

Cost and Strength Analysis of Normal and High Volume Fly Ash Concrete

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ABSTRACT

With the growing urbanisation and development the demand of concrete does not seem to go dormant in the future so it is essential that we find some environment friendly replacement like Fly Ash for its constituents like cement. In this present study first of all the need, scope and advantages of using High Volume Fly Ash Concrete is discussed. The existing records of use of Fly Ash in concrete is followed by the tests conducted on Aggregates like Sieve Analysis, Impact Value etc. After that comes experimental programme which includes tests done on concrete samples casted in the study in which cement is replaced by Fly Ash in different percentages and the strength characteristics of High Volume Fly Ash Concrete is checked. Last portion of this study deals with the various results obtained and interpretations are made regarding the cost of the various concrete mix used in the study and conclusion are drawn.

1. Introduction

Concrete, typically composed of gravel, sand, water, and Portland cement, is an extremely versatile building material that is used extensively worldwide. Reinforced concrete is very strong and can be cast in nearly any desired shape. Unfortunately, significant environmental problems result from the manufacture of Portland cement. Worldwide, the manufacture of Portland cement accounts for 6-7% of the total carbon dioxide (CO₂) produced by humans, adding the greenhouse gas equivalent of 330 million cars driving 12,500 miles per year [1].

Fortunately, a waste product Fly Ash can be substituted for large portions of Portland cement, significantly improving concrete's environmental characteristics. Fly Ash, consisting mostly of silica, alumina, and iron, forms a compound similar to Portland cement when mixed with lime and water. Fly ash is a non-combusted by-product of coal-fired power plants and generally ends up in a landfill. However, when high volumes are used in concrete (displacing more than 25% of the cement), it creates a stronger, more durable product and reduces concrete's environmental impact considerably. Due to its strength and lower water content, cracking is reduced.

In the HVFAC mechanism, physical and chemical factors combine at all ages to densify and bind the paste. In the early age of concrete, the important factors of strength development are

- (i) Physical effect - fine particles of fly ash act as micro aggregates and densify the mass
- (ii) Chemical contribution of the formation of ettringite or related sulpho-aluminate production.

In the later age hydration reaction dominates in the strength development process as additional binders are generated by reaction involving fly ash. Any concrete that uses more fly ash than 25% (weight of cement) would be considered high volume fly ash concrete. With high volume fly

ash concrete, you will see less early age strength, but the long term strength is about the same as with normal concrete.

Consequent upon increased generation of electricity through thermal route involving combustion of pulverized coal/ignite, concurrent generation of fly ash in bulk quantities is a matter of serious concern not only because of issues associated with its disposal and utilization but also because of its threat to public health and ecology. At present, large quantity of fly ash is being dumped in slurry form in large areas close to the power plants without being put to gainful use in India. Only a very small percentage (<35%) of fly ash generated in India is being used for gainful applications whereas the corresponding figures of other countries may vary from 60 to 100%.

Although fly ash offers environmental advantages, it also improves the performance and quality of concrete. Fly ash affects the plastic properties of concrete by improving workability, reducing water demand, reducing segregation and bleeding, and lowering heat of hydration. Fly ash increases strength, reduces permeability, reduces corrosion of reinforcing steel, increases sulphate resistance, and reduces alkali-aggregate reaction. Fly ash reaches its maximum strength more slowly than concrete made with only portland cement. The techniques for working with this type of concrete are standard for the industry and will not impact the budget of a job. So as a Civil Engineer we should effectively try to use fly ash in construction, as it helps in saving environment with reduced construction cost along with many other advantages, but now question rises to what extent or percentage fly ash could be used in concrete for construction works, and to answer this present study have been made.

2. Literature review

Nowadays concrete is the most widely used construction material. Durability of concrete is one of the most important considerations in the design of new structures (Roads, Buildings, Fly Overs etc.) and assessing the conditions of

existing structures. The last 20 to 30 years have seen the growing awareness among the Engineers of the need to ensure that the provisions are made for durability in concrete structure. More recently, there has also been a growing awareness of the importance of sustainability in concrete construction and in particular the more effective and efficient use of material.

This chapter deals with the reviews of the existing literature on the use of high volume fly ash concrete. The most important investigations, related to the current investigations are summarized and the salient facts which seems to emerge from the research are discussed. The discussion is generally confined to influence of fly ash addition in the properties of concrete, workability and compressive strength.

Brown, J.H. (1982)^[4] in his paper "The strength and workability of concrete with Fly Ash substitution" conducted several studies with fly ash replacing cement and fine aggregate at levels of 10- 40% by volume. He concluded that for each 10% of ash substituted for cement, the compacting factor or workability changed to the same order as it would by increasing the water content of the mix by 3-4%. When fly ash was substituted for sand or total aggregate, workability increased to reach a maximum value at about 8% ash by volume of aggregate. Further substitution caused rapid decrease in workability.

Gebler, S.H. and Klieger, P. (1983)^[5] in their paper "Effect of fly ash on the air void stability of concrete " investigated the requirements of Air Entraining Agent (AEA) for Class-C and Class-F fly ashes. They reported that:

- 1) Concretes made with Class C fly ash generally require less AEA than those made with Class F fly ashes.
- 2) For 6% air content in concrete, the AEA varied from 126 to 173% for fly ashes having more than 10% CaO, whereas it was in the range of 177 to 553% for fly ashes containing less than 10% CaO.
- 3) Increase in both total alkalis and SO₃ contents in fly ash affect the air entrainment favorably. A concrete containing a Class F fly ash that has relative high CaO content and less organic matter or carbon tends to be less vulnerable to loss of air.

Owens, P.L. (1989)^[6] in his paper "Fly ash and its usage in concrete" reported that with the use of fly ash containing large fraction of particles coarser than 45 μ m or a fly ash with high amount of unburned carbon, exhibiting loss on ignition more than 1%, higher water demand was observed.

Sivasundram, V. et al. (1990)^[7] in their paper "Selected properties of high volume fly ash concretes" investigated the setting time of high-volume fly ash concrete mixes, and concluded that the initial setting time of 1.50 hours was comparable to that of the control concrete, whereas the final setting time was extended by about 3 hours as compared to that of the control concrete.

2) Hardened Properties:

Carette, G.G. and Malhotra, V.M. (1983)^[8] in their research paper "Characterization of Canadian fly Ashes and their Performance in Concrete" studied the effect of Canadian fly ashes on the compressive strength of concrete mixes. Cement was replaced with 20% fly ash in all the mixes. Compressive strength was measured up to the age of 365 days. It was seen that compressive strength continued to increase with age, indicating pozzolanic action of fly ashes.

Joshi, R.C., and Lohtia, R.P. (1993)^[9] in their paper "Effects of premature freezing temperatures on compressive strength, elasticity and microstructure of high volume fly ash concrete" tested a large number of fly concrete mixes made by using three different fly ashes containing about 10% calcium oxide. The replacement level varied between 40 and 60% by weight of cement. The mixes were super-plasticized and air-entrained to obtain 100 to 120 mm slump and 6 \pm 1% air content.

The cementitious material content varied from 380 to 466 kg/m³, water to cementitious material ratio from

0.27 to 0.37, coarse aggregate ranged from 1,012 to 1,194 kg/m³, and fine aggregate or sand varied from 712 to 643 kg/m³. They reported that at 7 days, the fly ash concretes obtained strength between 27.9 and

41.0 MPa compared to 44.1 MPa of control concrete. However at the age of 28 days, the fly ash concretes developed strength varying from 37.6 to 50.7 MPa against 58.7 MPa for control concrete. At 120 days, strength of fly ash concrete ranged from 54.8 to 74.6 MPa whereas it was 74.6 MPa of control concrete.

Lohtia et al. (1996)^[10] in his paper "Creep of fly ash concrete " studied the creep and creep recovery of plain and fly ash concretes at stress-strength ratios of 20 and 35%. Fly ash content was varied between 0 and 25%. They concluded that:

- 4) Replacement of 15% of cement with fly ash was optimum with respect to strength, elasticity, shrinkage and creep of fly ash concrete.
- 5) Creep-time curves for plain and fly ash concretes were similar, and creep linearly related to the logarithm of time
- 6) With fly ash content up to 15%, increase in creep was negligible. However, slightly higher creep occurred with fly ash content more than 15%.
- 7) Creep coefficients were similar for the materials with fly ash content in the range of 0–25%.
- 8) Creep recovery was found to vary from 22 to 43% of the corresponding 150-day creep. For replacement beyond 15%, the creep recovery was smaller.

No definite trend of creep recovery as a function of stress-strength ratio was observed.

Haque et al. (1998)^[11] investigated the shrinkage of concrete containing 40–75% cement replacement with a bituminous fly ash (CaO 10%). They concluded that drying

shrinkage of concrete decreased with increase in fly ash content.

Saraswathy, V. et al. (2003)^[12] in their paper "Influence of activated fly ash on corrosion-resistance and strength of concrete" investigated the influence of activated fly ash on the compressive strength of concrete. Various activation techniques, such as physical, thermal and chemical were adopted. Concrete specimens were prepared with 10, 20, 30 and 40% of activated fly ash replacement levels with cement. Compressive strength was determined at 7, 14, 28 and 90 days. They concluded that:

1) Activation of fly ash improved the strength of concrete. However, the compressive strength of fly ash concrete was less than that of ordinary portland cement (OPC) even after 90 days of curing.

2) Among the activation systems, chemically activated coal fly ash (CFA) improved the compressive strength to a certain extent, only with 10 and 20% replacements. Since the CFA surface layer is etched by a strong alkali to facilitate more cement particles to join together and also the addition of CaO which is further promoting the growth of CSH gel and Ca(OH)₂ which is more advantageous to enhance the strength development.

Siddique, R. (2003)^[13] in his paper "Effect of fine aggregate replacement with class F fly ash on the mechanical properties of concrete", studied the effect of partial replacement of fine aggregate (sand) with varying percentages of Class F fly ash on the compressive strength, splitting tensile strength, flexural strength and modulus of elasticity of concrete up to the age of 365 days. Fine aggregate (sand) was replaced with five levels of percentages (10, 20, 30, 40, and 50%) of Class F fly ash by weight. Control mix (without fly ash) was proportioned to have a 28-day cube compressive strength of 26.4 MPa. Based on the results, it was concluded that:

- 1) Compressive strength of fine aggregate (sand) replaced fly ash concrete specimens was higher than the plain concrete (control mix) specimens at all the ages. The strength differential between the fly ash concrete specimens and plain concrete specimens became more distinct after 28-days.
- 2) Compressive strength continued to increase with age for all fly ash replacement levels.
- 3) The maximum compressive strength occurs with 50% fly ash content at all ages. It was 40.0 MPa at 28-day, 51.4 MPa at 91-day, and 54.8 MPa at 365-day.
- 4) Splitting tensile strength, and flexural strength of fine aggregate (sand) replaced fly ash concrete specimens was higher than the plain concrete (control mix) specimens at all the ages. The strength differential between the fly ash concrete specimens and plain concrete specimens became more distinct after 28-days.
- 5) Both splitting and flexural strengths continued to increase with age for all fly ash percentages.
- 6) At all the ages, the maximum splitting tensile strength

was observed with 50% fly ash content. It was 3.5 MPa at 28-day, 4.3 MPa at 91-day, and 4.4 MPa at 365-days.

- 7) Maximum flexural strength was found to occur with 50% fly ash content at all ages. It was 4.3 MPa at 28-day, 5.2 MPa at 91-day, and 5.4 MPa at 365-days.
- 8) Modulus of elasticity of fine aggregate (sand) replaced fly ash concrete specimens was higher than the plain concrete (control mix) specimens at all the ages. The differential between the fly ash concrete specimens and plain concrete specimens became more distinct after 28-days.
- 9) Modulus of elasticity of fine aggregate (sand) replaced fly ash concrete continued to increase with age for all fly ash percentages.
- 10) At all ages, the maximum value of modulus of elasticity occurs with 50% fly ash content. It is 24.5 GPa at 28-day, 28.0 GPa at 91-day, and 29.0 GPa at 365-day.

Atis et al. (2004)^[14] in their paper "Strength and shrinkage properties of mortar containing a nonstandard high-calcium fly ash" assessed the drying shrinkage of mortar mixtures containing high calcium non standard fly ash up to the age of 5 months. Five mortar mixtures including control Portland cement and fly ash mortar mixtures were prepared. Fly ash replaced cement on mass basis at the replacement ratios of 10, 20, 30 and 40%. Water-cementitious materials ratio was 0.4. Mixtures were cured at 65% relative humidity and $20 \pm 2^{\circ}$ C. They reported that shrinkage of Portland cement mortar at 5 months was 0.1228%. Shrinkage of fly ash mortar decreased with the increase in fly ash content. Shrinkages of mortar containing 10, 20 and 30% fly ash were 25, 37 and 43%, lower than the shrinkage of Portland cement mortar at the end of 5 months. The reduction in shrinkage with the use of fly ash in mortar could be explained by the dilution effect of fly ash. The expansive property of fly ash most probably contributed to the reduction in drying shrinkage.

Demirboga et al. (2007)^[15] in their paper "Thermo-mechanical properties of concrete containing high-volume mineral admixtures" investigated the Thermal Conductivity (TC) of HVFA concrete at the age of 28 days. Cement was replaced with 0, 50, 60, and 70% of Class C fly ash. They concluded that TC of concrete decreased to 32, 33, and 39% for 50, 60 and 70% fly ash replacement, respectively.

3. FLY ASH

Fly ash is one of the residues generated in combustion as shown in Figure 3.1, and comprises the fine particles that rise with the flue gases. Ash which does not rise is termed bottom ash. In an industrial context, fly ash usually refers to ash produced during combustion of coal. Fly ash is generally captured by electrostatic precipitators or other particle filtration equipment before the flue gases reach the chimneys of coal-fired power plants, and together with bottom ash removed from the bottom of the furnace is in this case jointly known as coal ash. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO₂)

(both amorphous and crystalline) and calcium oxide (CaO), both being endemic ingredients in many coal-bearing rock strata.

Toxic constituents depend upon the specific coal bed makeup, but may include one or more of the following elements or substances in quantities from trace amounts to several percent: arsenic, beryllium, boron, cadmium, chromium, chromium VI, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and PAH compounds.[22]



Figure 1: Fly Ash

In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now requires that it be captured prior to release. In the US, fly ash is generally stored at coal power plants or placed in landfills. About 43 percent is recycled, often used to supplement Portland cement in concrete production. Some have expressed health concerns about this.

In some cases, such as the burning of solid waste to create electricity, the fly ash may contain higher levels of contaminants than the bottom ash. So, mixing the fly and bottom ash together brings the proportional levels of contaminants within the range to qualify as nonhazardous waste in a given state, whereas, unmixed fly ash would be within the range to qualify as hazardous waste.

Types of Fly Ash

There are two types of fly ash based on the quantity of lime, the types are listed below:

- 1) Class F Fly Ash
- 2) Class C Fly Ash

Class F Fly Ash: The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 20% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geo-polymer.

Class C Fly Ash: Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO₄) contents are generally higher in Class C fly ashes.

At least one US manufacturer has announced a fly ash brick containing up to 50 percent Class C fly ash. Testing shows the bricks meet or exceed the performance standards listed in ASTM C 216[24] for conventional clay brick; it is also within the allowable shrinkage limits for concrete brick in ASTM C 55[25], Standard Specification for Concrete Building Brick. It is estimated that the production method used in fly ash bricks will reduce the embodied energy of masonry construction by up to 90%. Bricks and pavers were expected to be available in commercial quantities before the end of 2009.

4. Various usage of fly ash

Pulverized Fuel Ash is versatile resource material and can be utilized in variety of application. The pozzolanic property of fly ash makes it a resource for making cement and other ash based products. The Geo-technical properties of bottom ash, pond ash & coarse fly ash allow it to use in construction of embankments, structural fills, reinforced fills low lying area development etc. The physico chemical properties of pond ash is similar to soil and it contains P, K, Ca, Mg, Cu, Zn, Mo, and Fe, etc. which are essential nutrients for plant growth. These properties enable it to be used as a soil amender & source of micronutrients in Agriculture/ Soil Amendment.

The major utilization areas of PFA are as under: -

- Manufacture of Portland Pozzolana Cement & Performance improver in Ordinary Portland Cement (OPC).
- Part replacement of OPC in cement concrete.
- High volume fly ash concrete.
- Roller Compacted Concrete used for dam & pavement construction.
- Manufacture of ash bricks and other building products.
- Construction of road embankments, structural fills, low lying area development.
- As a soil amender in agriculture and wasteland development.

5. Aggregates

Aggregates are defined as inert, granular, and inorganic materials that normally consist of stone or stone-like solids. Aggregates are a component of composite materials such as concrete and asphalt concrete; the aggregate serves as reinforcement to add strength to the overall composite material. Due to the relatively high hydraulic conductivity value as compared to most soils, aggregates are widely used in drainage applications such as foundation and French drains, septic drain fields, retaining wall drains, and road side edge drains. Aggregates are also used as base material under

foundations, roads, and railroads. To put it another way, aggregates are used as a stable foundation or road/rail base with predictable, uniform properties (e.g. to help prevent differential settling under the road or building), or as a low-cost extender that binds with more expensive cement or asphalt to form concrete.

The American Society for Testing and Materials publishes an exhaustive listing of specifications for various construction aggregate products, which, by their individual design, are suitable for specific construction purposes. These products include specific types of coarse and fine aggregate designed for such uses as additives to asphalt and concrete mixes, as well as other construction uses. State transportation departments further refine aggregate material specifications in order to tailor aggregate use to the needs and available supply in their particular locations.

Sources for these basic materials can be grouped into three main areas: Mining of mineral aggregate deposits, including sand, gravel, and stone; use of waste slag from the manufacture of iron and steel; and recycling of concrete, which is itself chiefly manufactured from mineral aggregates. In addition, there are some (minor) materials that are used as specialty lightweight aggregates: clay, pumice, perlite, and vermiculite.

The advent of modern blasting methods enabled the development of quarries, which are now used throughout the world, wherever competent bedrock deposits of aggregate quality exist. In many places, good limestone, granite, marble or other quality stone bedrock deposits do not exist. In these areas, natural sand and gravel are mined for use as aggregate. Where neither stone, nor sand and gravel, are available, construction demand is usually satisfied by shipping in aggregate by rail, barge or truck. Additionally, demand for aggregates can be partially satisfied through the use of slag and recycled concrete. However, the available tonnages and lesser quality of these materials prevent them from being a viable replacement for mined aggregates on a large scale.

Large stone quarry and sand and gravel operations exist near virtually all population centers. These are capital-intensive operations, utilizing large earth-moving equipment, belt conveyors, and machines specifically designed for crushing and separating various sizes of aggregate, to create distinct product stockpiles.

6. Aggregate Used

Aggregates used in the present study are in accordance with size as shown below:

- 1) Coarse Aggregates
 - a) 10 mm (CA-I)
 - b) 20 mm (CA-II)
- 2) Fine Aggregates

1) Coarse Aggregate

Those particles that are predominantly retained on the 4.75 mm (No. 4) sieve, are called coarse aggregate. The crushed coarse aggregates of 10mm and 20mm were used in the present study shown in figure 2 and 3



Figure 2: 10 mm Graded Crushed Aggregates.



Figure 3: 20 mm Graded Crushed Aggregates.

2) Fine Aggregates

Those particles passing the 9.5 mm (3/8 in.) sieve, almost entirely passing the 4.75 mm (No. 4) sieve, and predominantly retained on the 75 μ m (No. 200) sieve are called fine aggregate.

7. Results and discussions

General

In this chapter the results of compressive and the flexural test on the concrete mixes with 28%, 50% and 70% fly ash by the mass of cement are presented and discussed. Comparisons of the results are made, in order to present the ideas of the present study. First the compressive strength test results are discussed followed by the results of flexural strength test.

Compressive strength

The compressive strength results with different percentage replacement (28%, 50% and 70%) of cement by fly ash in concrete at 3, 7 and 28 days of curing. These results are expressed graphically in Fig 4.

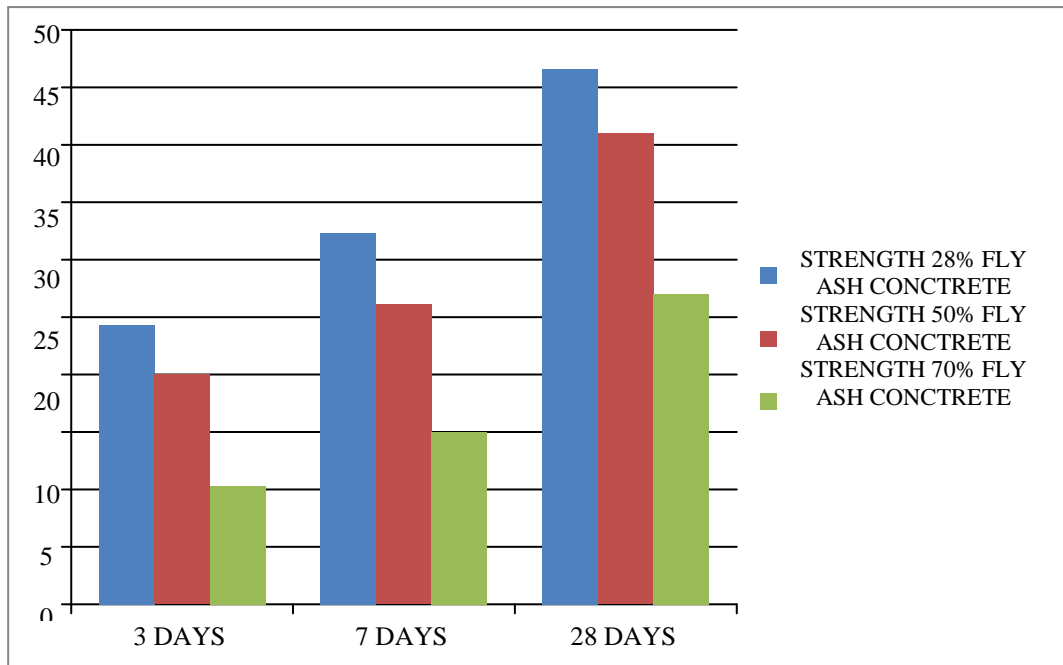


Figure 4: Compressive strength comparison of M40 concrete for 28%, 50% and 70% fly ash content.

Flexural strength

The flexural strength results with different percentage replacement (28%, 50% and 70%) of cement by fly ash in concrete at 28 and 56 days of curing. These results are expressed graphically in Fig 5.

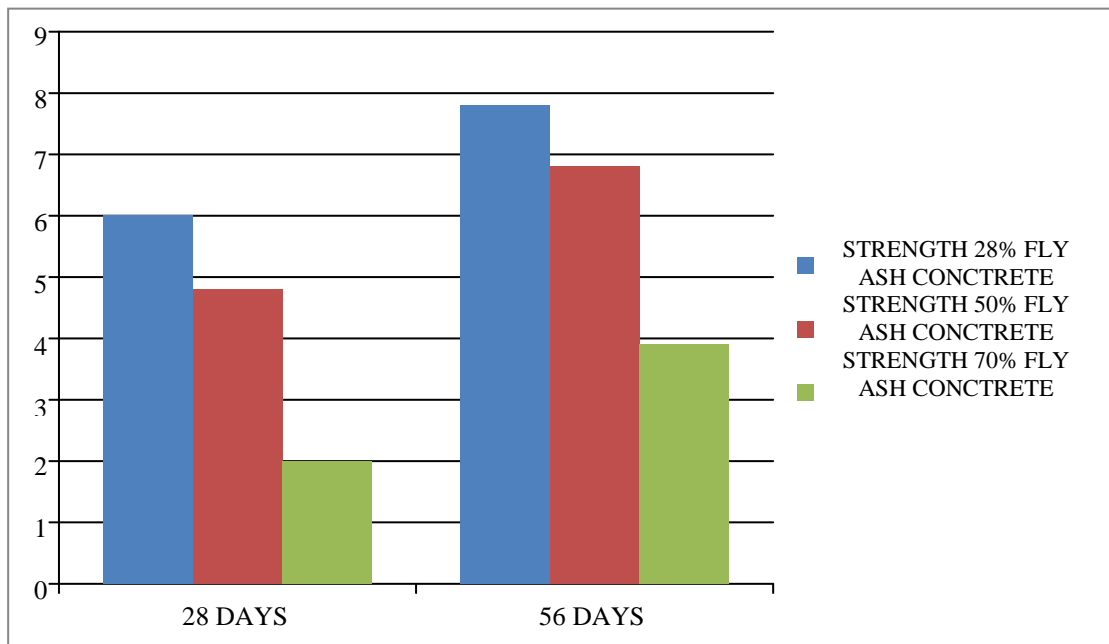


Figure 5: Flexural strength comparison of M40 concrete for 28%, 50% and 70% fly ash content.

8. Discussion

The following points are needed to be discussed from Fig 4 and 5:

- 1) The compressive strength of 28 days of 50% fly ash concrete is only 12% less than the 28% fly ash concrete.
- 2) The compressive strength of 28 days of 70% fly ash concrete is much low (43%) than the 28% fly ash concrete.
- 3) The flexural strength at 28 and 56 days for 50% fly ash concrete is 18% and 10% respectively less than the 28% fly ash concrete. This shows fly ash gives

less early age strength but increases the latter age strength.

- 4) The flexural strength of 28 and 56 days of 70% fly ash concrete is 66% and 50% respectively less than the 28% fly ash concrete. This is a huge difference and is not accepted.
- 5) Results obtained of 28% and 50% fly ash concrete are good and acceptable.
- 6) The results obtained of 70% fly ash concrete are comparable to M25 concrete.
- 7) The cost comparison of these will be done in next chapter.

9. Conclusions

In conclusion, the high-volume concrete offers a holistic solution to the problem of meeting the increasing demands for concrete in the future in a sustainable manner and at a reduced or no additional cost, and at the same time reducing the environmental impact of two industries that are vital to economic development namely the cement industry and the coal-fired power industry. The technology of high-volume fly

ash concrete is especially significant for countries like China and India, where, given the limited amount of financial and natural resources, the huge demand for concrete needed for infrastructure, road construction and housing can be easily met in a cost-effective and ecological manner. In this chapter concluding remarks are discussed obtained from the present study and scope of future work is also given.

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