

# Strength Characteristics of Concrete with Partial Replacement of Cement by Fly Ash and Activated Fly Ash



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**Abstract:** This paper reveals mainly about the prime effects of using fly ash, and activated fly ash which is considered to replace cement in concrete, on the concrete strength. For this reason, proper experiments has been done in the lab to investigate the behavior of fly ash and activated fly ash ratio on the strength and workability parameters of concrete. The compressive strength of concrete specimens with replacement ratios of 30% and 40% 50%, and aged 7 and 28 days are measured for M30 as per IS 10262 2009 grade of concrete and are compared with those of the concrete specimens without fly ash. The results shown that strength of partially replaced cement by activated fly ash in concrete enhanced strength is observed and it is slow but strong and continuous process when compared to the concrete without fly ash. And optimum replacement of fly ash ratio can be found out at the maximum compressive tensile and flexural strength of concrete. The main aim of this paper is to study the strength properties of concrete with fly ash and activated fly ash. And compare the results and opt for the best replacement to eliminate more use of cement in concrete.

**Index Terms:** Activated Fly ash, Fly ash, CVC, CSH, SCM.

## I. INTRODUCTION

Concrete is most ample used material in the construction process because of its flexibility in its use, and it consist of mainly three components cement fine and coarse aggregate. Among these cement is very important which a binding material. In construction, concrete is the only material which has properties such as Strength, Durability, and Resistant to Absorption. The development and use of mineral admixtures for cement replacement is vastly growing in construction industries due to achieve economy, energy saving, environmental protection and low consumption of available natural resource there by utilizing the by-product that are present. Mineral admixture usually used are Fly ash, rice husk ash, silica fumes etc.

Several thesis are carried out on replacement of cement in concrete by these mineral admixtures to develop the concrete with required strength, durability and impermeability” Design & testing of Fly-ash based Geo Polymer Concrete” A.Siva Krishna [1].

Among the entire available mineral admixture, fly ash is available in large quantities which are the by-product of coal in thermal power plant. According to the government of

India the estimated fly ash generated by power plant will be 600 million tons by the end of 2032“Experimental Study on Strength of Concrete by Partial Replacement of Cement by Nano Silica and Fly Ash” Tipraj [2].The utilization of fly ash in India is less than 25% of the total fly ash generated in power plants. Another important aspect is threat to the environment due to the emission of CO<sub>2</sub> in large quantity during the manufacturing of Portland cement. Emission of CO<sub>2</sub> can be reduced by replacement of Portland clinker with supplementary cementitious materials (SCM).Fly ash is used as a cementitious material during the manufacturing of cement called fly ash blended cement and countless research work have been published. “Performance analysis of Black Cotton Soil treated with Granite dust and Lime” Shaik Khader Vali Bab [3].



Fig: Flow Diagram of the project

## II. MATERIALS

Fly ash closely pertains to volcanic ashes used in manufacturing of the in the olden times know by hydraulic cements about 2,300 years ago.

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## Strength Characteristics of Concrete with Partial Replacement of Cement by Fly Ash and Activated Fly Ash

It is because the cement was manufactured nearby an area of small town in Italy of Pozzuoli – hence the name is being given later as pozzolanic. A pozzolan is a siliceous/aluminous material that, when added with lime and water, react and gives rise to a new compound. Fly ash is the well-known, and most commonly used in the construction work. Rather than volcanoes, today's fly ash is obtained easily from thermal power plants. These power plants uses coal to generate electricity and huge amount of fly ash is originated from these plants as a end product. Fly ash – the mineral residue produced by burning coal –this end product which is in the form of ash is collected from outlet and used for various purpose “Experimental study on shear behavior of activated fly ash concrete beams” Sunilaa George [5]. The Fly-ash mission had been used in construction but it came into existence in the year 1994 with the Department of Science and Technology as the nodal agency and the Technology. The Ministry of Environment and Forests, Govt. of India, Ministry of Power, Thermal Power stations, R& D Institutions and Industry together have released a Technology Project in Mission Mode. Their view is on the to show practically the technology focuses on coal ash for using it with confidence & to ensure for large scale utilization in construction works. And mainly cement is the backbone for worldwide constructional development. Statics show that one ton of Portland cement manufacturing will gives rise to 0.87 tonnes of Carbon dioxide in the Environment. Adding of **fly ash in cement concrete** reduces the releasing of the CO<sub>2</sub> problem to the extent of its proportion in cement “Corrosion Potential of Activated Fly Ash Concrete” Sunilaa George [6].

### Fly ash as a Substitute in Concrete

The difference between fly ash and cement can be easily seen under microscopic studies. Fly ash particle structures are spherical which will be helpful in the moment or flow of concrete and it is easily blend within the mixtures hence adds up to the workability of concrete. These things ill make the fly ash desirable admixture for concrete.

Mainly, the spherical shape of fly ash will produce ball bearing effect in the concrete mix; fly ash will also create less problems while the concrete is being pumped because of strong cohesive bond and less segregation. The spherical shape also reduces the friction between the concrete pump line .Apart from this it also noticed that flash ill reduces the heat during the reaction when mixed with concrete mix as the concrete gets the strength. Fly ash when used in concrete will also contribute to the increase in strength when it is viewed for longer time period because of presence of pozzolanic material “Experimental study on shear behavior of activated fly ash concrete beams” M.Alex [7].

The main motto behind using the fly ash in concrete is it will increases life cycle, durability expectations pertaining to with its use. during the hydration reaction is in progress, fly ash reacts with the calcium hydroxide which give rise to calcium silicate hydrate (CSH) and calcium aluminate, which in turn effects the leaching out the calcium hydroxide and concrete's permeability.by reducing the leaching it is also makes the concrete more porous and light in weight by lowering the W/c ratio which results in reduction in capillary pores which are present in concrete mass. The

consolidation of concrete is also improved by the shape fly ash particles.

### Factors affecting performances of fly ash in concrete.

- 1) Chemical and physical properties of fly ash.
- 2) The alkali content in the cement which influence alkali aggregate reaction in concrete.
- 3) The slower reaction fly ash will increase the strength of concrete so curing play vital role in the performance of fly ash.
- 4) Concrete quality in mix design and execution work.
- 5) Method of replacement.

The fly ash can be used in the construction work in two way the first method is to use the fly ash during the manufacturing of cement at the plant itself the second method is to use the fly ash with concrete by mixing it with cement in cast in situ, the second method provides more liberty that can be used in the concrete the main essence of fly ash is more user-friendly is the fineness, low carbon content etc. Since fly ash is produced by rapid cooling & solidification of molten ash, a large portion of components comprising of fly ash particles are in amorphous state. The amorphous characteristic greatly contributes to the pozzolanic reaction between cement & fly ash. The suitability of fly ash could be decided by finding the dry density of fully compacted sample, "Design of Fly ash Concrete" M.K.Gopalan [8].

### How much fly ash in concrete

Typically, during the manufacturing of cement at plant designer usually opt for about 30% of fly ash of total cementitious material although there has been many studies have been taken place for the past 15 years for using high volume or high percentage of fly ash in concrete when it is properly designed and constructed there will be some benefits of concrete which has got 40,50 and 60% fly ash replacements include dramatically reduced concrete permeability and excellent resistance to all forms of premature deterioration.

**Table 1: Physical Property of Fly Ash**

Specific gravity	2.146 to 2.42
Wet sieve analysis ( %retained on No. 325 BS sieve)	51.00 (Dry)
Specific surface (cm <sup>2</sup> /g Blaines)	2800 to 3250
Lime reactivity(kg/cm <sup>2</sup> )	56.25 to 70.3

### Effects of Fly Ash on concrete Fresh Concrete Workability

The fly ash when used in concrete it produces more volume of cementitious material i.e (cement + fly ash) when compared to concrete mix without fly ash. Due to fly ash the **Fine Aggregate (FA)**

**Table 2: Test results for Fine Aggregate**

Sl. No	Properties	Values
1	Specific gravity	2.7

2	Fineness	2.49
3	Bulk Density	1700 kg/m <sup>3</sup>
4	Water Absorption	1%

paste volume becomes more and rich which reduces the friction between aggregate which in turn increases the workability. The shape of the fly ash will be spherical usually which will contribute in increase in the workability of the concrete because of the effects called as ball-bearing.

**Bleeding**

Use of fly ash in air-entrained and in other type of concrete will provide a resistance against bleeding by giving high fineness volume and reduce water requirement for a given workability but increase in fineness will increase the water demand but the spherical nature of fly ash will nullify such requirement. The concrete with fly ash require less water for the same slump produced by conventional concrete.

**Strength and Rate of Strength of Hardened Concrete**

Strength of fly ash concrete mainly depends on three factor cement type, fly ash quality, temperature at which concrete is cured. The fly ash based concrete will develop low strength at early days of and 7 but as time passes the strength will increases because of slow pozzolanic reaction will result in higher ultimate strength hen cured properly. But care must be taken while using the fly ash based concrete in cold weather condition because of its adverse effect on the gain of strength.

**Advantages of Fly Ash in Concrete**

Fly Ash increases the workability of the concrete by reducing the water to cement ratio. The fly ash particles are spherical in shape whereas the grinded materials such as cement are solid and angular. Fly ash particles gives greater workability in cement mix for the same consistency Pump ability is greatly enhanced.

**The advantages of fly as in ready-mix concrete**

- 1-Improvement of workability for the given W/c ratio or workability enhancement without compromising in water content.
- 2- The separation of cement slurry is reduced and workability increased.
- 3- Fresh mixes pump more easily & workability retention is more dependable.
- 4- Better off-shutter finish & aesthetics.
- 5- Improved long term strength & durability performance.
- 6- Hydration of heat reduced in thick sections.
- 7- Reduced alkali-silica reactivity.
- 8- Lower permeability & durability performance.
- 9- Lower value of volume reduction & porosity as a result of lower water content.
- 10- Minimum segregation.
- 11- Environment-friendly

**III. METHODOLOGY**

The materials required for this project were collected and fly ash from thermal power plant brought to the lab and chemical were mixed with fly ash for its activation and chemical characteristics to know how it behaves when mixed with concrete with various preliminary test procedure and mix design the sample were casted and tested in the lab in accordance with Is specification.

**Sieve analysis of Fine Aggregate**

Sieve analysis is done in accordance to the IS specification (IS-383) a good quality of sand is used which is well graded sand mainly helps in filling of the voids present in concrete and it is free from organic matter and silt it conforms to zone –II of IS-383 with respect to particle size.

**Coarse Aggregate**

**Sieve analysis of Coarse Aggregate**

A good quality of coarse aggregate is used from locally available stone cursing units of 20mm down size conforming to IS specification.

**Table 3: Test results for coarse Aggregate**

Sl. No	Properties	Values
1	Specific gravity	2.70
2	Fineness	7.10
3	Bulk Density	1440 kg/m <sup>3</sup>
4	Water Absorption	0.7%

**Fly Ash:**

Fly ash basically originated from thermal power plant as an end product after burning that can be collected from the dust collecting unit, which is in the form of fine spherical particle. The size of these fly ash particle ranges from 1 to 150 micron average is being 45 microns and it depends upon type of collection unit installed in the early period they use to have mechanical collector which give rise to coarse particles but as technology advances people started to use electro static precipitators giving rise to finer particles using electrostatic precipitators.

Fly ash used in the experiment is brought from Ramagundam peddapalli distric.

**Table 4: Physical requirements of Fly ash (IS: 3812-Part-1:2003)**

Characteristics	Requirement
Fineness-specific surface in m <sup>2</sup> /kg by Blaine’s permeability method, min	320
Lime reactivity-Average compressive strength in N/mm2	4.5
Soundness by autoclave test expansion of specimens, percent, max	0.8

**Chemical Activation of fly Ash:**

To activate the fly ash, Sodium Silicate & calcium Oxide are used as activators. The chemical composition of the sodium silicate solution is Na<sub>2</sub>O=7.5–8.5%, SiO<sub>2</sub>=25-28%. The other characteristics of the Na<sub>2</sub>SiO<sub>2</sub> solution is specific gravity=1.35 g/cc. The activation of fly ash was done by using Cao and Na<sub>2</sub>SiO<sub>2</sub> in the ratio 1:8(this was concluded by various trial and error methods using various ratios of chemicals i.e. 1:2, 1:4, 1:6, 1:8, 1:10). The needed amount of sodium silicate which is in the gel form & calcium oxide in powder form are mixed properly to a paste of good consistency and it is heated at a temperature of 103<sup>0</sup> C in a vessel to get a proper mixing. The mixed chemicals then added to fly ash (5% by weight of fly ash) and used for the studies.



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## Mix Proportioning

The mix design was done in accordance with IS-1022 and proper care is taken so that characteristics strength of concrete should meet the test results keep this in view a higher target mean was taken in to account for compressive strength (fck).

Cement	=
437.77 Kg/m <sup>3</sup>	
Fine aggregates	= 650.92 Kg/m <sup>3</sup>
Coarse aggregates	= 1091.85 kg/m <sup>3</sup>
Water	
= 197 liters	
Water cement ratios	= 0.45

The mix proportion (M<sub>30</sub>) per cubic meter of concrete then becomes

Water	Cement	Fine aggregate	coarse aggregate
197lts.	438 kg	651kg	1092 kg
<b>0.45</b>	<b>1</b>	<b>1.4</b>	<b>:</b>
<b>2.49</b>			

## IV. EXPERIMENTAL ANALYSIS

### Compressive strength test

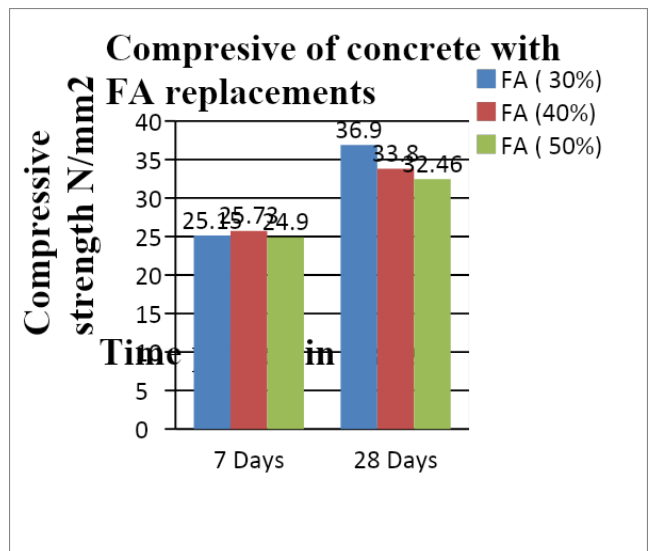
The cubes were casted and removed from mould cured specimens consist of activated and normal fly ash concrete. The volume of the cube is 3375 CM<sup>3</sup> in accordance to IS Specification. The casted cubes were taken for curing and tested after 7days, and 28days and the capacity of concrete cube noted in KN .i.e. Force (P) by placing on any one side of the cube. The cross sectional area (A) of cube is 225cm<sup>2</sup>. The load at which the specimens fails to take the load to the cross sectional area which is subjected to load gives the compressive strength of that particular cube. This test is carried out for M30 grade of concrete.

The formula for compressive strength can be given by,

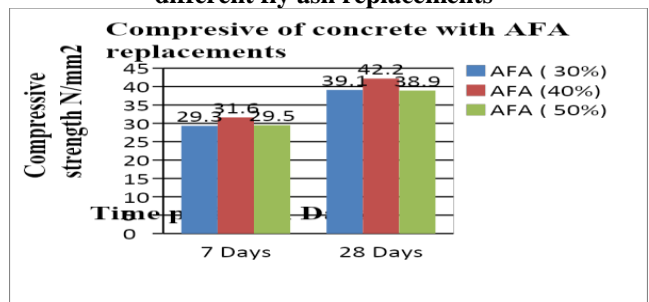
$$f_c = \frac{P}{A} \text{ N/mm}^2$$

Table 1: Compressive strength of M30 CVC

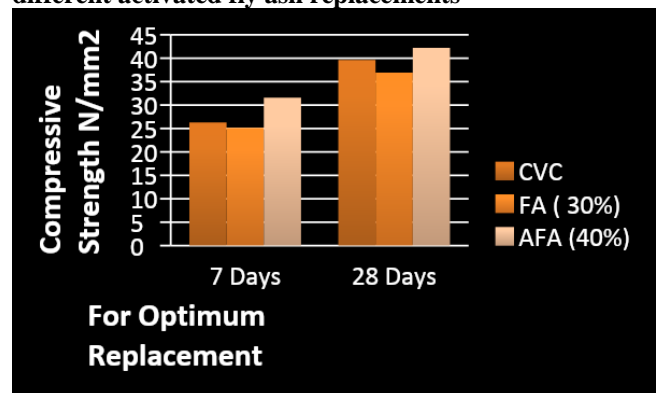
Curing period	Compressive Load(KN)	Compressive Strength (N/mm <sup>2</sup> )	Average Strength (N/mm <sup>2</sup> )
7 days	579.37	25.73	26.3
	605.25	26.90	
	591.00	26.27	
28 days	861.75	38.3	39.6
	895.72	39.81	
	915.52	40.69	



Graph 1: Compressive strength of concrete with different fly ash replacements



Graph 2: Compressive strength of concrete with different activated fly ash replacements



Graph 3: Compressive strength of Conventional, Fly ash, and AFA Concrete for excellent dosage values

### Results:

- 1) From the above compression strength values, activated fly ash concrete at 40% replacement is 42.2 N/mm<sup>2</sup> which is 10% higher than target mean strength of M30 design mix at 28 days.
- 2) When compared with CVC & fly ash concrete it is higher than 6.16% & 12.5% respectively at 28 days.

### Tests for Split Tensile Strength

This test is done on the cylinder shaped concrete specimen the cylinder is placed on its side longitudinally & loaded such as to induce transverse tension and it actually creates tensile stresses and relatively high compressive stresses on the cylinder when cylinder is given

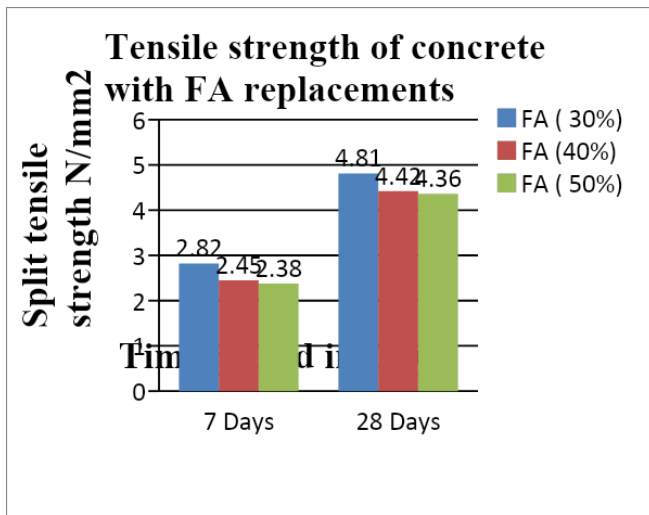
a load of compression along the plate kept parallel on the either side i.e top and bottom of cylinder then along the diameter major tensile stress will be created at the certain limit the cylinder fracture which can be given by the formula below,  $f_{cs}$ :

$$f_{cs} = \frac{2F}{\pi dl} N/mm^2$$

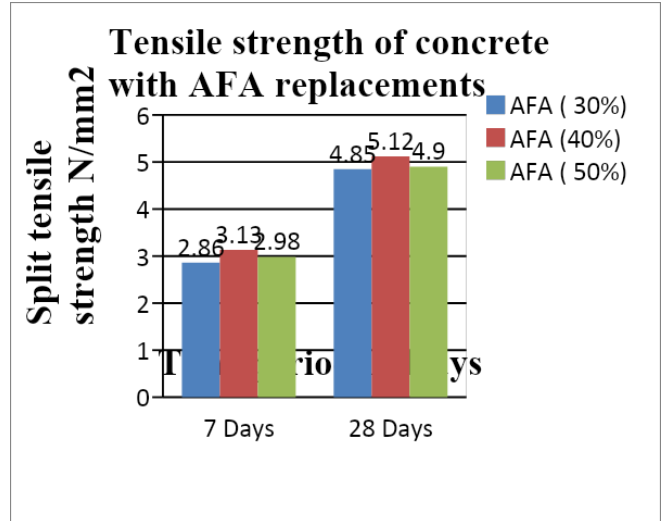
Where: F is the applied compressive load along the length of cylinder, d is the cylinder diameter; l is the cylinder length. Number of cylinder tested for different proportion with CVC, fly ash & activated Fly ash are shown in table.

Table 2: Split Tensile strength of CVC M30

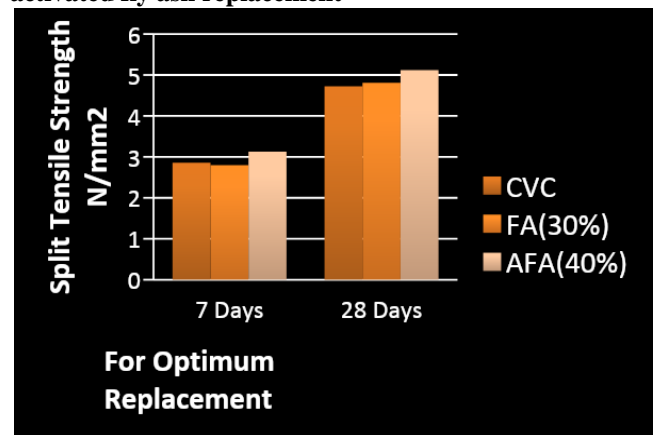
Curing period	Tensile Load(KN)	Tensile Strength (N/mm <sup>2</sup> )	Average Strength (N/mm <sup>2</sup> )
7 days	166.11	2.53	2.86
	207.10	2.93	
	220.53	3.12	
28 days	362.61	5.13	4.72
	348.48	4.93	
	289.81	4.10	



Graph 4: Tensile strength of Concrete with different fly ash replacement



Graph 5: Tensile strength of concrete with different activated fly ash replacement



Graph 6: Split Tensile strength among conventional, Fly ash, and AFA Concrete for excellent dosage values

**Result:**

The split tensile strength of AFA concrete at 40% replacement is 5.12 N/mm<sup>2</sup> after 28 days which is higher than CVC & FA concrete by 7.8% & 6.05% respectively.

**Tests for Flexural Strength:**

This test was carried out on a specimen of concrete called as prism or beam and the flexural strength sometimes called as modules of rupture the test was done in accordance to the IS specification and the strength can be calculated by the formula given below ,:

$$fb = \frac{p \times l}{bb^2} N/mm^2$$

b = width of the specimen in mm,

d = depth in mm of the specimen during of failure,

l = length of the specimen in mm on which it was placed,

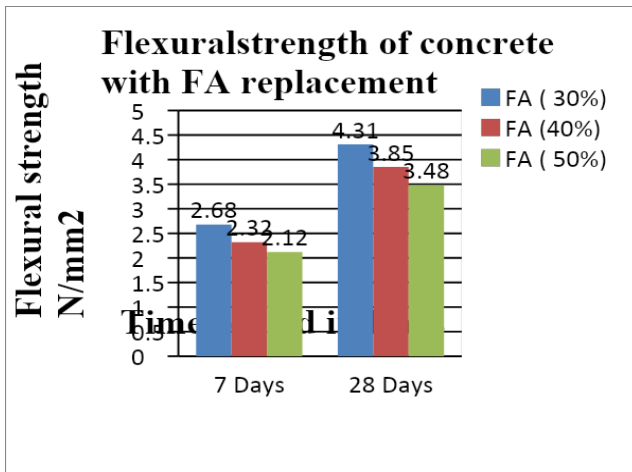
p = highest load applied on to the specimen in KN

Number of prisms tested for different proportion with CVC, fly ash & activated fly ash are shown in tables.

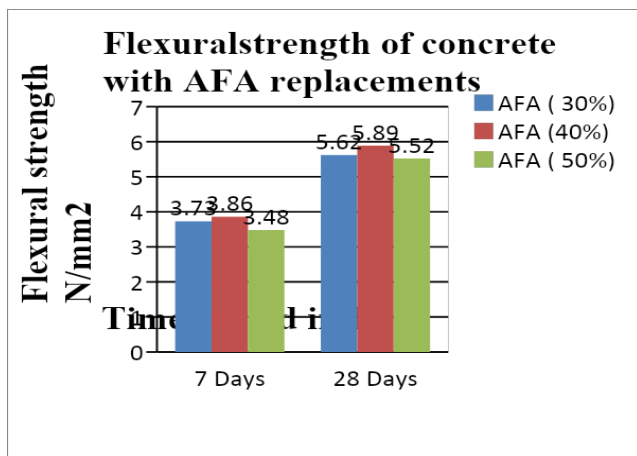
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**Table 4: Flexural strength of conventional concrete of M30 grade**

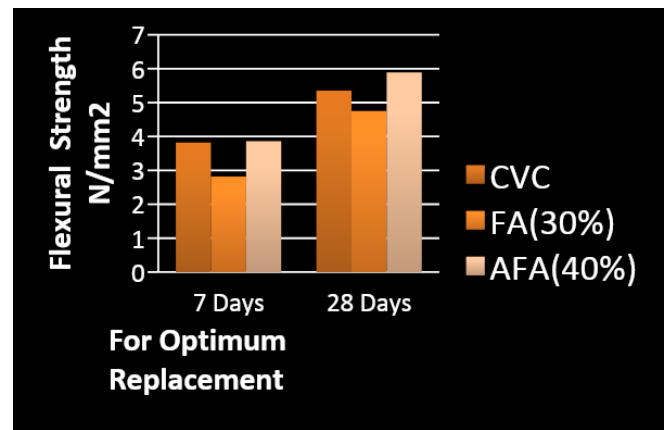
Curing period	Crushing load (KN)	Flexural Strength (N/mm <sup>2</sup> )	Average strength (N/mm <sup>2</sup> )
7 days	8.20	4.10	3.82
	7.50	3.75	
	7.22	3.61	
28 days	10.20	5.1	5.35
	10.96	5.48	
	10.94	5.47	



**Graph 7: Flexural strength of concrete with different fly ash replacement**



**Graph 8: Flexural strength of concrete with different fly activated ash replacement**



**Graph 9 Flexural strength among CVC, FA, and AFA Concrete for optimum replacement values**

**Result:**

The test results for Flexural strength of activated fly ash concrete at 40% replacement is 5.879 N/mm<sup>2</sup> after 28 days which is higher than CVC & FA concrete by 9.1% & 19.3% respectively.

**V. CONCLUSION:**

From all the above experimental test result it is concluded that

- 1) The workability of the concrete will get affected by increase in the fly ash content in the concrete.
- 2) It is observed that the fly ash content in the concrete can be replaced by a value of upto 30% and activated fly ash will give a good result up to a value of 40%.
- 3) There is a reduction in the strength of fly ash replaced concrete (30% fly ash) of 6.8% when compared to the normal conventional concrete.
- 4) But activated fly ash concrete proves to be more useful replacement when compared to conventional and fly ash replaced concrete there has been an increase of 6.16 and 12.5 % compressive strength w.r.t conventional and fly ash based counter parts.
- 5) 30% replacement has given a good result in the split tensile strength test there is an increase in strength of 1.9% higher than conventional concrete at 28 days.
- 6) 40% replacement of activated fly ash process to be optimum replacement there is an increase in strength of 7.8% and 6.05% higher than conventional and fly ash based concrete.
- 7) For the flexural strength of concrete testing was done on both i.e. conventional and fly ash concrete 30% fly ash replaced has proved to be a good replacement value with an increase in the strength of 9.4% compared to the conventional concrete at 28 days.
- 8) For an activated fly ash concrete it has shown that an increase in the strength about 9.1% and 19.3% w.r.t fly ash and conventional concrete is observed at 40% optimum replacement.
- 9) It is observed by the following test results that fly ash replaced concrete will give good strength at the 40% replacement after 28 days strength.

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