Challenge Journal of Concrete Research Letters

Research Article

Exploring optimum percentage of fly-ash as a replacement of cement for enhancement of concrete properties

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ABSTRACT

Researchers and decision makers are continuously looking out to determine the potential and effectiveness of fly-ash as a partial replacement of cement in concrete. The current study is carried out to check the optimum or nearly optimum quantity of fly-ash with which cement should be replaced to get most of the properties of concrete enhanced and to give the idea about the quantities of fly-ash that can be used in a better way and better cause so that a proper management scheme of its usage and disposal can be implied. Further, a comparison is given between normal concrete and fly-ash concrete to show the properties which can be enhanced by proper utilization of fly-ash as a partial replacement of cement. After carrying out the lab experiments, it has been seen that the replacement of fly-ash in concrete has resulted in general increase in compressive strength, flexural strength and splitting tensile strength up to 15% replacement and after then the strength is decreased considerably than that of normal concrete. Addition of fly-ash in concrete has resulted in decrease in the water absorption of concrete and hence decreases in permeability of concrete. There is a progressive increase in workability with increase in percentage of fly-ash in concrete. The current study has led to a 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.

ARTICLE INFO

Article history:
Received 31 January 2020
Revised 9 March 2020
Accepted 13 March 2020

Keywords:
Fly-ash
Compressive strength
Flexural strength
Splitting tensile strength
Workability

1. Introduction

First use of fly ash in concrete started in the United States in the early 1930's at University of California by Davis (1937). The major breakthrough in using fly ash in concrete was the construction of Hungry Horse Dam in USA in 1948, utilizing 120,000 metric tons of fly ash by Thomas (2010). This decision by the U.S. Bureau of Reclamation paved the way for using fly ash in concrete constructions. In India, Fly-ash was first used in the construction of Rihand Dam in Uttar Pradesh in 1962, replacing cement up to 15% showed in literature review by Bendapudi and Saha (2011). The Indian Standards IS:3812-1981 define, "Fly ash as a finely divided residue resulting from the combustion of ground or powdered bituminous coal or sub-bituminous coal (lignite) and transported by the flue gases of boilers fired by pulverized coal or lignite." A pozzolana is a siliceous or siliceous/ aluminous material which possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically reacts with Calcium Hydroxide liberated on hydration at ordinary temperature, to form compounds possessing cementitious properties explained by Gray and Lin (1972). Fly ash is best known and one of the most commonly used pozzolans in the world. We are using fly ash in almost all the activities where cement is involved like cement concreting, brick manufacturing, cement mortar for brick work & plastering.

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ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2020.01.003

Fly-ash is one of the residues generated in the combustion of coal. Fly ash is generally captured from the chimneys of coal-fired power plants and is one of two types of ash that jointly is known as coal ash; the other bottom ash is removed from the bottom of coal furnaces. Depending upon the source and makeup of the coal being burned, the components of fly ash vary considerably but all fly ash include substantial amounts of silicon dioxide (SiO_2) (both amorphous and crystalline) and calcium oxide (CaO). Toxic constituents include arsenic, beryllium, boron, cadmium, chromium, chromium VI, cobalt, lead, manganese, mercury, molybdenum, selenium, strontium, thallium, and vanadium, along with dioxins and PAH (Poly-Aromatic Hydrocarbons) compounds. Fig. 1 shows the photomicrograph showing fly-ash particles.

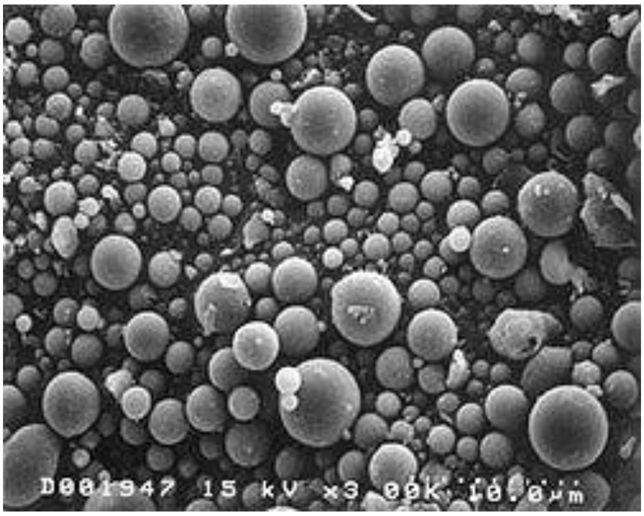

Fig. 1. Photomicrograph made with a Scanning Electron Microscope (SEM): Fly-ash particles at 3,000 x magnification (Credit: United States Department of Transportation - Federal Highway Administration).

In 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 United States, fly ash is generally stored at coal power plants or placed in landfills explained by Subramani and Sakthivel (2016). About 43 percent is recycled, often used to supplement Portland cement in concrete production. It is increasingly finding use in the synthesis of geo-polymers and zeolites. Fly-ash can also be used as a supplementary material for soil stabilization shown in literature review of Brooks (2009) and reclamation of saline soils shown by Ors et al. (2015). It is expected that use of fly-ash instead of lime in agriculture can reduce net CO_2 emission, thus reduce global warming also explained by Basu et al. (2009). High-Volume fly-ash concrete (HVFA) concrete is more suitable for the construction of rural, regional, and the national network of roads in India explained by Desai (2004). Studies show that partial replacement of concrete by fly-ash improves the concrete properties by considerable percentage explained by Marthong and Agrawal (2012).

2. Objectives of the Current Research

In this study, quantity of cement in concrete was replaced by 5%, 10%, 15%, 20%, 25 and 30% by weight of fly-ash and a comparative study was carried out:

1. To find-out the potential of fly-ash as a possible partial replacement of cement in terms of its binding property.
2. To check the optimum or nearly optimum quantity of fly-ash with which cement should be replaced to get most of the properties of concrete enhanced.
3. To compare the short-term and long-term strengths of normal concrete and fly-ash concrete.

3. Materials and Methods

Materials obtained for making concrete (cement, sand and coarse aggregate) were tested for their respective properties according to the respective IS codes. The size of the specimens and specifications of materials used are shown in Tables 1 and 2 respectively.

Table 1. Size of specimens used for testing of concrete.

S. No	Specimen	Size
1	Cube	(150 × 150 × 150) mm^3
2	Beam	(100 × 100 × 500) mm^3
3	Cylinder	(150mm ø, 300 mm height)

Table 2. Specifications of materials used in testing.

S. No	Material	Specifications
1	Cement	43 Grade (Khyber Cement)
2	Fly-ash	Class F-type obtained from JK Cements Khrew Kashmir
3	Coarse aggregate	20mm (Crushed) obtained from Crusher plant Ganderbal Kashmir
7	Fine Aggregate	Grading zone-1 procured from River Sindh Ganderbal Kashmir
5	Mix of Concrete	M20 (1:1.5:3) Nominal Mix
6	Water-Cement Ratio	0.38

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 fly-ash was pulverized to a limit so that it freely passes 90 µm sieve. 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) in NIT Srinagar. Tests were conducted on the procured materials whose results are summarized in Table 3.

Table 3. Test results of procured materials.

S. No	Material	Test Name	Test results obtained from samples (Average value)	Standard values as recommended by IS codes
1	Cement	Fineness	0.547%	Should be less than 10% of wt of cement particles larger than 90 µm. (micron) as per IS:4031-1988
		Standard consistency	30%	Should be about 30% by weight of cement as per IS:4031-1988
		Setting time	Initial setting time = 2 hrs. and 55 min	Should not be less than 30 minutes as per IS:4031-1988
			Final setting time = 5 hrs. and 35 min	Should not be more than 10 hours as per IS:4031-1988
		Soundness (Average expansion value)	1.67mm	Should not be more than 10mm as per IS:4031-1988
		Compressive strength	7 day strength=32.38	Should be more than 30.1N/mm^2 as per IS:4031-1988
			28 day Strength=45.47 N/mm^2	Should be more than 43 N/mm^2 as per IS:4031-1988
2	Coarse aggregate	Gradation (Fineness modulus)	3.047	Should not be more than 7 as per IS:383-1970
		Aggregate crushing value	16.08%	Aggregate Crushing Value shall not exceed 30% as per IS:383-1970
3	Fine aggregates	Sieve analysis	Grading zone = Zone-1 (Well graded Sand)	Curve conforming to IS:383-1970

Similarly physical and chemical properties of the fly-ash concrete were obtained from the database of JK cements Khrew Kashmir and are summarized in Table 4.

4. Test Results of Normal Concrete

Ten specimens of cube, cylinder and beam were cast with slump of normal concrete as 25 mm and compaction factor as 0.893.

Five casted specimens of cube, cylinder and beam were tested after 7 days and 28 days. The specimens were tested for compressive strength, flexural strength and splitting tensile strength.

Compressive strength test is conducted on cubes casted which were loaded on their opposite faces in a Compression Testing Machine (CTM). 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. The compressive strength is calculated as:

$$S_C = L_P / C_A \quad (1)$$

where S_C = compressive strength, L_P = load at failure, C_A = cross sectional area.

Flexural strength test of concrete is performed on beam specimens. The loading applied on the beam is a two point loading in which loads are applied at (1/3) rd points of the beam. 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. The flexural strength is calculated as:

$$S_F = 2PL / BD^2 \quad (2)$$

where S_F = flexural strength, P = load at failure/2, L = length of beam between supports, B = breadth of beam, D = depth of beam.

Splitting tensile strength 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. The loading condition produces a high compressive stress below the two surfaces to which the load is applied and 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 splitting tensile strength is calculated as:

$$S_H = 2P/\pi HD \tag{3}$$

where S_H = horizontal tensile stress, P = load at failure, H = height of cylinder, D = diameter of cylinder

The test results obtained are the average results summarized in Table 5.

Table 4. Properties of fly-ash.

S. No	Characteristic	Results Obtained	Standard values as recommended by IS:3812-1981	
			Grade - I	Grade - II
		PHYSICAL PROPERTIES		
1	Fineness (m^2/kg)	361.3	Should not be less than 320	Should not be less than 250
2	Lime reactivity (MPa)	4.92	Should not be less than 4	Should not be less than 3
3	Compressive strength (MPa)	81	Not less than 80% of the strength of corresponding cement mortar cubes	
4	Drying shrinkage (%)	0.011	Should not be more than 0.15	Should not be more than 0.10
5	Autoclave expansion (%)	0.01	Should not be more than 0.8	Should not be more than 0.8
		CHEMICAL PROPERTIES		
6	SiO_2+Al_2O_3+Fe_2O_3 %	91.95	Should not be less than 70	Should not be less than 70
7	SiO_2 %	58.66	Should not be less than 35	Should not be less than 35
8	Al_2O_3 %	28.76	-	-
9	Fe_2O_3 %	4.53	-	-
10	CaO %	1.58	-	-
11	MgO %	0.48	Should not be more than 5	Should not be more than 5
12	SO_3 %	0.18	Should not be more than 2.75	Should not be more than 2.75
13	Alkalis (Na_2O_{eq})	0.78	Should not be more than 1.5	Should not be more than 1.5
14	Na_2O %	0.14	-	-
15	K_2O %	0.97	-	-
16	LOI (loss on ignition) %	2.00	Should not be more than 12	Should not be more than 12

Table 5. Average value of results obtained from testing of normal concrete M20.

S. No	Test name	Specimen	Results
1	Compressive Strength	Cube	Average 7 days compressive strength = 17.23 N/mm^2
			Average 28 days compressive strength = 25.21 N/mm^2
2	Flexural Strength	Beam	Average 7 days Flexural strength = 3.87 N/mm^2
			Average 28 days Flexural strength = 5.22 N/mm^2
3	Splitting Tensile Strength	Cylinder	Average 7 days splitting tensile strength = 1.71 N/mm^2
			Average 28 days splitting tensile strength = 2.43 N/mm^2
4	Permeability	Beam	Average percentage weight of water absorbed = 0.79%
		Cylinder	Average percentage weight of water absorbed = 0.82%

5. Test Results of Fly-Ash Concrete

Fly ash was used as 5%, 10%, 15%, 20%, 25 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. 12 specimens were casted for each trial consisting of 4 cubes, 4 beams and 4 cylinders. 6 specimens, two from each category, were cured for 7 days and rest 6 for 28 days. In-situ tests were carried out for each trial.

The test results for 5%, 10%, 15%, 20%, 25% and 30% trails are summarized in Tables 6-11, respectively.

Table 6. Test results for 5% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.834	26mm	Average 7 days compressive strength = 23.22 N/mm^2 Average 28 days compressive strength= 32.58 N/mm^2
2	Flexural Strength	Beam	0.834	26mm	Average 7 days flexural strength= 4.12 N/mm^2 Average 28 days flexural strength= 8.87 N/mm^2
3	Splitting Tensile Strength	Cylinder	0.834	26mm	Average 7 days splitting tensile strength= 1.87 N/mm^2 Average 28 days splitting tensile strength = 2.76 N/mm^2
4	Permeability	Beam Cylinder			Average %age weight of water absorbed =0.68% Average %age weight of water absorbed =0.72%

Table 7. Test results for 10% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.872	26mm	Average 7 days compressive strength = 23.20 N/mm^2 Average 28 days compressive strength = 32.26 N/mm^2
2	Flexural Strength	Beam	0.872	26mm	Average 7 days flexural strength= 4.10 N/mm^2 Average 28 days flexural strength= 8.25 N/mm^2
3	Splitting Tensile Strength	Cylinder	0.872	26mm	Average 7 days splitting tensile strength = 1.96 N/mm^2 Average 28 days splitting tensile strength = 2.86 N/mm^2
4	Permeability	Beam Cylinder			Average %age weight of water absorbed =0.59% Average %age weight of water absorbed =0.51%

Table 8. Test results for 15% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.876	27mm	Average 7 days compressive strength = 21.22 N/mm^2 Average 28 days compressive strength = 31.90 N/mm^2
2	Flexural Strength	Beam	0.876	27mm	Average 7 days flexural strength = 4.02 N/mm^2 Average 28 days flexural strength = 8.16 N/mm^2
3	Splitting Tensile Strength	Cylinder	0.876	27mm	Average 7 days splitting tensile strength = 1.82 N/mm^2 Average 28 days splitting tensile strength = 2.69 N/mm^2
4	Permeability	Beam Cylinder			Average %age weight of water absorbed =0.58% Average %age weight of water absorbed =0.57%

Table 9. Test results for 20% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.882	27mm	Average 7 days compressive strength = 17.12 N/mm² Average 28 days compressive strength = 27.18 N/mm²
2	Flexural Strength	Beam	0.882	27mm	Average 7 days flexural strength = 3.27 N/mm² Average 28 days flexural strength = 7.46 N/mm²
3	Splitting Tensile Strength	Cylinder	0.882	27mm	Average 7 days splitting tensile strength = 1.51 N/mm² Average 28 days splitting tensile strength = 2.39 N/mm²
4	Permeability	Beam Cylinder			Average %age weight of water absorbed =0.60% Average %age weight of water absorbed =0.61%

Table 10. Test results for 25% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.892	28mm	Average 7 days compressive strength = 15.12 N/mm² Average 28 days compressive strength = 24.18 N/mm²
2	Flexural Strength	Beam	0.892	28mm	Average 7 days flexural strength = 2.89 N/mm² Average 28 days flexural strength = 6.26 N/mm²
3	Splitting Tensile Strength	Cylinder	0.892	28mm	Average 7 days splitting tensile strength = 1.23 N/mm² Average 28 days splitting tensile strength = 2.12 N/mm²
4	Permeability	Beam Cylinder			Average %age weight of water absorbed = 0.62% Average %age weight of water absorbed = 0.68%

Table 11. Test results for 30% replacement trail.

S. No	Test Name	Specimen	Compacting factor	Slump(mm)	Results
1	Compressive Strength	Cube	0.898	30mm	Average 7 days compressive strength = 11.19 N/mm² Average 28 days compressive strength = 23.28 N/mm²
2	Flexural Strength	Beam	0.898	30mm	Average 7 days flexural strength = 2.81 N/mm² Average 28 days flexural strength = 4.21 N/mm²
3	Splitting Tensile Strength	Cylinder	0.898	30mm	Average 7 days splitting tensile strength = 1.20 N/mm² Average 28 days splitting tensile strength = 2.07 N/mm²
4	Permeability	Beam Cylinder			Average %age weight of water absorbed =0.68% Average %age weight of water absorbed =0.76%

6. Comparative Analysis

A comparative study was performed to check the effectiveness of different percentages of fly-ash and bar-charts were prepared as shown in Figs 1-6.

Further Tables 12 and 13 show the strength comparison of normal concrete and different trials of fly-ash concrete.

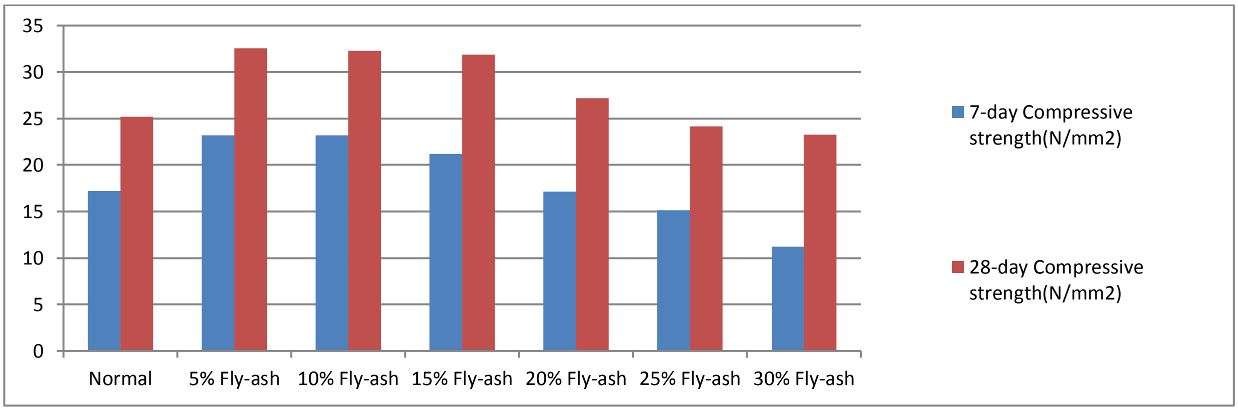

Fig. 1. Comparison of 7 days and 28 days compressive strength of normal and fly-ash concrete.

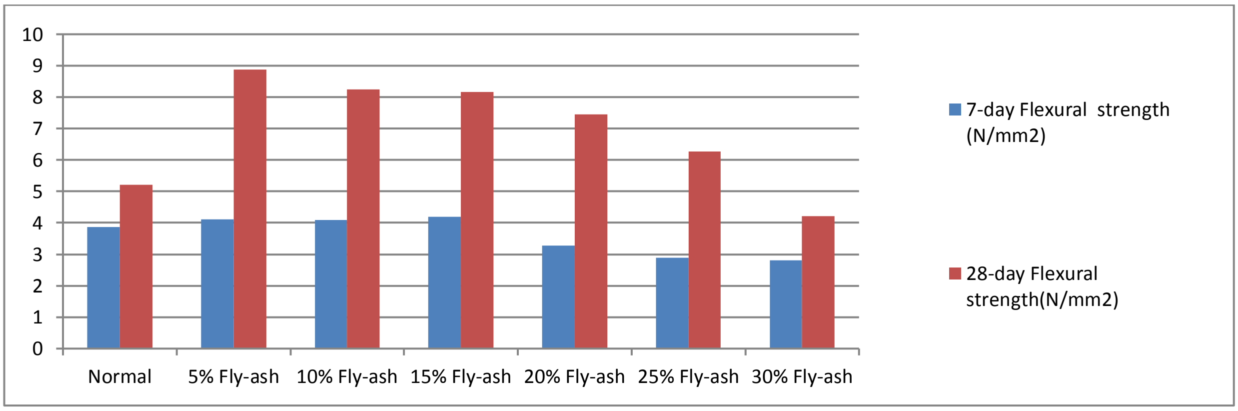

Fig. 2. Comparison of 7 days and 28 days flexural strength of normal and fly-ash concrete.

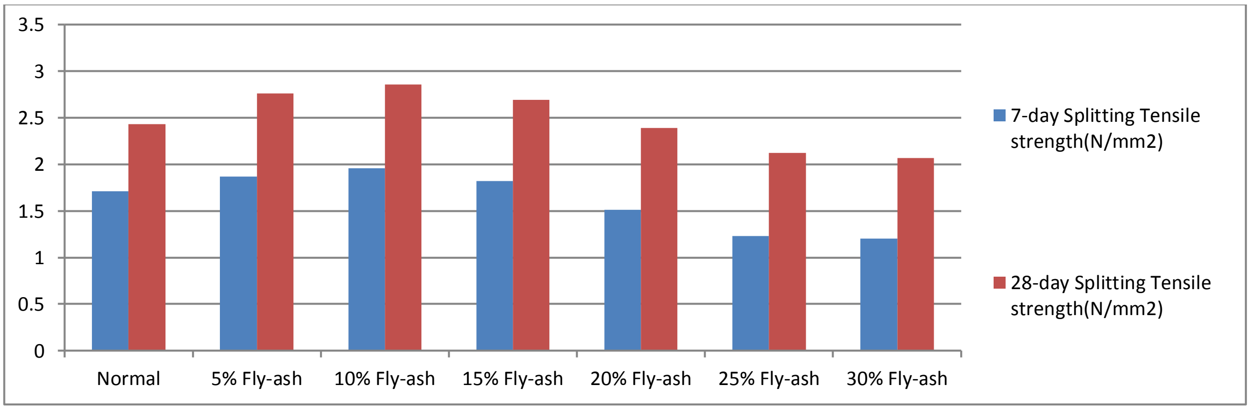

Fig. 3. Comparison of 7 days and 28 days splitting tensile strength of normal and fly-ash concrete.

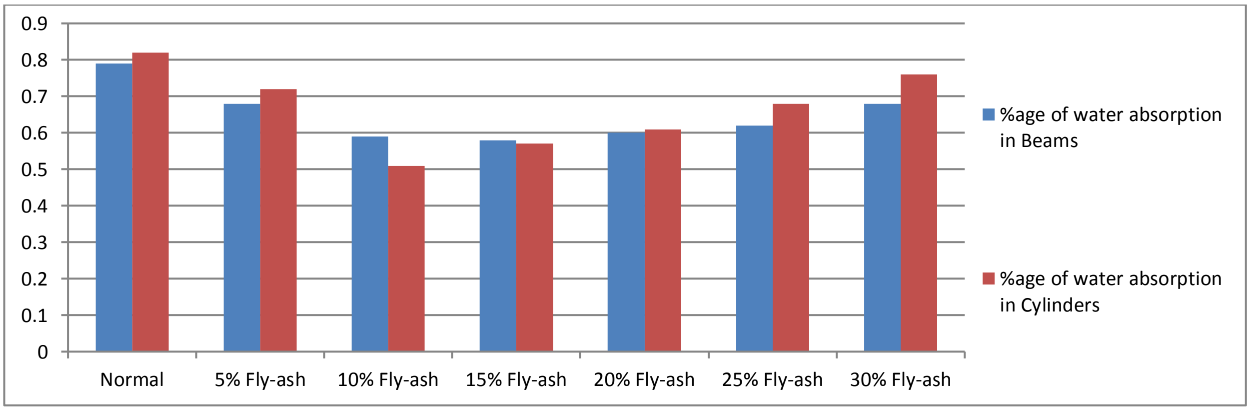

Fig. 4. Comparison of percentage of water absorption of normal and fly-ash concrete.

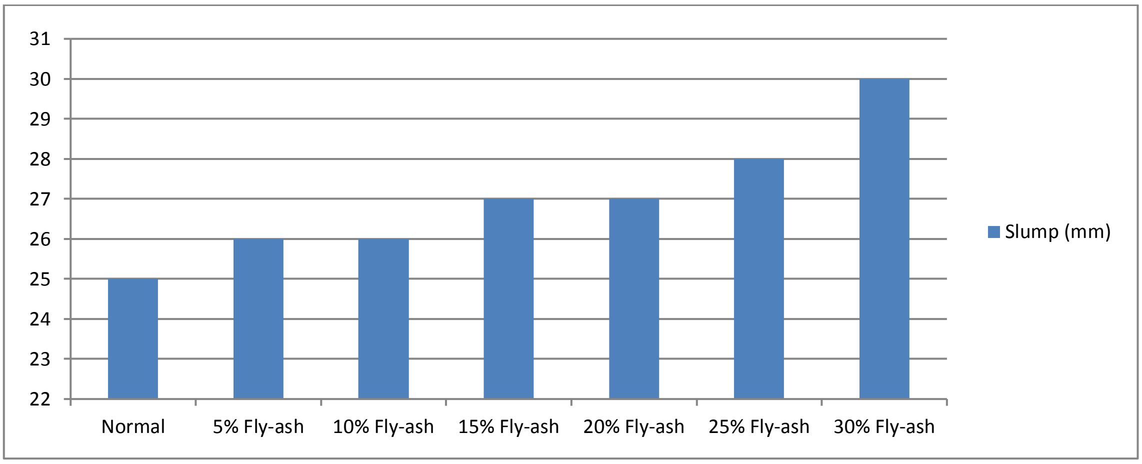

Fig. 5. Comparison of slump of normal and fly-ash concrete.

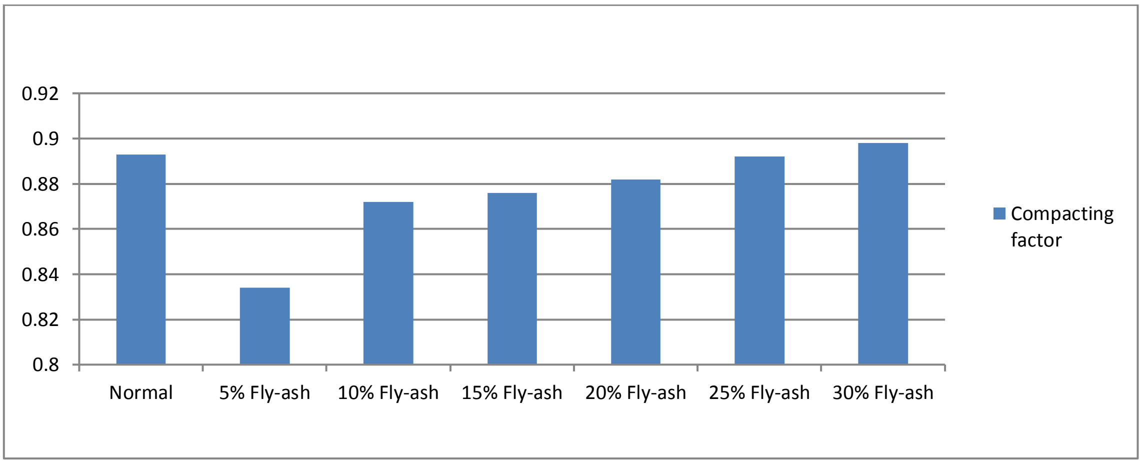

Fig. 6. Comparison of compacting factor of normal and fly-ash concrete.

Table 12. 7 days strength comparison of normal and fly-ash concretes.

Type of concrete	7 days strength (N/mm^2)					
	Compressive strength	%age increase/ decrease	Flexural strength	%age increase/ decrease	Splitting tensile strength	%age increase/ decrease
Normal concrete	17.23	-	3.87	-	1.71	-
5% fly-ash concrete	23.22	34.76	4.12	6.45	1.87	9.35
10% fly-ash concrete	23.20	34.64	4.10	5.94	1.96	14.61
15% fly-ash concrete	21.22	23.15	4.02	3.87	1.82	6.43
20% fly-ash concrete	17.12	-0.63	3.27	-15.50	1.51	-11.69
25% fly-ash concrete	15.12	-12.24	2.89	-25.32	1.23	-28.07
30% fly-ash concrete	11.19	-35.05	2.81	-27.39	1.20	-29.82

Table 13. 28 days strength comparison of normal and fly-ash concretes.

Type of concrete	28 days strength (N/mm²)					
	Compressive strength	%age increase/ decrease	Flexural strength	%age increase/ decrease	Splitting tensile strength	%age increase/ decrease
Normal concrete	25.21	-	5.22	-	2.43	-
5% fly-ash concrete	32.58	29.23	8.87	69.92	2.76	13.58
10% fly-ash concrete	32.26	27.96	8.25	58.04	2.86	17.69
15% fly-ash concrete	31.90	26.53	8.16	56.32	2.76	13.58
20% fly-ash concrete	27.18	7.81	7.46	42.91	2.39	-1.64
25% fly-ash concrete	24.18	-4.08	6.26	19.92	2.12	-12.75
30% fly-ash concrete	23.28	-7.65	4.21	-19.34	2.07	-14.81

7. Economic Analysis

In this economic analysis the cost of fly-ash has been taken as zero as it has been procured free of cost from the JK cements factory Khrew Kashmir. Since the transportation cost and the cost of sand and aggregates is same for both normal concrete and fly-ash concrete, so they are not taken into account. Hence this economic analysis has been conducted on the basis of quantity of cement used in both the cases only. Fly-ash obtained was pulverized but its cost has been neglected for the present economic analysis.

Normal Concrete (1:1.5:3)

Volume of one cube = 3.375×10^{-3} m^3
Cement used in one cube = 1.473 kg
Cost of 1 kg of cement = Rs. 5.00
Cost of cement per cube = Rs. 7.365
Cost of cement used in 1 m^3 of concrete= Rs. 2182.17

Fly-Ash Concrete

The economic analysis of fly-ash concrete for different trails is summarized in Table 14.

Table 14. Economic analysis for different trails of fly-ash concrete.

S. No	Fly-ash replacement	Quantity of cement replaced per cube	Cost of cement replaced per cube (Rupees)	Cost of concrete per cube cost of cement replaced in 1 m³ of concrete (Rupees)
1	5%	0.07365	0.368	109.03
2	10%	0.1473	0.7365	218.21
3	15%	0.22095	1.10475	327.32
4	20%	0.2946	1.473	436.43
5	25%	0.36825	1.84125	545.54
6	30%	0.4419	2.2095	654.65

8. Conclusions

After experimentation and testing of various specimens, the following conclusions were drawn:

- The short-term compressive, flexural and splitting tensile strengths (7-day) of Fly-ash concrete increased to some extent up to partial replacement of 15% and then after it considerably decreased.
- The water absorption percentage of fly-ash showed a considerable decrease giving an idea about the decrease in permeability by partial replacement of cement by fly-ash. However the percentage absorption showed an increasing trend after the trails of 25% fly-ash replacements.
- Test comparisons show that partial replacement of cement between 10% to 15 % show a maximum

efficiency in increasing the strength and other properties of concrete and hence it can be concluded that the optimum percentage of fly-ash by which cement should be replaced lies between 10% to 15%.

- The workability showed a linear increase with an increasing slump and compacting factors with increase in percentage of fly-ash.
- Economic analysis shows that Partial replacement of cement by fly-ash can boost the economy by reducing the overall cost of concrete.
- Utilization of fly-ash in concrete has provided an excellent means of disposal of fly-ash which has adverse environmental impacts.

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