MECHANICAL PROPERTIES OF CONCRETE COMPOSITES WITH REPLACEMENT OF CLASS C FLY ASH AND SILICAFUME

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Abstract— The results of experimental investigations on the study of concrete with partial replacement of cement are presented in this paper. The concrete grade of M30 has been selected and designed as per Indian Standard method. The specimens based on control mix have been cast without fly ash and silica fume. Cement was replaced by 0%, 10%, 20%, 30%, 40%, 50% and 60% of fly ash by the weight. 20 % of silica fume was added to all those mixes and further replacement of cement was tried. Necessary tests were carried out in fresh and hardened concrete. Workability was found from slump test. Tests for compressive strength were carried out on specimens at the age of 1, 7, 14, 28, 56 and 90 days. The split tensile strength and bond strength tests were also carried out at the age of 28 days. The test results were compared with the results of specimen prepared after control mix. The results showed that the strength development of fly ash concrete was less in early ages and increased at higher ages when compared with control specimens. From this study it was concluded that 50% replacement of cement by fly ash contribute reasonable strength along with 20% of silica fume.

Index Terms— *High volume fly ash, Compressive strength, Split tensile strength, Bond strength, Superplaticizes, Concrete Grade and Silica fume.*

1 INTRODUCTION

Concrete is well known heterogeneous mix of cement, water and aggregates. The admixtures may be added in in concrete in order to enhance some of the properties ties desired specially. In its simplest form, concrete is a mixture of paste and aggregates. Various materials such fly ash are added to obtain concrete of desired property. The character of the concrete is determined by quality of the paste. The key to achieving a strong, durable concrete rests in the careful proportioning, mixing and compacting of the ingredients. The quantity of fly ash produced from thermal power plants in India is approximately 80 million tons each year and its percentage utilization is less than 10 % . Majority of fly ash produced is of Class F type. During the last few years some cement companies have started using fly ash in manufacturing cement, known as "Pozzolona Portland Cement", but the overall percentage utilization remains very low and most of the fly ash are dumped as landfills(Siddique, 2003)[1]. Class C Fly ash is high lime ash originating from lignite coal. It may occasionally has a lime content of 24 percent. High lime ash has some cementitious properties of its own (Nevlille, 1995)[2].

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In this study an attempt has been made to explore the extent of replacing cement with fly ash and with fly ash and silica fumes. The strength variations of hardened concrete and the workability of fresh concrete for the mixes prepared with the partial replacement of cement with the above said fly ash combinations are discussed.

2 MATERIALS

The various materials used in this work are discussed with their properties as follows.

2.1 Cement

Ordinary Portland Cement of 53 grade was used in this study. The oxide composition limits of OPC (Neville, 1995) [2]are given in Table 1.

Table.1
Composition limits of Portland Cement

Chemical Composition	Content in percent
CaO	60-67
SiO_2	17-25
Al_2O_3	3-8
Fe_2O_3	0.5-6
MgO	0.5-4
Na_2O	2-3.5
SO_3	2-3.5

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Specific gravity value of OPC 53 grade is 3.15(IS: 12269, 1987)[3]. The initial and final setting times of cement were calculated in the laboratory and the values are determined as 92 minutes and 440 minutes respectively.

2.2 Fine Aggregate (FAg)

The fine aggregate (FAg) taken for this work is the locally available natural river sand and it was collected and cleaned for impurities. Sand particles passing through IS sieve 4.75 mm were used in this work. It was tested in the laboratory as per specifications recommended by IS:383-1970[4]. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.52 and 2.62 respectively.

2.3 Coarse Aggregate (CAg)

Crushed angular granite stones of maximum particle size 20 mm were used as coarse aggregate. The material were collected and cleaned for impurities. Particles of nominal size 20 mm were used and tested in the laboratory as per specifications recommended by IS:383-1970[4]. The specific gravity and fineness modulus of fine aggregate were determined and they were 2.69 and 6.8 respectively.

2.4 Fly ash (FA)

Calcium content in fly ash governs its ability to provide high early strength, which aids in accommodating construction sequencing. The higher calcium contents of Type C fly ash are able to provide primary cementing action. Overly high carbon contents in fly ash make air entertainment difficult as carbon absorbs air-entraining agents. Loss on Ignition (LOI) is a measure of unburned carbon remaining in the fly ash. It is desirable to maintain the lowest level of LOI possible, especially for air entrained concrete. A low LOI is also desirable to prevent discoloration of the concrete. Fineness of fly ash particles is a critical factor determining their pozzolanic ability (Fast, 2000)[5]. The chemical composition of Class C fly ash (SERC,2005)[6] is given in Table 2.

Table 2
Chemical Composition of Fly ash

Chemical Composition	Content in percent by mass
SiO_2	52.50
Al_2O_3	32.63
Fe_2O_3	6.16
CaO	0.30
Na_2O	0.10
K_2O	0.25
LOI	0.40

Fly ash (Class C) was collected from Neyveli Lignite Thermal Power Corporation. The specific gravity of fly ash was 2.30. Fly ash mineralogy and particle size rather than chemistry determine most of the fly ash effectiveness. Particles larger than 45 microns are essentially inert. Strength activity with cement is a measure of the reactivity of fly ash in a mix. Fly ash properties of structural performance can be specified, measured and monitored.

2.5 Superplasticizer (SP)

Extreme workability can be produced with the help of superplastcizers. And thus, reduction in water content can be achieved. The increased workability is produced due to electrochemical activity. Superplasticizer molecules and cement particles are oppositely charged and hence they repel each other. This increases the mobility and hence makes concrete flow. Also superplasticizers enable savings in cement for given strength (Santhakumar, 2007)[7]. The superplasticizer of brand name CONPLAST-SP430 was used in this work. It is based on sulphonated naphthalene formaldehyde condensate and conforming to IS: 9103-1999 and ASTM C- 494.

2.6 Silica Fume (SF)

Silica fume is formally known as artificial pozzolona. It is a by-product of the manufacture of silicon and ferrosilicon alloys. It exists as extremely fine spherical particles of amorphous silica (SiO_2). Amorphous silica is highly reactive and the smallness of the particles speeds up the reaction with calcium hydroxide produced by the hydration of Portland cement. The very small particles of silica fume can enter the space between the particles of cement and thus improve packing (Neville, 1995)[2].The silica fume in dry densified form obtained from Elkem India (P) Ltd, Mumbai conforming to ASTM-1240 was used in this work in the preparation concrete specimens.

3 METHODOLOGY

The various methods followed to prepare the specimens and the tests on fresh and hardened concrete are discussed under the following topics.

3.1 Mixture proportions

The minimum concrete grade recommended by IS 456: 2000 is M20. It is widely used in all ordinary structures in India. The minimum required characteristic strength is 20 N/mm^2 (IS: 456 2000)[8]. The target mean strength is determined using the guidelines issued by Durocrete mix design manual. The target mean strength is calculated as 28.25 MPa. Hence M30 is considered in this work for further study. A control concrete mix having compressive strength of 30MPa after 28 days was designed. No admixtures were added to the control mix. The preliminary mix design was carried out based on the recommendations of ACI committee 211.4R-93 and IS : 456 - 2000.The additional trial was carried out to optimize the level of workability and cohesiveness of fresh concrete by adding a sulphonated naphthalene based super plasticizer as a chemical admixtures. Fourteen types of mixes were prepared and assigned different identification notations. Such notations and the quantities of materials required for one meter cube of different concrete mixes are summarized in Table 3. Six mixtures have been prepared by replacing cement with Fly ash by 10%, 20%, 30%, 40%, 50% and 60% of mass and mixes are designated as 10 FA, 20 FA, 30 FA, 40 FA, 50 FA and 60 FA.

Table 3
Materials required for one cubic meter of selected concrete mixtures

MIX ID	FA	SF	Cement (kg)	FAg (kg)	SF (kg)	FA (kg)	CAg (kg)	Water (kg)	SP (kg)
Control	0	0	380	711	-	-	1283	160	5.70
10FA	10	0	342	711	-	38	1283	160	5.70
20FA	20	0	304	711	-	76	1283	160	5.70
30FA	30	0	266	711	-	114	1283	160	5.70
40FA	40	0	228	711	-	152	1283	160	5.70
50FA	50	0	190	711	-	190	1283	160	5.70
60FA	60	0	152	711	-	228	1283	160	5.70
20SF	0	20	304	711	76	-	1283	160	5.70
10FA20SF	10	20	266	711	76	38	1283	160	5.70
20FA20SF	20	20	228	711	76	76	1283	160	5.70
30FA20SF	30	20	190	711	76	114	1283	160	5.70
40FA20SF	40	20	152	711	76	152	1283	160	5.70
50FA20SF	50	20	114	711	76	190	1283	160	5.70
60FA20SF	60	20	76	711	76	228	1283	160	5.70

One mix has been prepared by replacing cement with 20% of silica fume alone. The identification is designated as 20SF. Six mixes were prepared with different percentage of combinations of fly ash and 20 percent silica fume. The percentage of fly ash content and the percentage of silica fume are mentioned in each designated notations. For example, 10FA20SF denotes 10 % of fly ash and 20 % of silica fume.

3.2 Preparation and casting of test specimens

The weighed ingredients were mixed in concrete mixture machine. Steel moulds were used to prepare test specimens. Suitable mould releasing agent was applied over the inner surface of the mould to get undamaged test specimens. The test specimens for compression test is cube of size 100 x 100 x 100 mm and for Split tension test is cylinder of dia 150 mm and height 300 mm. The fresh concrete mix was filled in the moulds in three equal layers and each layer was well compacted using table vibrator. All top surfaces of the specimens were leveled using finishing trowel before the initial setting time of the concrete .The test specimens were covered with wet gunny bags after setting time. All the specimens were demoulded and immersed in water for curing after 24 hours of casting. The specimens were taken out of curing tank after 3,7 and 28 days of curing for tests.

3.3 Experimental tests

Tests were conducted both on fresh and hardened concrete. The various tests conducted are discussed as below.

3.3.1 Fresh Concrete

The concrete must have workability such that compaction to maximum density is possible (Neville, 1995)[2]. As the compaction involves in later strength of the concrete, a good compaction must be arrived. The workability of a concrete can be determined from some of the fresh concrete properties such as slump, unit weight and fresh concrete temperature. They were determined according to Indian standard specifications IS: 1199-1959[9]. The various test conducted and results obtained from these tests on fresh concrete are summarized in Table 4.

Table 4
Test results on fresh concrete

S.No	MIX ID	Slump test (mm)	Unit weight (kg/m^3)	Temperature (° C)
1	Control	98	2420	28
2	10FA	90	2418	27
3	20FA	75	2415	26.5
4	30FA	65	2416	26.5
5	40FA	58	2414	27
6	50FA	47	2412	26.8
7	60FA	44	2410	25
8	20SF	96	2413	27
9	10FA20SF	94	2414	27
10	20FA20SF	78	2416	26.5
11	30FA20SF	67	2418	26.5
12	40FA20SF	62	2415	27
13	50FA20SF	53	2413	26.8
14	60FA20SF	48	2412	25

The description of workability with the magnitude of slump is summarized in Table 5

Table 5
Description of workability and magnitude of slump (Bartos, 1992)[10]

Description of workability	Magnitude of slump in mm
No Slump	0
Very Low	5-10
Low	15-30
Medium	35-75
High	80-165
Very High	165 to Collapse

3.3.2 Hardened concrete

The compression strength tests and split tensile strength tests were conducted on hardened concrete so as to study their mechanical properties. The test procedures specified by IS:516 – 1959 were strictly followed. The results of tests reported here represent the average value obtained from a minimum of three sample specimens.

3.3.2.i Compressive strength

Compressive strength tests were done on 150 x 150 x 150 mm cube specimens in compression testing machine of capacity 200 kN. The ultimate load taken by the specimen was taken for consideration. The concrete specimens were tested at different ages of 1 day, 3, 7, 28, 56 and 90 days. The compressive strength of specimens of different age is summarized in Table. 6.

Table 6
Compressive strength of specimens of different age

Mix ID	Compressive strength (M Pa)					
	1 Day	3 Days	7 Days	28 Days	56 Days	90 Days
Control	6.87	14.34	29.67	39.58	41.32	44.27
10FA	4.68	6.28	19.00	38.00	43.30	44.30
20FA	4.26	6.90	20.40	39.00	44.69	46.69
30FA	4.18	7.12	21.40	40.00	45.87	45.87
40FA	4.10	7.26	22.38	41.00	48.23	46.23
50FA	4.32	8.67	23.35	42.82	50.23	55.92
60FA	4.00	8.08	23.00	41.00	45.00	46.43
20SF	6.84	16.91	31.09	44.66	45.79	49.00
10FA20SF	7.00	12.39	32.58	48.00	56.30	56.00
20FA20SF	7.90	13.98	37.60	49.00	58.12	60.12
30FA20SF	8.87	14.70	38.25	54.00	59.43	60.43
40FA20SF	9.00	15.90	40.28	60.30	60.35	63.35
50FA20SF	9.33	22.73	41.56	62.37	63.98	65.68
60FA20SF	8.89	29.68	38.00	59.30	50.47	52.47

3.3.2.ii Split tensile strength test

It is very difficult to measure the tensile strength of concrete directly. The split tensile strength is simple to perform and gives more uniform results than other tension tests. Strength determined in the splitting test is believed to be closer to the true tensile strength of concrete (Shetty, 2005)[11]. Split tensile strength tests were done on 150 mm dia and 300 mm high cylindrical specimens in compression testing machine of capacity 200 kN. The cylindrical concrete specimens were tested at the age of 28 days for split tensile strength with diametric compression. The ultimate load taken by the specimen was taken for consideration. The split tensile strength of specimens is summarized in Table 7.

Table 7
Split tensile and bond strength at the age of 28 days

Mix Id	Split tensile strength(Mpa)
Control	3.70
10FA	3.70
20FA	3.80
30FA	3.90
40FA	4.00
50FA	4.10
60FA	4.10
20SF	4.60
10FA20SF	4.80
20FA20SF	4.90
30FA20SF	5.00
40FA20SF	5.53
50FA20SF	5.50
60FA20SF	4.97

3.3.2.iii Bond strength test

Bond strength between paste and steel reinforcement is of considerable importance. The bond strength in concrete is a function of compressive strength and is approximately proportioned to the compressive strength upto about 20 MPa (Shetty, 2005). The bond strength in this study is determined by pull out test conducted on 150 x 150 x 150 mm concrete cube embedded with 20 mm dia mild steel bar at the center. The cube is fixed and the MS bar is pulled out in UTM of capacity 100 kN. The cubical specimens were tested at the age of 28 days for bond strength. The ultimate load taken to pull the bar from the specimen against the friction between surface mild steel bar and concrete is considered. The bond strength of specimens are summarized in Table 8.

Table 8
Bond strength at the age of 28 days

Mix Id	Bond Strength (Mpa)
Control	10.28
10FA	10.10
20FA	9.80
30FA	9.65
40FA	9.70
50FA	9.79
60FA	9.45
20SF	10.28
10FA20SF	10.22
20FA20SF	10.30
30FA20SF	10.42
40FA20SF	10.48
50FA20SF	10.52
60FA20SF	10.30

4. RESULTS AND DISCUSSION

4.1Fresh Concrete

The slump tests,unit weight and temperature of the fresh concrete mix have been tested. The discussion on its results is as follows.

4.1.1Slump Test

The slump of values of various mixture proportions provides an idea about the various workable limits of the proposed mixtures. The control mix and the mix 10FA are highly workable. The mixes containing further increased percentage of fly ash have medium workability. Mix 20SF has high workability. The slump value of mix 10FA20SF is also highly workable. The slumps of other mixes have slump magnitude of medium workability. The mix 60FA has got minimum slump value. The comparison of slump values of all proposed mixes is graphically shown in Fig.1.

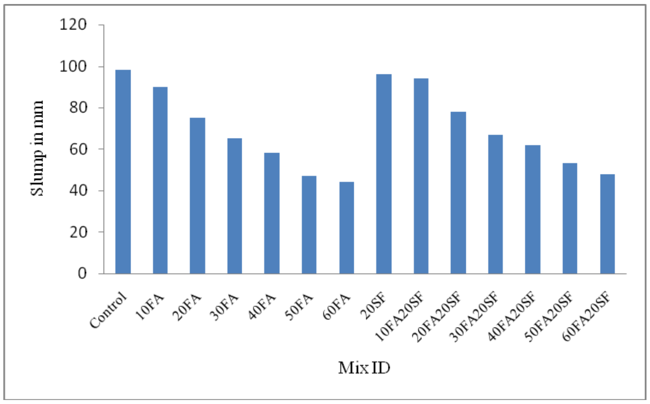

Fig.1 Slump values of all mixture proportions

4.1.2 Unit weight

The average unit weight of all the proposed mixtures is 2414.71 kg/m^3. All the mixes have unit weight above 2400 kg/m^3. The minimum unit weight out of all 14 mixes is 2410 kg/m^3 for the mix 60FA and the control mix has maximum unit weight of 2420 kg/m^3. The comparison of unit weight of all proposed mixes is graphically shown in Fig.2.

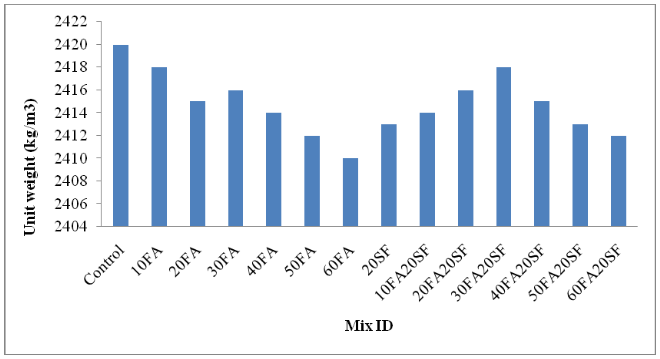

Fig.2 Unit weight of all mixture proportions

4.1.3 Temperature

The temperature was measured using digital thermometer. The control mix has the maximum temperature 28 degree celcius out of all 14 mixes. The average temperature of the mixes is 26.61°C. The minimum temperature is measured at the mixes 60FA and 60FA20SF. The comparison of temperature of all proposed mixes is diagrammatically shown in Fig.3.

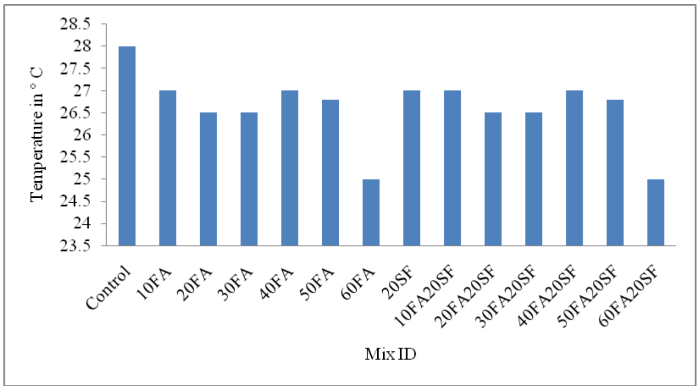

Fig.3 Temperature of all mixture proportions

4.2 Hardened Concrete

4.2.1 Compressive strength

The compression strength values provide information about the development gradient of concrete strength and the development of early strengths. The compressive study analysis has been made under five time intervals. A maximum compressive strength of 62.37 MPa was developed in the mix 50FA20SF and the same gains maximum strength in 7, 56 and 90 days old samples also. The compression strength is minimum in 10FA mix. The mix 60FA20SF behaves different by attaining early compression strength in 3 days and attaining comparatively less compression strength in 90 days. The comparison of compression strength of all proposed mixes is diagrammatically shown in Fig.4.

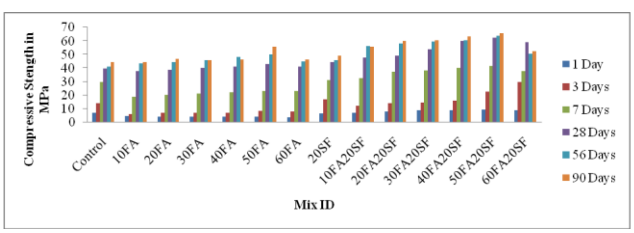

Fig. 4 Compression strength of specimens

The rate of gain in compressive strength is analysed with the help of serial plot drawn with age in abscissa and compression strength in ordinate. The rate of gain in compression strength of the proposed specimens is compared with the rate of gain in strength of control mix. The gain in strength with respect to age is graphically represented in Fig 5. The control mix has shown consistent gain in strength with age. But the mixes blended with Fly ash have no appreciable early strength. However those mixes have gained the strength more than the target strength in later days. The mix 50 FA has gained a maximum strength of 55.92 MPa after 90 days. The further increase in fly ash replacement ie, above 50 % has shown reduction in both early and later compressive strengths. The additions of silica fumes in rest of the mixes have shown appreciable increase in compressive strength. The specimen prepared from mix 20SF which has 20 % of cement replacement with silica fume has produced appreciable early and later compressive strength and gained compressive strength values more than the specimen prepared from control mix proportions.

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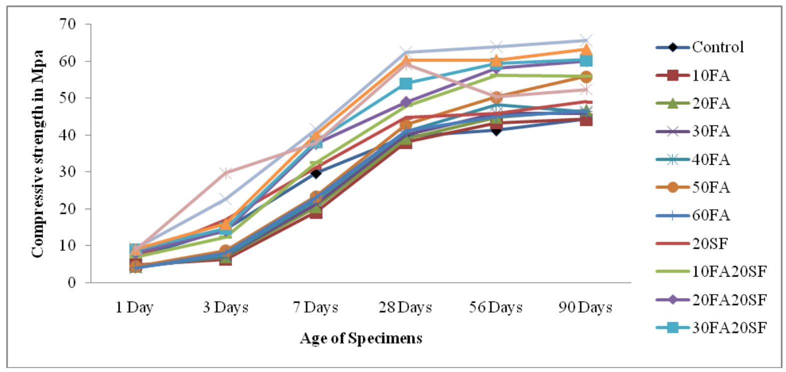

Fig. 5 Gain in compression strength of specimens with age.

The specimens prepared using mix proportions 10FA20SF, 20FA20SF and 30FA20SF have shown reduced early strength than that of specimen prepared with silica fume and without fly ash. From 40FA20SF proportion, the early strength started increasing. A good result of both early and later compressive strength was observed in the specimen prepared using 50FA20SF proportion.

4.2.2 Split tensile strength

The results of splitting tensile strength of the concrete specimens of this study provide necessary informations about the role of fly ash and silica fumes in enhancement of tensile strength of concrete. There is no change in the tensile strength of specimens prepared in control mix and in mix 10FA. With the further addition of fly ash in the other mixes, increasing split tensile strength were obtained. The rate of increase in tensile strength is observed further high in the specimens proportioned with fly ash and silica fumes. A maximum tensile is obtained in the mix 40FA20SF. Tensile strength is observed reducing from the proportions having fly ash more than 40% along with 20% silica fumes. The tensile strength of all the specimens were graphically presented in Fig.6.

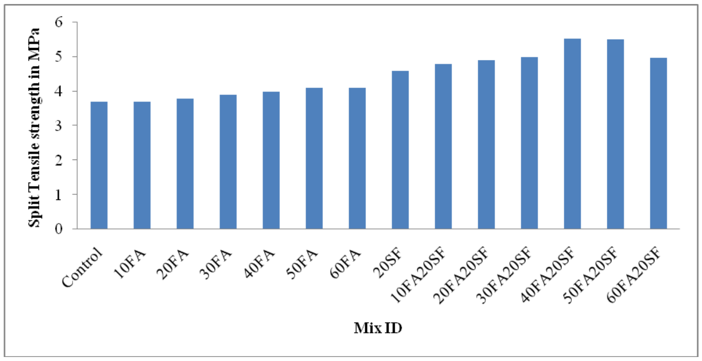

Fig. 6 Split tensile strength of the specimens

4.2.3 Bond strength

The results bond strength of the test specimens provide necessary information about the role of fly ash and silica fumes in the development of bond strength in concrete. The bond strength was observed to be continuously reducing with increase in the fly ash content. But with addition of silica fumes, increasing trend in the bond strengths were observed in the specimens. The bond strength values of the specimens are graphically presented in the Fig.7

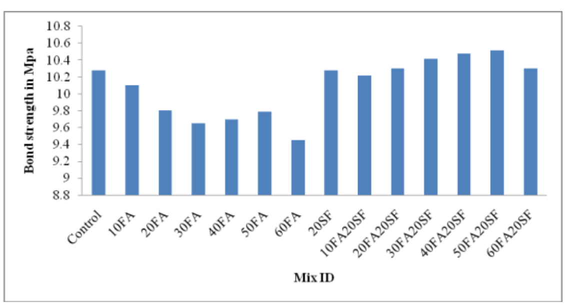

Fig. 7 Bond strength of the specimens

The maximum bond strength of 10.52 MPa was observed in the specimen prepared from the mix 50FA20SF. The minimum bond strength of 9.45 MPa was observed in the specimen prepared from the mix 60FA.

5. CONCLUSIONS

The following conclusions can be drawn from the results of present investigations.

- Highly workable concrete can be achieved with addtion of fly ash and silica fume together upto 30 % replacement of cement.
- The role of cement replacement admixtures such as fly ash and silica fumes may be considered insignificant in altering unit weight of the concrete.
- Temperature of the fresh concrete may be reduced with addition of cement replacement admixtures.
- Both fly ash and silica fumes may be considered as very important cement replacement admixtures in building up physical strength of hardened concrete.
- Silica fumes may be considered to be good admixture in building up of appreciable early and later strengths of hardened concrete.
- Both fly ash and silica fumes may be considered as very important cement replacement admixtures in building up tensile strength of hardened concrete.
- Silica fumes may be considered as better admixture in building up of good bond.

REFERENCES

[1]. Siddique Rafat,2003,"Effect of fine aggregate replacement with class F flyash on the mechanical properties of concrete ",Cement and concrete Research,Elsevier Science Ltd,Vol(33),pp-539-547.

[2]. A.M.Neville., 1995,"Properties of Concrete", 4^{th} ed, Dorling Kindersley Pvt Ltd,Noida,India,pp-84-85.

[3]. IS:12269, 1987, Specification for 53 grade Ordinary Portland Cement, Bureau of Indian Standards, New Delhi.

[4]. IS:383, 1970, Specification for Coarse and Fine Aggregates from Natural sources for Concrete, Bureau of Indian Standards, New Delhi.

[5] A .Fast Paul., 2000," High Volume Fly Ash Concrete Usuage", Great Vancouver Regional District AIR 2000 Program Bulletin.

[6]. SERC, 2005," Demonstration of Utilizing High Volume Fly Ash Based Concrete for Structural Applications", Report for CII, India, SERC, Chennai, India, pp 15-16.

[7]. A.R.Santhakumar, 2007," Concrete Technology", Oxford University Press, New Delhi,pp-79-80.

[8]. IS:456- 2000, Indian Standard Code of Practice for Plain Reinforced Concrete, , Bureau of Indian Standards, New Delhi.

[9]. IS:1199- 1959, Indian Standard Methods of Sampling and Analysis of Concrete, , Bureau of Indian Standards, New Delhi.

[10]. P.Bartos, 1992, Fresh Concrete, Elsevier, Amsterdam pp-292

[11]. M.S. Shetty, 2005," Concrete Technology", S.Chand& Company Ltd., New Delhi, pp-315,433