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Research Article

Investigating the Compressive Strength of Concrete by Partial Replacement of Cement with High Volume Fly Ash

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Abstract

The application of concrete in construction is as old as the days of Greek and Roman civilization. But for numerous reasons, the concrete construction industry is not sustainable. Firstly, it uses up huge quantities of virgin materials. Secondly, the principal binder in concrete is Portland cement (major contributor to greenhouse gas emissions). Thirdly, many concrete structures suffer from lack of durability. In this report, a brief review is presented with mixtures containing 10%, 20%, 30% and 40% Fly Ash by the bulk of the cementitious material (OPC) for M 30 and M 40 grade of concrete. The test result indicates that the compressive strength of mix with 10%, 20% and 30% replaced with fly ash were more as compared with conventional concrete thus enhancing the durability of structures. Yet, in reality approximately 50% of the Fly Ash produced throughout the world is stockpiled/land filled as a wasteland. The adoption of high-volume fly ash concrete system will enable the construction industry to get more sustainable by addressing the above three topics.

Keywords: *Cementitious, Compressive strength, Conventional Concrete, Durability, Fly Ash, High Volume Fly Ash Concrete (HVFAC), OPC (G-43)*

1. Introduction

Fly ash is a BY-PRODUCT of coal combustion power plants. Fly ash is a siliceous, or siliceous and aluminous, material which in itself possesses little or no cementitious value, but are mostly finer than cement, which in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. Utilization of fly ash in concrete started in the United States in the early 1930's. The first comprehensive work was that described in 1937, by R. E. Davis at the University of California. The major breakthrough in using fly ash in concrete was the construction of Hungry Horse Dam in 1948, utilizing 120,000 metric tons of fly ash. This decision by the U.S. Bureau of Reclamation paved the way for using fly ash in concrete structures. In addition to economic and ecological benefits, the utilization of fly ash in concrete improves its workability, reduces segregation, bleeding, heat evolution and permeability, inhibits alkali-aggregate reaction, and enhances sulfate resistance. Even though the role of fly ash in concrete has increased in the last 20 years, less than 20% of the fly ash collected is applied in the cement and concrete industries. Concrete with high percentages of fly ash looks and finishes the same as regular concrete, with a few small modifications. Fly ash already replaces around 15% of cement in much of the concrete used today, but we can manage a lot better by utilizing it to replace 50% or more. The substitution of fly ash as a cementitious component in concrete depends upon various factors. The design strength, workability of the concrete, water demand and comparative cost of fly ash as compared to cement. Utilization of fly ash minimizes the Carbon dioxide emission problem to the extent of its proportion in cement. Nevertheless, the basic underlying principle of sustainable development is to reduce, reuse and recycle. This can be achieved by reusing waste products (fly ash) by proper planning for collection and weighing the many cases of environmental impacts (e.g. global warming, resource depletion such as coal) at different life cycle stages of Portland cement (e.g., manufacturing, transportation, use, disposal). Worldwide, the manufacture of Portland cement accounts for 6-7% of the entire carbon-di-oxide (CO_2) created by mankind, adding the greenhouse gas equivalent of 330 million cars driving 12,500 miles per year. The usage of High Volume Fly Ash concrete in construction is a solution to environmental degradation being caused by the cement industry. As cement industry, itself, is responsible for 7% of world's carbon dioxide emissions, responsible for global warming, attention needs to be made by the construction industry to work out the trouble. This project report is an effort to find a suitable and full utilization for a particular fly ash sample and therefore cut down the need for vast fields for disposal of fly ash which in turn causes considerable harm to the surroundings.

1.1Present Scenario on Fly Ash in India

a) Over 75% of the total installed power generation is coal-based.

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b) 230 - 250 million MT coal is being utilized every year
c) High ash contents varying from 30 to 50%.
d) More than 110 million MT of ash generated every year.
e) Ash generation likely to reach 300 million MT by 2015.
f) Presently 65,000 acres of land occupied by ash ponds.
g) Presently, as per the Ministry of Environment & Forest Figures, 30% of Ash is being used in Fillings, embankments, construction, block & tiles, and so on
h) Rajiv Gandhi Rural Housing Corporation Ltd. has done pioneering work in using fly ash products in the projects implemented by it. Fly ash-based building components like blocks, bricks, door and window frames are extensively employed in the construction of houses in Raichur, Bellary, Uttara Kannada and Shimoga Districts.
i) The Government of India has withdrawn 8% **excise duty** imposed earlier on fly ash products. Now no excise duty is imposed on the fabrication of commodities in which a minimum of 25% fly ash is applied. Similarly for import of equipment, machinery and capital goods required for the production of fly ash based products, additional customs duty has been freed.
j) There are 11 major thermal power plants in Chhattisgarh State which produces FLY ASH to the air about 26880 metric metric tons/day i.e. nearly 9.7 million tones of fly ash annually , out of which 4 major thermal power plants in KORBA district alone generates 24000 metric tons/day or 8.7 million tons of fly ash annually. This is nearly 90 % of total ash generated in the STATE & about 8.7 % of the total ash generated in the country.

1.2 High Volume Fly Ash Concrete (HVFAC)

The High Volume Fly Ash Concrete (HVFAC) was developed by CANMET (The Canada Centre for Mineral and Energy Technology) in the year 1986. For enhancing the durability of concrete, larger quantities of fly ash i.e. of the order of 25% to 60% should be used in PCC by weight of the cementitious material. Such a concrete with high volumes of fly ash in it is called High volume Fly Ash Concrete. From a theoretical consideration and practical experience it is determined that 50% or more cement replacement by fly ash, it is potential to develop sustainable, high performance concrete mixes that show higher workability, higher ultimate strength and high durability, (Malhotra, 1999). High volume fly ash concrete

(HVFAC) has very low water content. Because of the low water content, a high range water reducer or super plasticizer is used to achieve desired workability. With super plasticizers, concrete with as low as 0.2 W/C ratios are possible with good workability and strength as high as 83 N/mm^2 is possible at test age of 28 days (ACI-211, 1993).The maximum strength reported with fly ash and super plasticizer is about 60 N/mm^2, (Swamy, 1985). The fact that the role of high volume fly ash along with super plasticizer in concrete exhibits good workability and high early strength is emphasized by (Raju, 1991). (Kohubu, 1968) provided a major breakthrough in using Fly Ash in Concrete as it was the first comprehensive survey of its own sort. (Malhotra and Ramezanianpur, 1994) made a comparison of properties of concrete with varying percentages of fly ash. (Halstead,Woodrow J. ,1986) explains the uses of Fly Ash in Concrete with special reference to the time of setting, bleeding, heat of hydration and pump ability. (Mehta, 1983) explains the use of cementitious by-products as mineral admixtures for concrete. (Helmuth, 1987) describes that the use Fly Ash in concrete has increased in last 20 years. However, less than 20 % of the Fly Ash collected was used in Cement and Concrete Industry. It is explained that one can safely use Fly Ash in Concrete in Pavements for economic & ecological benefits. (Adams, T.H, 1988) encourages the use of Fly Ash in Concrete Pavements. The price of Fly Ash concrete is less than the price of mixes with ordinary cement and Fly Ash Concrete is also given preference as it is technically more appropriate. (ACI 211, 1996) recommends Fly Ash replacement in cement between 15% to 35%. (Mehta, 2001) refers to Concrete technology for sustainable development with the intent to reduce greenhouse gas emissions by Cement industry. (Malhotra and Mehta, 2002) described High Volume Fly Ash Concrete with the larger replacement of Fly Ash (>30%) in cement as a beneficial practice for sustainable, durable and economic Concrete. (Ujjwal Bhattacharjee *et al*, 2002) has enlightened the areas in which fly ash usage has potential in India. He pointed out that despite quite optimistic levels of usage of fly ash in India; only less than 25% of the total fly ash produced is being employed. (Rafat Siddique, 2004) carried out experimental investigations on class F fly ash concrete with three percentages of replacement i.e. 40%, 45% and 50%. He concluded that partial replacement of cement by fly ash in concrete results in a decrease in compressive strength, Split tensile strength, modulus of elasticity and abrasion resistance at 28 days of age.

Nevertheless, all these properties of hardened concrete to show significant improvement at 90 days and thereof. (Ozkan Sengul, 2005) studied the effect of partial replacement (0% to 70%) of cement by fly ash in concrete on its compressive strength. He reported that high volume fly ash concrete has decreased compressive strength at 28 days, better strength at later ages i.e. 5 and 120 days, increased brittleness index and better resistance to chloride ion penetration. (Naik H.K., 2007) reviewed some of the experimental studies in the research lab to study the suitability of use of a peculiar case of fly ash sample with the aim to reduce environmental degradation being caused by disposition of high volumes of fly ash in landfills. (Sukhvarsh Jerath, p.E. *et al*, 2007) reported that addition of fly ash content from 30% to 45% increased the strength of concrete without loss of compressive and flexural strength. (Binod Kumar *et al*, 2007) studied the suitability of super plasticizer HVFA concrete for pavements. He concluded that HVFA concrete by 50% - 60% fly ash can be planned to match the strength and workability requirement of concrete pavements. (Vengata, 2009) have reported that the addition of fly ash in high volumes considerably decreases the permeability of concrete, even though the intensity level of fly ash concrete at 28 days is not advancing. (Mehta, 2004) has reviewed the theory and construction practice of concrete mixture with more than 50% fly ash. He has discussed the mechanisms of incorporating high volumes of fly ash in concrete for reducing water demand, improving workability, minimizing thermal and drying shrinkage and enhancing strength. The present study for which this literature has been collected is directed for the adoption of high-volume fly ash concrete for sustainable growth of the construction industries.

2. Experimental Materials

2.1 Materials

A. Cement

Commercially available Ordinary Portland Cement of 43 grades manufactured by the JP Cement Company confirming to IS 8112:1989 was used in the field (Specification, Bureau of Indian Standards, New Delhi). The Properties of Cement are shown in Table 1

Table 1: Properties of Cement

Details	Normal Consistency (%)	Specific Gravity	Setting Time (Min.)	
			Initial	Final
OPC(G-43)	26.75	3.15	95	450

B. Fine Aggregate

Locally available river sand passed through 4.75mm IS sieve is applied as fine aggregate. The specific gravity of sand is 2.60 and fineness modulus is 3.30. The free and compacted bulk density values obtained are 1645 Kg/m^3 and 1780 Kg/m^3 and water absorption is 1.10%.

C. Coarse Aggregate

The Coarse aggregate are obtained from a local quarry is used. The coarse aggregate with a maximum size 20 mm having a specific gravity 2.70 and fineness modulus of 6.60. The loose and compacted bulk density values obtained are 1600 Kg/m^3 and 1790 Kg/m^3 respectively, water absorption of 1.50%.

D. Fly Ash

Fly ash (Class F Type) having specific gravity of 2.50 obtained from Paricha Thermal Power Plant at Jhansi (U.P.) was used for the replacement of cement.

3. Mix Proportions

In this study, the concrete mix is planned as per IS: 10262-1982 (Recommended Guidelines for Concrete Mix Design—Bureau of Indian Standards, New Delhi), IS: 456-2000 (Plain and Reinforced Concrete—Code of Practice—Bureau of Indian Standards, New Delhi) to achieve the target mean compressive strength at 28 days of 38 N/mm^2 for M30 Mix Design and 48 N/mm^2 for M40 Mix Design (IS: 10262-1982, Recommended Guidelines for Concrete Mix Design—Bureau of Indian Standards, New Delhi). The grades of concrete, which we adopted, are M30 and M40. The concrete mix proportion (cement: fine aggregate: coarse aggregate) is 1:2:2.5 (w/c = 0.50) and 1: 1.54: 2.68 (w/c= 0.40). Fly ash was used to replace the Ordinary Portland cement at various stages of 0%, 10%, 20%, 30% and 40% by mass of cementitious material.

4. Preparation and Details of Specimen

The study is conducted to analyze the compressive strength of concrete when the base materials, i.e. Cement is replaced with fly ash, respectively. The fly ash replacement was kept at 0%, 10%, 20%, 30% and 40%. In all total 15 cubes of OPC (150mm × 150mm × 150mm) were examined and results were analyzed after curing 28 days. The each test result is the average test result of three test cubes. Data obtained from the replacement is compared with data from a Conventional concrete.

5. Results and Discussions

After a detailed study, the compression results obtained for M 30 and M 40 grade of concrete are as follows (Table 2 and Table 3)

Table 2: Compressive Strength of Concrete (M 30)

S.No.	Specimen	Compressive Strength at 28 days (N/mm^2)
1.	Conventional Concrete	36.50
2.	10%	49.55
3.	20%	45.71
4.	30%	41.35
5.	40%	30.50

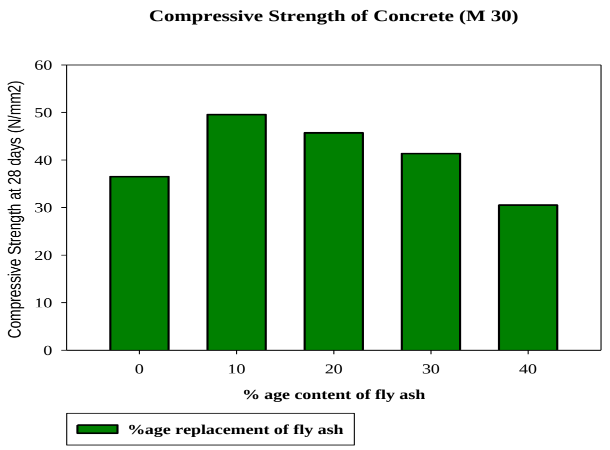

Fig. 1 Compressive Strength of different types of specimens at 28 days curing

Table 3: Compressive Strength of Concrete (M 40)

S.No.	Specimen	Compressive Strength at 28 days (N/mm^2)
1.	Conventional Concrete	45.60
2.	10%	56.20
3.	20%	51.35
4.	30%	45.70
5.	40%	34.91

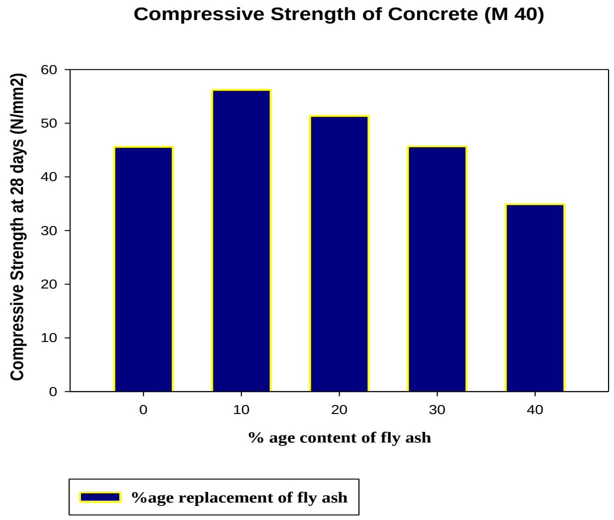

Fig. 2 Compressive Strength of different types of specimens at 28 days curing

The test result demonstrates that the compressive strength of mix with 10%, 20% and 30% replaced with fly ash were more as compared with conventional concrete thus enhancing the durability of structures (fig. 1 and 2). The early increase in strength of fly ash decreases the role of concrete as it fires the free calcium oxide which reacts throughout the curing operation. The strength of the Mix with 40% replacement with fly ash was lesser than the conventional concrete (fig. 1 and 2). The rate of gain in compressive strength for all the mixes substituted with fly ash was higher than conventional concrete. The result obtained for 28-day compressive strength confirms that the optimal percentage for replacement of cement with fly ash is about 30% as shown in fig.1 (M 30) and fig.2 (M 40). Fig. 3 represents the combine results of Compressive Strength for M 30 & M 40 concrete grade at 28 days curing**.**

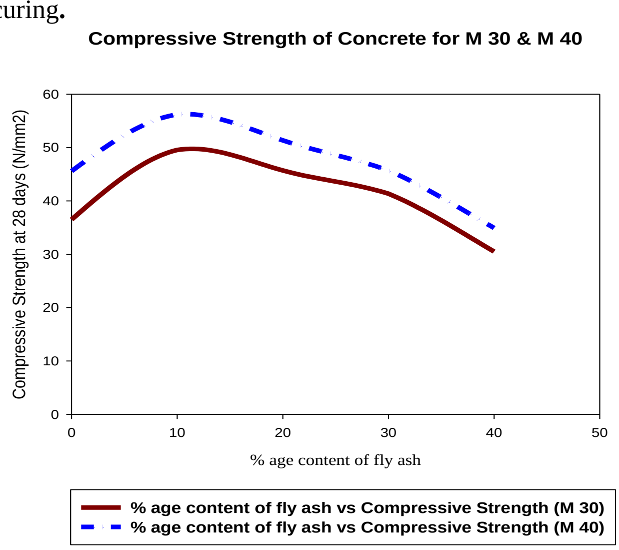

Fig. 3 Accumulation of Compressive Strength for M 30 & M 40 concrete grades at 28 days curing

Conclusion

Fly ash is a rich cementitious industrial waste which has the great potential to replace Portland cement. This paper incorporates that the 28 days compressive strength of the Mix can be achieved with a replacement of 30% of fly ash with the cement. When the percentage of replacement is increased the water/ binder ratio gets reduced, thereby, increasing the compressive strength. Also, it is observed that the compressive strength of concrete having more than 40% replacement of cement by fly ash suffers adverse effects though water/ binder ratio is gradually lost weight. The compressive strength of the concrete mix with 40% replacement with fly ash was lesser than the conventional concrete at 28 days. The result obtained for 28-day compressive strength confirms that the optimal percentage for replacement of cement with fly ash is about 30% as shown in fig.1 (M 30) and fig.2 (M 40). Hence, this paper presents an effort for the purpose of high volume fly ash concrete to reach a sustainable growth.

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