Fly Ash Concrete - A comparative Study

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***Abstract*—The utility of flyash as partial replacement in concrete mixes is on rise these days. Flyash is a waste product which is generated in thermal power stations. The quantity of fly ash produced from thermal power plants in India is approximately 110 million tons each year, and its percentage utilization is less than 20%. Majority of fly ash produced is of Class F typ . Such type of fly ash is produced by burning of anthracite or bituminous coal and possess pozzolanic properties. The use of these materials would reduce the disposal problems now faced by the thermal power stations and industrial plants. During the last few years, some cement companies have started using fly ash in manufacturing cement, known as 'Pozzolana Portland cement', but the overall percentage utilization remains very low, and most of the fly ash is dumped at landfills. Fly ash is generally used as replacement of cement, as an admixture in concrete, and in manufacturing of cement. For a variety of reasons ,the concrete construction industry is not sustainable .First ,it consumes huge quantities of virgin materials .Second ,the principal binder in concrete is Portland cement ,the production of which is a major contributor to greenhouse gas emission that are implicated in global warming and climate change .Third ,many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of the industry. Because the fly ash concrete system addresses all three sustainability issues, its adoption will enable the concrete construction industry to become more sustainable .In this research strength and durability of fly ash concrete are addressed after conducting tests on various specimens. Increase in strength as well as workability is achieved for upto certain values of replacement of fly-ash. For countries like China and India, this technology can play an important role in meeting the huge demand for infrastructure in a sustainable manner.**

***Index Terms*—Component, formatting, style, styling, insert.** *(key words)*

I. Introduction

Scientists, engineers and technologists are continuously on the lookout for materials which can be used as substitutes for con-ventional materials or which possess such properties which would enable their use for new designs and innovations. Concretes containing alternative materials as constituents fall under the first category. The raw materials for making cement and concrete are essentially limitless, since practically all of earth's crust can be utilized, if associated cost and energy requirements can be complied with. This course of action cannot be taken as there are other constraints that demand closer examination.

The successful utilization of a waste material depends on its use being economically competitive with the conventional natural material. These costs are primarily made up of handling, processing and transportation. The form in which they are used is wide and varied; they may be used as a binder, as a partial replacement of conventional Portland cement or directly as aggregates in their natural or processed states. The stability and durability of products made of concrete using waste materials over the expected life-span is of utmost importance, particularly in relation to building and structural applications. Keeping all these considerations in mind and taking note of all required standard specifications, wherever possible, our project aims at determining the usefulness of Fly-Ash as a partial replacement of cement in concrete. The research work will explore several relevant issues that will be vital when using fly-ash in concrete. The research work will also examine ways to optimize the use of fly-ash so that it will give maximum benefits to concrete.

In the recent times, the importance and use of fly-ash in concrete has grown so much that it has almost become a common in-gredient in concrete, particularly for making high strength and high performance concrete. Extensive research has been done all over the world on the benefits that could be accrued in the utilization of fly-ash as a supplementary cementitious material. High volume fly ash concrete is a subject of current interest all over the world. In view of global warming, efforts are on to reduce the emission of CO2 to the environment. Cement industry is a major contributor in the emission of CO2 as well as using up high levels of energy resources in the production of cement. By replacing cement with a material of pozzolanic characteristic, such as the fly ash, the cement and concrete industry together can meet the growing demand in the construction industry as well as help in reducing the environmental pollution.

India is a resourceful country for fly ash generation with an annual output of over 110 million tones, but utilization is still be-low 20% in spite of quantum jump in last three to four years. Availability of consistent quality fly ash across the country and awareness of positive effects of using fly ash in concrete are pre requisite for change of perception of fly ash from a 'A waste material' to 'A resource material'.

Technological efforts have been made to improve the quality of fly ash. At present most of the power plants are using Electro Static Precipitators (ESP) through which fly ash is collected in different chambers according to its particle size. Hence a uniform good quality fly ash can be collected from these power plants. Some of the power plants have gone a step further by developing a collection system, in which the fly ash collected from different fields is combined and the final product is taken to an air classifying plant where coarse particles are removed. The final beneficial product is then stored in a silo to be used in cement and concrete industry.

1.1 Sensitivity analysis of Fly ash as a replacement for cement

Fly ash is used in concrete for the following properties of fly ash, which are useful for good quality concrete.

1. Workability - Fly ash particles are almost totally spherical in shape, allowing them to flow and blend freely in mixtures. The "ball – bearing" effect of fly ash particles creates a lubricating action when concrete is in its plastic state. Concrete is easier to place with less effort, responding better to vibration to fill forms more completely. Ease of Pumping, pumping requires less energy and longer pumping Distances are possible.

2. Water Demand Reduction - Water demand depends on particle size distribution, particle packing and voids present. The conventional concrete mixes do not have an optimum particle size distribution and hence their water requirement is high. Moreover, the portland cement particles have surface charges, which form flocs, thus trapping large volumes of water. Thus the water that is actually added to concrete mixes to achieve the desired consistency is much higher than actually required for the normal hydration reactions.

   By use of fly-ash we can achieve a 20 % reduction in amount of water added. This phenomenon is attributable to three mechanisms:

   - Finer fly-ash particles get adsorbed on oppositely charged surfaces of cement particles and thus flocs are not formed. Consequently cement particles will be dispersed and large amounts of water will not be trapped.
   - Fly-ash particles have a smooth and glassy surface due to which the interparticle friction is less. Mobility is high and thus the desired workability is achieved at relatively low water content.
   - Fly-ash has a lower density and higher volume per unit mass, thus is more efficient void filler than Portland cement. Since the particle packing effect is increased a lesser volume of cement paste is needed for plasticizing, thus de-creasing the water employed.

3. Contribution to strength of concrete - Fly-ash when used in concrete, contributes to the strength of concrete due to its pozzolanic reactivity. However, since the pozzolanic reaction proceeds slowly, the initial strength of fly-ash concrete tends to be lower than of normal concrete. Due to continued pozzolanic reactivity concrete develops greater strength at later age which may exceed that of normal concrete.

4. Decreased Permeability - Increased density and long term pozzolanic action of fly ash, which ties up free lime, results in fewer bleed channels and decreases permeability. The pozzolanic reaction also contributes to making the texture of concrete dense resulting in de-crease of water permeability and gas permeability.

5. Increased Durability - Dense fly ash concrete helps keep aggressive compounds on the surface, where destructive action is lessened. Fly ash concrete is also more resistant to attack by sulphate, mild acid, soft water, and seawater.

6. Reduced Sulphate Attack - Fly ash ties up free lime that can combine with sulfate to create destructive expansion. So it helps in reducing sulphate attack.

7. Reduced Efflorescence - Fly ash chemically binds free lime and salts that can create efflorescence and dense concrete holds efflorescence producing compounds on the inside.

8. Reduced Shrinkage- The largest contributor to drying shrinkage is water content. The lubricating action of fly ash reduces water content and drying shrinkage.

9. Reduced Heat of Hydration - The pozzolanic reaction between fly ash and lime generates less heat, resulting in reduced thermal cracking when fly ash is used to replace Portland cement.

10. Reduced Alkali Silica Reactivity - Fly ash combines with alkalis from cement that might otherwise combine with silica from aggregates, causing destruc-tive expansion.

11. Improved Finishing - Sharp, clear architectural definition is easier to achieve.

12. Reduced Bleeding - Fewer bleed channels decreases porosity and chemical attack. Improved paste to aggregate contact results in enhanced bond strengths.

13. Reduced Segregation - Improved cohesiveness of fly ash concrete reduces segregation that can lead to rock pockets and blemishes.

1.2 Objectives of the Research

In this research, Fly-ash has been used for partial replacement of cement in concrete at 10%, 20% and 30% by weight and a comparative study has been done between normal concrete and fly ash concretes so as:

- To explore and assess the possibility of using fly ash in concrete in terms of its cementitious properties.
- To compare the 7 days and 28 days compressive strengths of plain concrete and fly ash concrete.
- To compare the 7 days and 28 days flexural strengths of normal concrete and fly ash concrete.
- To compare the 7 days and 28 days splitting tensile strengths of normal concrete and fly ash concrete.
- To compare workability of normal concrete and fly ash concrete.

II. PROCEDURES AND EXPERIMENTAL REPORTS

Materials obtained for making concrete (cement, sand and aggregate) were tested for their respective properties according to the respective IS codes.

Fly-ash procured was sieved to remove any impurities and then pulverized in a pulverizer to increase its fineness to make it suitable for replacing cement in concrete. The specimens (cubes, cylinders, beams) have been tested for compressive, split cylinder and flexural tests. The tests were carried after curing period of 7 and 28 days with the help of UTM

(Universal Testing Machine) and Compression Testing Machine (CTM).

2.1. System Parameters
Grade of cement used= 43 Grade(Khyber Cement)
Fly-ash Class used=F-Type
Aggregate size used=20mm
Mix of concrete = 1: 1.5: 3 (nominal mix) (M 20)
Water / Cement ratio = 0.45

Size of specimens:
1. Cube : (150 × 150 × 150) $mm^{3.}$
2. Beam : (100 × 100 × 500) mm^3
3. Cylinder : (150mm ø, 300mm height)

Characteristics of Fly-Ash (IS: 3812-1989)
Fly-ash was obtained from JK Cements at Khrew, who procured it from NTPC's thermal power plant at Ropar, Punjab.

Table A. Fly-ash characteristics.

S.No.	Characteristic	Result	Requirements as per IS: 3812 –1989	
			Grade – I	Grade - II
PHYSICAL PROPERTIES				
1.	Fineness (m^2/kg)	361.3	320 (Min.)	250
2.	Lime reactivity (MPa)	4.92	4 (Min.)	3
3.	Compressive strength (MPa)	81	Not less than 80% of the strength of corresponding cement mortar cubes	
4.	Drying shrinkage (%)	0.011	0.15 (Max.)	0.10 (Max.)
5.	Autoclave expansion (%)	0.01	0.8 (Max.)	0.8 (Max.)
CHEMICAL PROPERTIES				
6.	(SiO_2+Al_2O_3 +Fe_2O_3)%	91.95	70.0(min.)	70.0(min.)
7.	SiO_2 %	58.66	35.0(min.)	35.0(min)
8.	Al_2O_3 %	28.76	-	-
9.	Fe_2O_3 %	4.53	-	-
10.	CaO %	1.58	-	-
11.	MgO %	0.48	5.0(max.)	5.0(max)
12.	SO_3 %	0.18	2.75(max.)	2.75(max.)
13.	Alkalis(Na_2O_{eq})	0.78	1.5(max.)	1.5(max.)
14.	Na_2O %	0.14	-	-
15.	K_2O %	0.97	-	-
16.	LOI (loss on ignition)%	2.00	12.0(max.)	12.0(max.)

The mentioned properties in Table A of Fly-ash were obtained from the JK Cements factory at Khrew.

2.2. Tests conducted on fresh concrete (in-situ tests):
Following in-situ tests to measure workability of fresh concrete were conducted:
- Slump test

Slump Test:
Slump test is the most commonly used method of measuring consistency of concrete which can be employed either in laboratory or at site of work (Fig.2.1).

Fig. 2.1 Slump Test.

2.3. Tests Conducted On Hardened Concrete:
1. Compressive strength test.
2. Flexural strength test.
3. Split cylinder test.

1. Compressive strength test:
This test is conducted on cubes which are loaded on their opposite faces in a Compression Testing Machine (CTM) (Fig. 2.2,2.3). Six samples were cast, three of which were tested after 7 days and rest three after 28 days. The load at which first crack appears is considered as the failure load and the compressive strength is calculated corresponding to this particular value of load.

Compressive strength = Load of failure / (Cross –Sectional Area)
Where, cross-sectional area = (150 × 150) mm^2

Fig. 2.2 Compressive strength test in a CTM

Fig. 2.3 Formation of cracks in Compressive strength test.

2. Flexural strength test

Flexural strength test of concrete is performed on beams. The loading applied on the beam is a two point loading in which loads are applied at (1/3) rd points of the beam (Fig.2.4).The beam is placed in the testing machine in such a way that the load points are 13.3 cm apart from each other as well as from each support. The load is increased until the specimen fails and this load is noted as failure load . Flexural strength is then calculated from the following formula:

$$\text{Flexural strength} = \frac{2 \times P \times l}{b \times d^2}$$

where,
P= (load at failure)/2
l= length of beam between supports (clear span) (400 mm)
b= breadth of beam (100 mm)
d= depth of beam (100 mm)

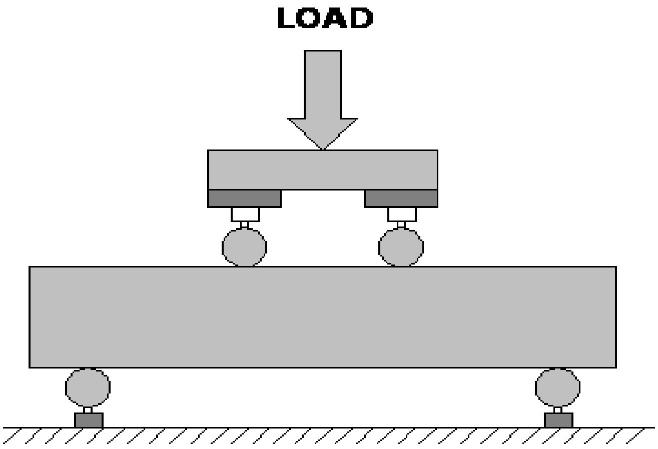

Fig. 2.4 Two-point loading arrangement for Flexural strength test

3.Split cylinder test

The test is carried out by placing a cylindrical specimen, horizontally between the loading surfaces of a Compression Testing Machine and the load is applied until failure of the cylinder, along the vertical diameter (Fig.2.5, 2.6).

The loading condition produces a high compressive stress below the two surfaces to which the load is applied. But the larger portion corresponding to depth is subjected to a uniform tensile stress acting horizontally. It is estimated that the compressive stress is acting for about $(1/6)^{th}$ depth and the remaining $(5/6)^{th}$ depth is subjected to tension.

The horizontal tensile stress is given by the following equation:

$$\text{Horizontal tensile stress} = \frac{2 \times P}{\pi \times L \times D}$$

where, P= load at failure
L= length or height of cylinder (300 mm)
D= diameter of cylinder (150 mm)

Fig. 2.5 Splitting tensile strength test in a CTM.

Fig. 2.6 Formation of crack along the diameter of cylinder.

Procedure of testing illustrated by Figures:

Fig. 2.7 Mixing of fly-ash with cement.

Fig.2.8 Mixing of concrete.

Fig. 2.9 Vibration of concrete cubes being done on a table vibrator.

2.4 Comparative Test Report of Normal and Fly-ash replaced concrete

A. Normal Concrete test Report:

Six specimens each of cube, cylinder and beam were cast. Three of each were tested after 7 days and 28 days. The test results obtained are shown in the following observation table:

1. Compressive strength cube test:

TABLE B Compressive Strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day compressive strength N/mm^2	28 day compressive strength N/mm^2
01.	25	394	601	17.51	26.71
02.	25	406	606	18.04	26.93
03	25	386	566	17.16	25.16

Result:

Average 7 days compressive strength = 17.57 N/mm^2

Average 28 days compressive strength = 26.27 N/mm^2

2. Flexural strength:

Table C. Flexural strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day Flexural strength N/mm^2	28 day Flexural strength N/mm^2
01.	25	11.50	14.50	4.60	5.80
02.	25	8.50	11.00	3.40	4.40
03	25	10.00	14.00	4.00	5.60

Result:

Average 7 days Flexural strength = 4 N/mm^2

Average 28 days Flexural strength = 5.27 N/mm^2

3. Splitting tensile strength (cylinder test):

Table D. Splitting tensile strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day splitting tensile strength N/mm^2	28 day splitting tensile strength N/mm^2
01.	25	118.00	177.00	1.67	2.50
02.	25	137.00	158.00	1.93	2.23
03	25	130.00	164.00	1.84	2.32

Result:

Average 7 days splitting tensile strength = 1.81 N/mm^2

Average 28 days splitting tensile strength = 2.35 N/mm^2

Slump of normal concrete = 25 mm

B. Fly Ash replaced-Concrete Test Report:

Fly ash was used as 10%, 20% and 30% replacement of cement by weight after pulverizing and sieving it to remove any impurities. The fly ash was thoroughly mixed with cement manually before using for making concrete for casting fly ash concrete specimens. 18 specimens were cast for each trial consisting of 6 cubes, 6 beams and 6 cylinders. 9 specimens (3 each) were cured for 7 days and rest 9 for 28 days. In-situ tests were carried out for each trial.

1. Trial No. 1 (10% cement replacement by fly ash):

a. Compressive strength cube test:

Table E. Compressive strength results.

Sample No.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day compressive strength N/mm^2	28 day compressive strength N/mm^2

01.	26	460	738	20.44	32.80
02.	26	519	731	23.07	32.49
03	26	525	727	23.33	32.31

Result:
Average 7 days compressive strength = 22.28 N/mm^2
Average 28 days compressive strength = 32.53 N/mm^2

b.Flexural Strength:

Table F. Flexural strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day Flexural strength N/mm^2	28 day Flexural strength N/mm^2
01.	26	10.00	19.40	4.00	7.76
02.	26	11.00	20.60	4.40	8.24
03	26	12.50	19.00	5.00	7.60

Result:
Average 7 days flexural strength = 4.47 N/mm^2
Average 28 days flexural strength = 7.87 N/mm^2

C. Splitting tensile strength(cylinder test) :

Table G. Splitting tensile strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day splitting tensile strength N/mm^2	28 day splitting tensile strength N/mm^2
01.	26	121	213	1.71	3.01
02.	26	120	152	1.69	2.15
03	26	118	180	1.67	2.55

Result:
Average 7 days splitting tensile strength = 1.69 N/mm^2
Average 28 days splitting tensile strength = 2.57 N/mm^2
Slump value = 26 mm

1. Trial No. 2 (20% cement replacement by fly ash):

a. Compressive strength cube test:

Table H. Compressive strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day compressive strength N/mm^2	28 day compressive strength N/mm^2
01.	28	382	603	16.98	26.80
02.	28	366	586	16.27	26.04
03	28	360	590	16.00	26.22

Result:
Average 7 days compressive strength = 16.42 N/mm^2
Average 28 days compressive strength = 26.35 N/mm^2

b.Flexural strength:

Table I. Flexural strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day Flexural strength N/mm^2	28 day Flexural strength N/mm^2
01.	28	8.00	19.20	3.20	7.68
02.	28	8.50	19.00	3.40	7.60
03	28	7.50	19.50	3.00	7.80

Result:
Average 7 days flexural strength = 3.20 N/mm^2
Average 28 days flexural strength = 7.69 N/mm^2

C. Splitting tensile strength(cylinder test):

Table J. Splitting tensile strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day splitting tensile strength N/mm^2	28 day splitting tensile strength N/mm^2
01.	28	116	174	1.64	2.46
02.	28	120	249	1.69	3.52
03	28	110	200	1.55	2.83

Result:
Average 7 days splitting tensile strength = 1.63 N/mm^2
Average 28 days splitting tensile strength = 2.94 N/mm^2
Slump value = 28 mm

3. Trial No. 3 (30% cement replacement by fly ash):
a. Compressive strength cube test :

Table K. Compressive strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day compressive strength N/mm^2	28 day compressive strength N/mm^2
01.	29	309	552	13.73	24.53
02.	29	295	520	13.16	23.11
03	29	262	513	11.64	22.80

Result:
Average 7 days compressive strength = 12.84 N/mm^2
Average 28 days compressive strength = 23.48 N/mm^2

b. Flexural strength:

Table L. Flexural strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day Flexural strength N/mm^2	28 day Flexural strength N/mm^2
01.	29	9.00	9.00	3.60	3.60
02.	29	8.50	10.00	3.40	4.00
03	29	8.00	10.00	3.20	4.00

Result:

Average 7 days flexural strength = 3.20 N/mm^2

Average 28 days flexural strength = 3.87 N/mm^2

C. Splitting tensile strength (Cylinder test) :

Table M. Splitting tensile strength results.

Sample no.	Slump (mm)	Load at failure (kN) 7 days	Load at failure (kN) 28 days	7 day splitting tensile strength N/mm^2	28 day splitting tensile strength N/mm^2
01.	29	104	225	1.47	3.18
02.	29	110	206	1.56	2.91
03	29	108	210	1.53	2.97

Result:

Average 7 days splitting tensile strength = 1.52 N/mm^2

Average 28 days splitting tensile strength = 3.02 N/mm^2

Slump value = 29 mm

I.COMPARATIVE ANALYSIS OF TEST RESULTS

The comparative analysis of Test reports is done for already mentioned objectives:

A comparative study can be performed from the results achieved in different trials of normal concrete and fly ash concrete at different percentages of fly ash.

A comparative study of the results is shown by the following bar charts:

1. Comparative study of Compressive strength:

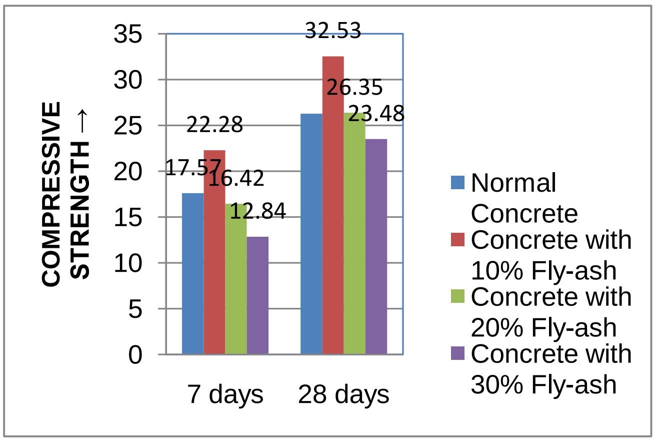

Fig. 3.1. Comparison of 7 and 28 days compressive strengths of normal concrete and Fly-ash concrete 2 Comparative study of Flexural Strength.

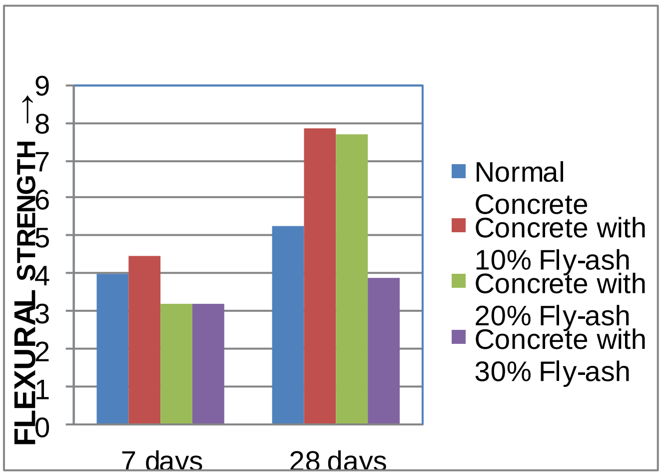

Fig. 3.2. Comparison of 7 and 28 days Flexural strengths of normal concrete and Fly-ash concrete.

3. Comparative study of Splitting Tensile Strength

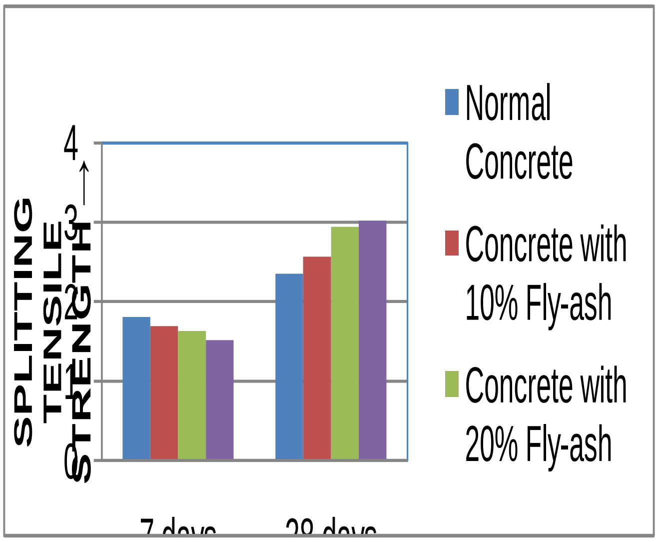

Fig. 3.3. Comparison of 7 and 28 days splitting tensile strengths

4. Comparative study of slump value/workability:

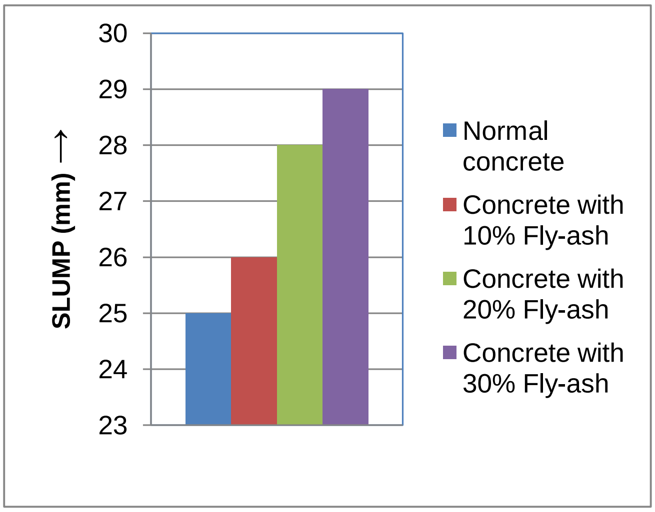

Fig. 3.4. Comparison of workability of normal concrete and fly ash concrete.

III. CONCLUSION

After careful and elaborate study of the use of fly-ash for replacement of cement in concrete at different percentages, it can be concluded that:

1. 7 days compressive strength of Fly-ash concrete has decreased (except for 10% Fly-ash concrete), but 28 days compressive strength has increased (except for 30% Fly-ash concrete).
2. 7 days flexural strength of Fly-ash concrete has decreased (except for 10% Fly-ash concrete), but 28 days flexural strength has increased (except for 30% Fly-ash concrete
3. Splitting tensile strength at 7 days decreases progressively as the percentage of Fly-ash increases, but 28 days strength increases progressively as the percent-age of Fly-ash increases.
4. There is a progressive increase in workability with increase in %age of Fly-ash in concrete.
5. Utilization of Fly-ash in concrete has provided us an excellent means of dis-posal of Fly-ash which is a big environmental nuisance.

The project work has also led us to the conclusion that in order to achieve best results in use of Fly-ash concrete, the Fly-ash used for replacing cement in concrete should have the required properties as specified by the standards and proper techniques of processing Fly-ash as well as mixing of Fly-ash with cement must be employed.

FUTURE SCOPE

From the results obtained throughout the project use of Fly-ash can be recommended in the civil engineering areas such as:

- Mass concreting works e.g. dams where low permeability and low heat of hydra-tion is required.
- Under water structures such as bridge piers, docks, harbours etc.
- Structures near coastal and humid areas.
- Precast and pre-stressed structures to make them light in weight.

Use of fly-ash in these structures results in considerable economy without compromis-ing on strength.

At last we can say that, "If Fly-ash is properly and scientifically used in concrete it can give other materials a run for their money and take concrete world to a higher echelon."

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