete. The water usage should be minimum and must be adequate for the hydration process of the cement. Any additional water during the hydration process will only lead to the creation of capillary pores, when the concrete hardens. Thus, there is a need to prepare the cement with the sufficient consistency for the required workability. It is important to have the bonding among the used admixture and the cement and also with the water used for the mixing process.

Other two parameters to look carefully at are quality and the quantity of water used. To maintain the desired efficiency, the water must be free from other undesired salts, which may interact with the raw materials and produce other by-products. Other materials such as suspended particles can be avoided as they greatly affect the setting, hardening and bond characteristics. Presence of algae content in the water used for making concrete marked a significant reduction in concrete strength by reduction of bond formation, by combining with cement or by creating large amounts of air voids in concrete. Water must be confined to the stated BIS: 456-2000 requirements. Generally, water suitable for drinking, potable water is best suited for making concrete.

F. Superplasticizer

Superplasticizer are the chemical admixtures known as water reducers. They have the capacity to reduce the water usage in the concrete by 30%. These superplasticizers achieve reduction of water usage without altering their workability, as they are surfactant in nature and disperse the cementitious particles in the mix. For this study, a super plasticizer CONPLAST SP430 is used for obtaining the workable concrete at low W/B ratio. CONPLAST SP430 complies with BIS: 9103-1999 and BS:5075-part3 and ASTM C494. They work by repelling the cement grains as they are oppositely charged. This repelling process makes the concrete flow by increasing the mobility. Additionally, they reduce the cement content for the same workability, which is ideal for pumping the concrete. The properties of superplasticizer used are tabulated in Table 6.

Table 6. Properties of Superplasticizer

Properties	**Result**
Superplasticizer variant	Sulfonated naphthalene formaldehyde condensate
Specific gravity	Ranging from 1.25- 1.5
Chloride	Nil
Dosage recommended	0.5 to 1.8 litres per 100 Kg of cement
Additional air entrainment	1%
Compatibility	All type of cement except high alumina cement
Solid content	40%
Workability	Produce high workable flowing concrete mix without segregation and requires no compaction.
Cohesion	Minimising segregation and improving surface finish
Compressive strength	Early strength up to 40 to 50%

III. MIX PROPORTIONS

The mix design of concrete is an activity through which the proportions of the materials used for making concrete are established with an attempt to achieve the required strength and durability at its minimum, with their possible economy. Two kinds of costs are involved in making the concrete are the cost of materials and the labour.

Table 7. Mix proportion

Raw materials	**Mix Proportion**	**Weight per m³ of concrete [in kg/m³]**
Cement and flyash	1	385
Fine aggregate	1.89	728
Coarse aggregate	3.2	1232
Water	0.4	140

The cost for labour consists of formwork, batching, mixing, transporting, and curing of the concrete is literally the same for all concrete types. Therefore, the mix design aims at selecting the cement with minimum possible requirement with no negligence in their performance, strength and durability. The mix proportion used for the study was M30 concrete. The mix proportions for the experiments have been calculated as per IS 10262.The materials required for per cubic meter of concrete is tabulated in Table 7.

IV. Results and Discussion

A. Compressive Strength

The compressive strength for this study, the concrete cubes of size 150mm x 150mm x 150mm were casted to test their compressive strength after being cured for 7 days, 28 days and 90 days respectively. The concrete cubes were casted by the replacement of cement with fly ash at various percentage of replacement. The replacement is done for 0%, 40%, 45% and 50% , and for each replacement three cubes were casted. The water to cement ratio is maintained at 0.45 for this study, and were kept constant.

Figure 2. Compressive test for cube

The results of the test for compressive strength of concrete cubes after being cured for 7,28 and 90 days are tabulated in Table 8.

Table 8. Results for the strength of compression

S.No	**Percentage of fly ash replacement**	**Compressive strength at the end of 7 days [in MPa]**	**Compressive strength at the end of 28 days[in Mpa]**	**Compressive strength at the end of 90 days [in Mpa]**
01.	0%	25.50	37.42	40.60
02.	40%	17.20	28.38	32.70
03.	45%	15.23	26.60	30.90
04.	50%	14.89	23.50	28.50

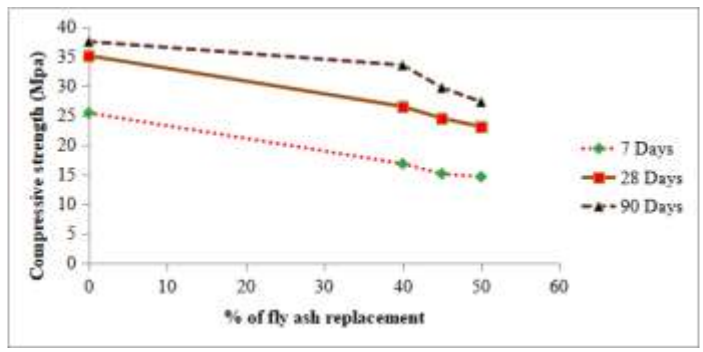

Figure 3 . Graph showing variation of compressive strength

The mix M1 with 0% fly ash acquired compressive strength of 25.5 MPa when they are cured for 7 days, whereas the mixes M2 ,M3 and M4 with 40%,45% and 50% fly ash replacement acquired compressive strength of 17.20 MPa,15.23 MPa and 14.89 MPa respectively for the same 7 days of curing. While being cured for 28 days, the 0% fly ash gained compressive strength of 37.42 MPa, whereas the 40%,45% and 50% fly ash replacement mixes gained compressive strength of 28.38 MPa,26.60 MPa and 23.50 MPa respectively, showed a reduction of 30%,38% and 42% in strength when compared to 0% fly ash containing concrete mix.

The test results at the end of 28 and 90 days of curing showed a significant and progressive improvement in their compressive nature, where the percentage of increase in the strength was between 20 to 25%.This increase of strength has two main reasons-due to the continued hydration process of the cement and, the other, due to the pozzolanic reaction of the fly ash, which is present in large amounts [40%-50% replacement].Although the replacement of fly ash in huge amounts decreased the strength of the concrete then the conventional one, they can be still used for general concrete construction [for the concrete mix with 50% fly ash replacement] and the other [concrete mix with 40-45% replacement of fly ash] can be used as structural concrete.

B. Split Tensile Strength Test

This split tensile strength test is an indirect test to find out the tensile strength of the concrete mix. For the split tensile strength test, the concrete cylinders were casted with size of 150 mm x 300 mm and were tested using HELICO compression testing machine of 400 tonne capacity confining to IS: 5816 – 1970. The load was applied uniformly until the specimen split and the readings were recorded. The splitting tensile strength has been calculated using the following formula.

Split tensile strength $=2P/(\pi D L) N/mm^2$

Figure 4. Split tensile strength

The results of the test for compressive strength of concrete cubes after being cured for 7, 28 and 90 days are tabulated in Table 9.

Table 9. Split Tensile Strength results

S. No	Percentage of fly ash replacement	Split Tensile strength at the end of 7 days [in MPa]	Split Tensile strength at the end of 28 days [in MPa]	Split Tensile strength at the end of 90 days [in MPa]
01.	0%	2.80	3.36	4.67
02.	40%	1.91	2.80	3.28
03.	45%	1.57	2.00	2.90
04.	50%	1.10	1.75	2.50

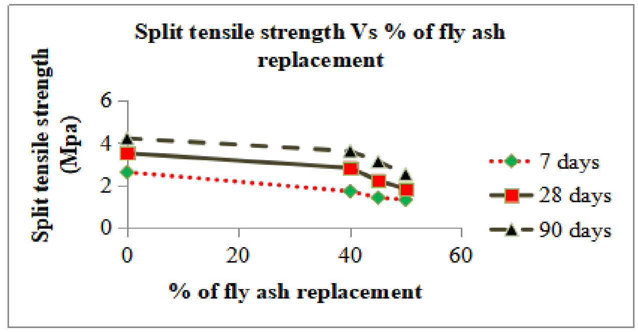

Figure 5. Graph showing variation of split tensile strength

The test results observed in split tensile strength were much similar to the test result variation obtained in the compression testing process. As happened with the compressive nature, the split tensile strength also decreased with the increase in the fly ash replacement, however, the split tensile strength significantly improved with the curing age. After the 7 days of curing process, the concrete mix M1 [0% fly ash] was found to be 2.80 MPa, whereas the mix M2 with 40% fly ash replacement ,mix M3 with 45% fly ash replacement and mix M4 with 50% fly ash gave the results of 1.91 MPa , 1.57 MPa and 1.10 MPa respectively, contributing to an overall decrease of 25% to 45% strength reduction than the conventional mix with the strength of the control mixture M1 (0% fly ash).However, splitting tensile strength was found to increase with age. After the 90 days of curing, the results were significantly improved, obtaining the strength of 4.67 MPa,3.28 MPa ,2.90 MPa and 2.50 MPa for the mixes M1,M2,M3 and M4 respectively, which was 5-35% higher than the results obtained after 28 days of curing. From the results obtained, it can be easily concluded that the increased percentage of strength at 7 and 90 days of curing was much more than the strength obtained at the end of 28 days, which can be due to pozzolanic action of the fly ash present in huge amounts.

C. Flexural Strength

The flexural strength for the concrete mix was calculated by casting the reinforced beam of size 1100mm x 100mm x 150 mm, after being cured for the span of 28 days. Once they are cured, the surface of the beam was thoroughly washed and cleaned for the clean visibility of the formed cracks. The test was carried out on the concrete mix containing no fly ash,40 % fly ash replacement,45 % fly ash replacement and 50% fly ash replacement.

Figure 6. Flexural Strength Test

For this study, the flexural strength was calculated at the end of 28 days of curing and the results were tabulated in Table 10.

Table 10. Tests of flexural strength test

S.No	Percentage of fly ash replacement	Load at initial crack in 28 days[in kN]	Ultimate Load in 28 days [in kN]	Nature of failure
01.	0%	18	67.5	Flexural failure
02.	40%	31	59	Flexural failure
03.	45%	17	57	Flexural failure
04.	50%	22	53.2	Flexural failure

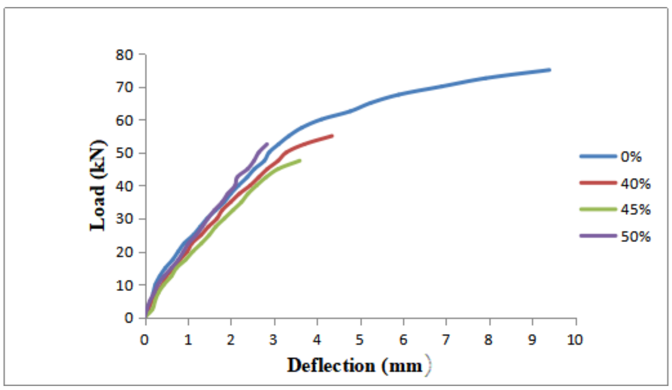

Figure 7. Graph showing variation of flexural strength

After analysing the test results, it was found that the flexural strength also increased with increased curing age, like the same happened with the compressive and split tensile test. The concrete mix M1 with 0% fly ash replacement obtained the flexural strength of 5.8 MPa after 28 days of curing, whereas the mix M2 with 40 % replacement and mix M3 with 45% replacement and mix M4 with 50% fly ash replacement obtained flexural strength of 3.75 MPa,3.0 MPa and 2.5MPa respectively. The results clearly indicate the strength development depending upon the fly ash content.

V. Conclusion

From the analysis of the test results, the results clearly indicated the strength reduction of the fly ash concrete at the age of 7 days and 28 days of curing, but the strength significantly improved beyond the 28 days of curing. The strength obtained beyond 28 days of curing for all the replacement proportions- 40%,45% and 50% replacement of the fly ash is sufficient requirement for the construction of reinforced cement concrete. In addition to all these, the replacement of fly ash in huge volumes produced an slump loss of at a reduction of 50% average, when compared to the conventional concrete slump loss rate. For these type of high volume replacement of fly ash combinations, the correlations found represents a tool for the selection of initial proportions of target properties which includes the strength of compressive nature, its tensile split and flexural strength also.

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