Report No. T(S)006

USE OF HIGH VOLUME FLY ASH IN CONCRETE FOR BUILDING SECTOR

Sponsored by

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The use of high volume fly ash (30-50 %) in concrete for building sector for M20, M30 and M40 grades have been made for various properties as desired by the sponsorer. The responsibility of the Central Building Research Institute (CBRI), Roorkee is limited to the test results as referred in the report. All procedural, legal or operational concerns, including implementation, supervision and execution at site will be the sole responsibility of the party using this report.

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Project Title

"Use of Higher Volume Fly Ash in Concrete for Building Sector"

Team Members

1. Prof. VK Mathur (Director)
2. Dr. CL Verma
3. Sh. BS Gupta
4. Dr. SK Agarwal
5. Dr. Awadhesh Kumar

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Introduction:

The use of high volume fly ash (HVFA) concrete fits in very well with sustainable development. High volume fly ash concrete mixtures contain lower quantities of cement and higher volume of fly ash (up to 60%). The use of fly ash in concrete at proportions ranging from 35 to 60 % of total cementitious binder has been studied extensively over the last twenty years and the properties of blended concrete are well documented. The replacement of fly ash as a cementitious component in concrete depends upon several factors. The design strength and workability of the concrete, water demand and relative cost of fly ash compared to cement. From the literature it is generally found that fly ash content in the cementitious material varies from 30-80% for low strength (20 MPa) to high strength (100MPa).

Studies conducted at Canada Center for Mineral and Energy Technology (CANMET) and University of Calgary have indicated that structural concrete with 28 days strength around 60MPa and of adequate durability can be produced by the Canadian fly ash replacing up-to 60% cement by weight and incorporating high range water reducing and air entraining admixtures in concrete. Dunstan and Thomas[1] have studied the performance of high volume fly ash concrete for structural purposes.

Naik and Ramme[2] presented two case histories wherein 70% cement was replaced by class C fly ash to pave a 254 mm thick roadway. To obtain high workability and durability a high range water reducing agent and an air-entraining agent was added to the concrete mix. The other case reported by the same author's involved placing of the same High Performance Concrete in the construction of 138 kV transformer foundations. No problems were reported during or after construction in both projects and the use of High Volume Fly ash Concrete (HVFC) resulted in considerable economy and technical benefits.

Hague etal.[3] conducted tests on concrete mixes in which bituminous fly ashes formed up to 75% of the cementitious material, which varied between

325 and 400 kg/m^3. They concluded that such high volume fly ash concretes with adequate strength, volume stability, and durability have a great potential for use in structural applications particularly in pavements.

Langley etal.[4] reported two case histories where High Volume Fly ash Concretes were used with class Fly ash constituting 55% of the cementitious material along with a superplasticizer. In one case, where columns, beams and floor slab in a building complex required 50 MPa concrete at 120 days, the High Performance Concrete yielded concrete with 74 MPa compressive strength at120 days, thus exceeding the strength requirement. No unexpected problems were reported and the HVFC proved to be an economical solution for the particular project. In second case, the same type of HVFC was used in drilled caisson piles to support a 22 storey building on the Halifax Water Front, Nova Scotia in Canada. The minimum 28 day the high fly ash concrete that had compressive strength of the order of 32 MPa and 51 MPa at 7days and 28 days, respectively, easily met compressive strength requirement of 45 MPa for the pile concrete.

Malhotra etal.[5] studied in detail the properties of concretes with a wide range of Canadian fly ashes at 58% of the total cementitious materials. These concretes were tested for compressive strength, creep strain and resistance to chloride ion penetration at various ages up to one year. The results of study by Joshi etal.[6,7] indicated that with fly ash replacement levels up to 50% by cement weight, concrete with 28-day strength ranging from 40 to 60 MPa and with adequate durability can be produced with cost saving of 16% by 50% replacement level.

Bouzoubaa etal.[8,9] at CANMET Canada have done studies on the mechanical properties of concrete made with blended high volume fly ash cements. Physical properties of high volume fly ash cements and mortars have been also been studied. The use of the high volume fly ash cements improves the resistance of the concrete to the chloride ion penetration.

In India, Fly ash mission has initiated projects on use of higher volume fly ash concrete construction. Gujrat Ambuja cements had laid down a high volume fly ash (50%) concrete road at their Ropar Plant, Punjab. The grade of the concrete was M-40.

Objective and Scope of the Work:

In the present proposal it is planned to conduct lab investigation using high volume of fly ash (30-50%). for different grades of concrete (M-20, M-30 and M-40) for building sector.
The main purpose of this investigation is to develop confidence among user agencies in India to use higher volume fly ash concrete in the building construction.
The following tests were conducted on the concretes.

1. Compressive Strength
2. Rapid Chloride Permeability tests
3. Permeability coefficient measurements

Materials:

53 grade Ordinary Portland cement conforming to BIS 12269-1987 was used. Its physical properties and chemical composition are given in table –1
Class F fly ash from Dadri, New Delhi conforming to BIS 3812-2000 was used in the present study. Its physical properties and chemical composition are also given in table –1. The scanning electron microscope of the fly ash is shown in the figure- 1. The X ray of Dadri fly ash is shown in figure 2.

Admixtures
Two high range water reducing admixtures; one based on poly carboxylate and other naphthalene sulfonate polymer based were used in the present study. Naphthalene sulfonate polymer was used in the final study due to high cost of poly carboxylate superplasticizer in India.

Aggregates
Crushed stones of 20mm down and 10mm down were used as coarse aggregate. Local river sand was used as fine aggregate in the concrete mixtures. Various physical properties of coarse and fine aggregates are given in table -2

Table -1 Physical and Chemical analysis of Portland Cement and Fly Ash

Property	Portland Cement (53 grade)	Fly Ash (Dadri)
CaO	**61.5**	**3.68**
Silica content	**20.6**	**60.27**
Al_2O_3	**5.10**	**25.46**
Fe_2O_3	**3.90**	**6.02**
LOI	**1.51**	**1.10**
Magnesia	**3.00**	**0.29**
Alkalies	**0.35**	**2.64**
SO_3	**2.10**	**0.12**
Chloride	**0.012**	**---**
Specific gravity	**3.14**	**2.25**
Specific Surface cm^2/g	**2980**	**3980**
C_3S	**47.7**	
C_2S	**23.3**	
C_3A	**6.9**	
C_4AF	**11.9**	
Setting Time (Min.)		
Initial	**145**	
Final	**230**	
Compressive Strength (Kg/cm^2)		
1day	**215**	
3day	**435**	
7day	**510**	
28day	**630**	

Physical Properties of Aggregates

Density of Coarse Aggregate 2.7

Density of Fine Aggregate 2.6

Water absorption of coarse aggregate 0.5%

Water absorption of fine aggregate 2.5%

Fineness modulus of Fine aggregate 2.965

Fineness modulus of coarse aggregate 6.96

Activated Reactivity Index 120

Table –2 Sieve Analysis of Aggregate

Coarse Aggregate				
Sieve, mm	20 mm (I)	10mm (II)	Mixed	BIS 383
20	100	100	100	95-100
10	4	100	42.4	25-55
4.75	0	4	1.6	0-10

Fine Aggregate	
Sieve size, mm	Passing %
4.75	100
2.36	85
1.20	66
0.60	39
0.30	11
0.15	2.5

Experimental Program:

The proportions of the trial mixtures for M20, M30 and M40 grade concretes are summarized in Tables 3 to 9. These mixes were designed according to IS: 10262 and modified based on observations with the intention of using minimum cement content. The coarse and fine aggregates were weighed at room temperature. The coarse aggregate was then immersed in water for 24 hours. The excess water was decant off and the water remained in the container was determined by the weight difference between the two. In case of fine aggregate known quantity of water was added in the fine aggregate and was allowed to stand for 24 hours this procedure was used to insure that the aggregates were used in a saturated condition in order to know the exact value of the w/cm of the mixtures. For each concrete mixture 100mm cubes were cast for the determination of compressive strength and permeability coefficient tests, 100x50 mm cylinder were cast for determining the rapid chloride penetration tests. No superplasticizer was used in M-20 grade concrete.

The specimens were cast in two layers and were compacted. The specimens were covered with wet gunny bags and saturated burlap and were kept in the constant room maintained at 27± 2C^{o}. After 24 hours the specimens were demolded and stored in 100% RH until required for testing at various time intervals.

The rapid chloride ion penetration test was carried out using Proove'it PR-1090 Model with concrete sample (100 mm dia., 50mm high)

The permeability coefficient was determined using Torrent Permeability Tester (Proceq, Switzerland) model No. ETI –H0455. 100 mm concrete samples were dried for two weeks after 28 days of curing.

Properties of the Hardened Concrete:

The compressive strength, rapid chloride ion penetration and permeability coefficient of various mixes are given in table13.

The compressive strength of various concrete mixes at 7 and 28 days with various percentages of fly ash is shown in Figures 3-6.

The cost analysis of various concrete mixes has also been calculated and are given in Tables 14-16

Table-3 Trial Mix Design of M20 Grade Concrete with Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementit-ious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
235	---	235	153.0	0.65	703.27	783.65	522.43	100	20.5	36.0
280	---	280	163.0	0.58	677.87	755.34	503.56	90	28.0	41.5
196	84	280	157.5	0.56	673.37	750.33	500.22	100	18.0	36.0
210	90	300	160.0	0.53	663.95	739.83	493.22	100	20.5	39.0
180	120	300	156.0	0.52	664.07	739.96	493.31	95	19.0	35.0

Table-4 Trial Mix Design of M-30 Grade Concrete With 30% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
260.0#	---	260	134.0	0.52	692.36	771.79	514.53	80	30.5	44.5
182.0#	78.0	260	125.0	0.48	707.00	787.80	525.20	100	24.0	38.0
192.5#	82.5	275	130.0	0.47	700.16	780.18	520.12	92	26.0	43.5
259.0*	111.0	370	144.0	0.39	629.77	701.75	467.80	125	34.5	50.0
280.0*	120.0	400	144.5	0.36	620.00	691.20	476.80	100	35.5	52.0
294.0*	126.0	420	145.5	0.35	613.5	683.67	455.78	90	42.5	58.0
308.0*	132.0	440	146.5	0.33	601.9	670.74	440.72	85	45.0	60.0

* 0.5 % polycarboxylate based superplasticizer
\# 1.0 % naphthalene based superplasticizer

Table-5 Trial Mix Design of M-30 Grade Concrete With 40% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
180*	120	300	120	0.40	690.14	769.01	512.67	95	27.0	43.0
192*	128	320	128	0.40	679.54	757.70	504.80	100	28.2	46.0
222#	148	370	140	0.38	625.32	696.79	464.52	125	30.0	44.0
240#	160	400	142	0.36	618.60	689.28	459.80	115	31.0	46.0
252#	168	420	143	0.34	612.80	682.84	455.52	105	35.0	48.0
264#	176	440	145	0.33	605.90	675.18	450.10	80	38.0	52.0

* 0.5 % polycarboxylate based superplasticizer
\# 1.0 % naphthalene based superplasticizer

Table-6 Trial Mix Design of M-30 Grade Concrete With 50% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
180#	180	360	133	0.37	632.12	704.40	470.00	80	27.0	44.0
190#	190	380	134	0.35	626.64	698.25	465.20	105	28.0	50.5
200#	200	400	138	0.34	619.50	690.30	460.20	100	29.0	51.0
210#	210	420	140	0.33	612.47	682.40	454.95	90	30.0	52.0
220#	220	440	142	0.32	605.31	674.49	459.67	85	32.5	53.5

1.0 % naphthalene based superplasticizer

Table-7 Trial Mix Design of M-40 Grade Concrete With 30% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
300*	----	300	130.0	0.43	702.68	782.98	521.99	85	38.5	55.5
252*	108	360	138.0	0.38	655.69	730.63	487.08	80	37.0	55.0
273*	117	390	142.0	0.36	644.8	718.5	479	80	37.0	61.0
315#	135	450	151.0	0.34	612.05	682	454.67	85	42.0	64.0
336#	144	480	152.5	0.32	602	670.9	447.28	80	43.5	63.0
350#	150	500	154.0	0.31	595.49	663.54	442.36	80	47.0	66.0
364#	156	520	156.0	0.30	589	656.4	437.6	80	48.5	68.0

* 0.5 % polycarboxlate based superplasticizer
# 1.0 % naphthalene based superplasticizer

Table-8 Trial Mix Design of M-40 Grade Concrete With 40% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water Litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
252*	168	420	148.5	0.35	619.02	689.76	459.84	85	29.5	53.0
270*	180	450	149.5	0.33	610.68	680.47	453.65	80	36.0	57.5
300#	200	500	150.0	0.30	594.00	662.00	441.20	90	39.0	60.0
312#	208	520	152.0	0.29	587.00	654.60	436.40	85	42.0	65.0
324#	216	540	153.5	0.28	580.00	646.80	431.20	80	45.0	67.0

* 0.5 % polycarboxlate based superplasticizer
# 1.0 % naphthalene based superplasticizer

Table-9 Trial Mix Design of M-40 Grade Concrete With 50% Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementit-ious content kg/m^3	Water litres	$\frac{W}{(C+FA)}$	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	CS 7 days MPa	CS 28 days MPa
235*	235	470	152.5	0.33	599.36	667.86	445.24	90	28.5	53.5
260#	260	520	153.0	0.29	586.00	652.80	435.20	120	34.0	56.0
270#	270	540	154.0	0.29	579.00	645.00	430.00	85	40.5	60.0
280#	280	560	156.0	0.28	571.40	636.70	430.10	80	42.0	65.0

* 0.5 % polycarboxlate based superplasticizer
# 1.0 % naphthalene based superplasticizer

On the basis of test results obtained from the trial mixes, final concrete mixes were cast with minimum cement content fulfilling the strength requirements. The details of these mixes, setting time and density are given in the Table 10-12. Napthalene sulfonate condensate (1%) was used in final casting.

Table-10 Mix Design of M20 Grade Concrete with Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementit-ious content kg/m^3	Water litres	W / (C+FA)	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	Density kg/m^3	Setting time (Hrs. min.) Initial	Final
235	-----	235	143.0	0.61	703.27	783.65	522.43	80	2350	5.45	7.15
196	84	280	150.5	0.54	673.37	750.33	500.22	80	2365	7.15	8.25
180	120	300	152.0	0.51	664.07	739.96	493.31	80	2355	8.50	10.25

Table-11 Mix Design of M-30 Grade Concrete With Fly Ash

Cement kg/m^3	Fly ash kg/m^3	T. Cementit-ious content kg/m^3	Water litres	W / (C+FA)	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	Density kg/m^3	Setting time (Hrs. min.) Initial	Final
260.0	---	260	134	0.52	692.36	771.79	514.53	80	2390	7.20	8.35
192.5	82.5	275	130	0.47	700.16	780.18	520.12	92	2385	9.10	10.25
180.0	120.0	300	128	0.43	690.14	769.01	512.67	90	2380	9.50	11.15
180.0	180.0	360	135	0.37	632.12	704.40	470.00	80	2375	9.40	11.40

Table-12 Mix Design of M-40 Grade Concrete With Fly Ash*

Cement kg/m^3	Fly ash kg/m^3	T. Cementitious content kg/m^3	Water litres	W/(C+FA)	Fine Agg. kg/m^3	CA<20 mm Kg/m^3	CA<10 mm kg/m^3	Slump mm	Density kg/m^3	Setting time (Hrs. min.) Initial	Final
300	----	300	130.0	0.43	702.68	782.98	521.99	85	2385	7.50	8.55
252	108	360	138.0	0.38	655.69	730.63	487.08	90	2375	9.45	10.50
252	168	420	148.5	0.35	619.02	689.76	459.84	80	2375	10.25	11.25
235	235	470	154.0	0.33	599.36	667.80	445.24	80	2365	11.25	11.45

Table 13: Properties of the Hardened Concrete of Various Mixes

Mix No.	Cement (%)	Flyash (%)	Cementitious content kg/m^3	$\frac{W}{(C+FA)}$	CS(7D) MPa	CS(28d) MPa	Chloride Permeability Coulombs 28 days	Permeability Coefficient KT 10^{-16} 28days
20	100	00	235	0.61	19.5	34.0	3480	0.038
23	70	30	280	0.54	17.5	34.5	2560	0.029
24	60	40	300	0.51	16.5	35.5	2145	0.022
30	100	00	260	0.52	27.5	44.0	1351*	0.014
33	70	30	275	0.47	25.5	43.0	995	0.010
34	60	40	300	0.43	26.5	42.5	890	0.006
35	50	50	360	0.37	25.5	43.0	775	0.004
40	100	00	300	0.43	38.5	57.0	1295*	0.009
43	70	30	360	0.38	28.5	55.0	990	0.005
44	60	40	420	0.35	29.5	53.0	812	0.002
45	50	50	470	0.33	28.0	53.0	761	<0.002

* On lower side

Table – 14 Cost Analysis of M20 grade Concrete with Fly ash

Sl. No.	ITEMS	UNIT	RATE	Fly ash	Fly ash	Fly ash
				Concrete	Concrete	Concrete
			(in Rs.)	M20	M23	M24
	MATERIALS:					
	(including carriage)					
1.	Cement	Kg	3.20	235	196	180
2.	Fly ash	Kg	0.50	0	84	120
5.	Fine Aggregate	Cu.m	490.00	0.70	0.67	0.66
6.	Coarse Agg.(10 mm Size)	Cu.m	470.00	0.52	0.50	0.49
7.	Coarse Agg.(20 mm Size)	Cu.m	470.00	0.78	0.75	0.74
8.	Water	Kg	0.00	153	157.5	156
9.	Super plasticizer	Liter	30.00	0	0	0
	LABOUR:					
	Skilled	each	130.00	0.18	0.18	0.18
	Unskilled	each	93.00	2.15	2.15	2.15
	Hire & Running Charges :					
	Mechanical Mixer 0.14 cubic meter					
	Vibrator(Needle type 40 mm)	each	50.00	50.00	50.00	50.00
	Sundries	L.S>	10.00	10.00	10.00	10.00
		-	-	-	-	-
		Total		1993.81	1870.26	1824.38
	Water Charges @ 1%			19.94	18.70	18.24
		-	-	-	-	-
		Total		2013.75	1888.96	1842.63
	Contractor's Profit			201.38	188.90	184.26
	& Overheads @ 10%					
		-	-	-	-	-
	Cost per Cu.m of Conc.	**G.Total**		**2215.00**	**2078.00**	**2027.00**

Table – 15 Cost Analysis of M30 grade Concrete with Fly ash

Sl. No.	ITEMS	UNIT	RATE	Fly ash	Fly ash	Fly ash	Fly ash
			(in Rs.)	Concrete M30	Concrete M33	Concrete M34	Concrete M35
	MATERIALS:						
	(including carriage)						
1.	Cement	Kg	3.20	260	192.5	180	180
2.	Fly ash	Kg	0.50	0	82.5	120	180
5.	Fine Aggregate	Cu.m	490.00	0.69	0.70	0.69	0.63
6.	Coarse Agg.(10 mm Size)	Cu.m	470.00	0.51	0.52	0.51	0.47
7.	Coarse Agg.(20 mm Size)	Cu.m	470.00	0.77	0.78	0.77	0.70
8.	Water	Kg	0.00	134	130	128	133
9.	Super plasticizer	Liter	30.00	2.6	2.75	3	3.6
	LABOUR:						
	Skilled	each	130.00	0.18	0.18	0.18	0.18
	Unskilled	each	93.00	2.15	2.15	2.15	2.15
	Hire & Running Charges :						
	Mechanical Mixer 0.14 cubic meter						
	Vibrator(Needle type 40 mm)	each	50.00	50.00	50.00	50.00	50.00
	Sundries	L.S>	10.00	10.00	10.00	10.00	10.00
		-	-	-	-	-	-
		Total		2137.18	1977.32	1949.91	1919.06
	Water Charges @ 1%			21.37	19.77	19.50	19.19
		-	-	-	-	-	-
		Total		2158.55	1997.09	1969.41	1938.25
	Contractor's Profit			215.85	199.71	196.94	193.82
	& Overheads @ 10%						
	Cost per Cu.m of Conc.	**G.Total**		**2374.00**	**2197.00**	**2166.00**	**2132.00**

Table – 16 Cost Analysis of M40 grade Concrete with Fly ash

Sl.No.	ITEMS	UNIT	RATE	Fly ash	Fly ash	Fly ash	Fly ash
			(in Rs.)	Concrete M40	Concrete M43	Concrete M44	Concrete M45
	MATERIALS:						
	(including carriage)						
1.	Cement	Kg	3.20	300	252	252	235
2.	Fly ash	Kg	0.50	0	108	168	235
5.	Fine Aggregate	Cu.m	490.00	0.70	0.66	0.62	0.60
6.	Coarse Agg.(10 mm Size)	Cu.m	470.00	0.52	0.49	0.46	0.45
7.	Coarse Agg.(20 mm Size)	Cu.m	470.00	0.78	0.73	0.69	0.67
8.	Water	Kg	0.00	130	138	148.5	152.5
9.	Super plasticizer	Liter	30.00	3	3.6	4	4.7
	LABOUR:						
	Skilled	each	130.00	0.18	0.18	0.18	0.18
	Unskilled	each	93.00	2.15	2.15	2.15	2.15
	Hire & Running Charges :						
	Mechanical Mixer 0.14 cubic meter						
	Vibrator(Needle type 40 mm)	each	50.00	50.00	50.00	50.00	50.00
	Sundries	L.S>	10.00	10.00	10.00	10.00	10.00
		-	-	-	-	-	-
		Total		2291.00	2145.36	2137.38	2110.69
	Water Charges @ 1%			22.91	21.45	21.37	21.11
		-	-	-	-	-	-
		Total		2313.91	2166.82	2158.76	2131.80
	Contractor's Profit			231.39	216.68	215.88	213.18
	& Overheads @ 10%						

Evaluation of the Measured Values:

On the basis of the results of various investigations into the durability of cover concrete, the following procedure was defined for evaluating the quality of cover concrete* with respect to its durability.

If the measurements are carried out on dry concrete (i.e. the concrete surface has not been contact with water for about two weeks), the quality of the cover concrete can be determined directly from the measured kT values as given in Table 17:

Table 17 : Quality Classes of Cover Concrete

Quality of Cover Concrete	Index	KT (10^{-16} m^2)
very bad	5	>10
Bad	4	1.0-10
Normal	3	0.1-1.0
Good	2	0.01-0.1
Very good	1	<0.01

* Torrent, R.J, Ebensberger L. Studie uber Methoden zur Messung und Beurteilung der Kennwerte des Uberdeckkungsbetons auf der Bundesamt fur Strassenbau, Switzerland, Research Contract No. 89/89, January 1993.

Figure –1 Scanning Electron Micrograph of Dadri fly Ash

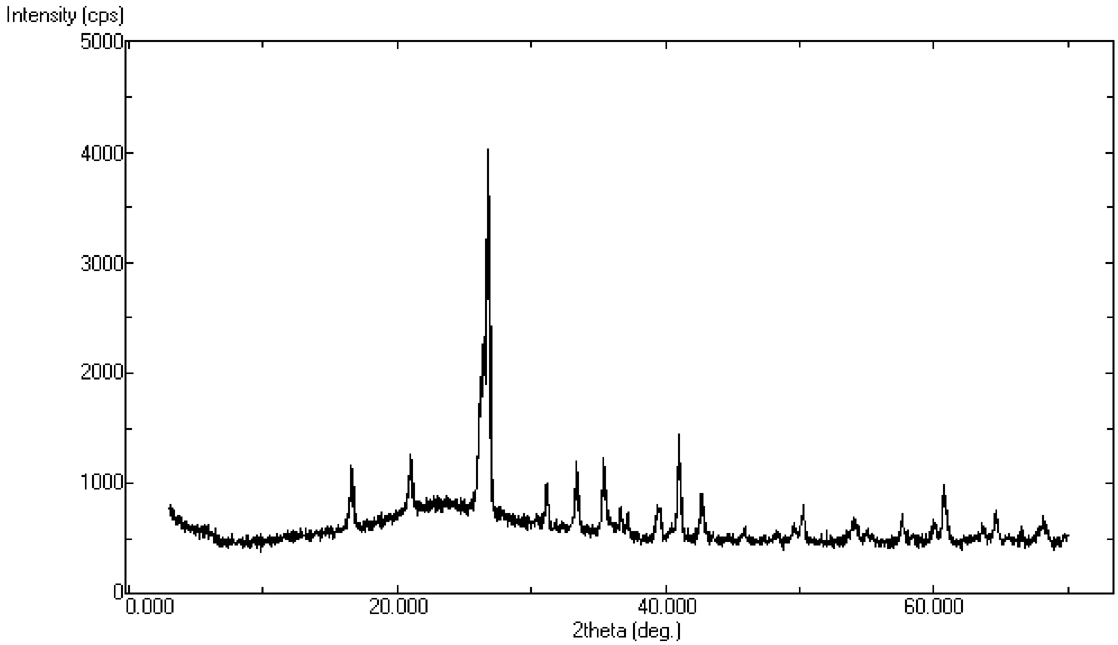
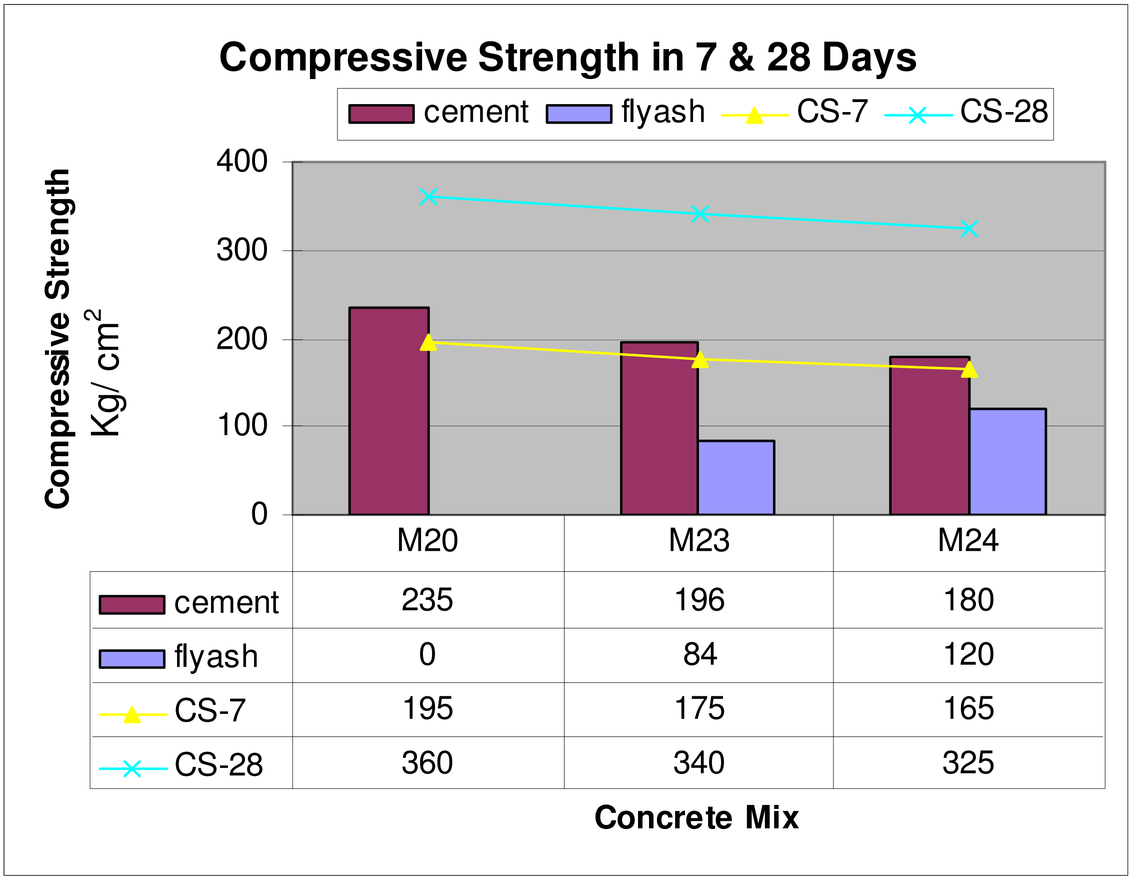
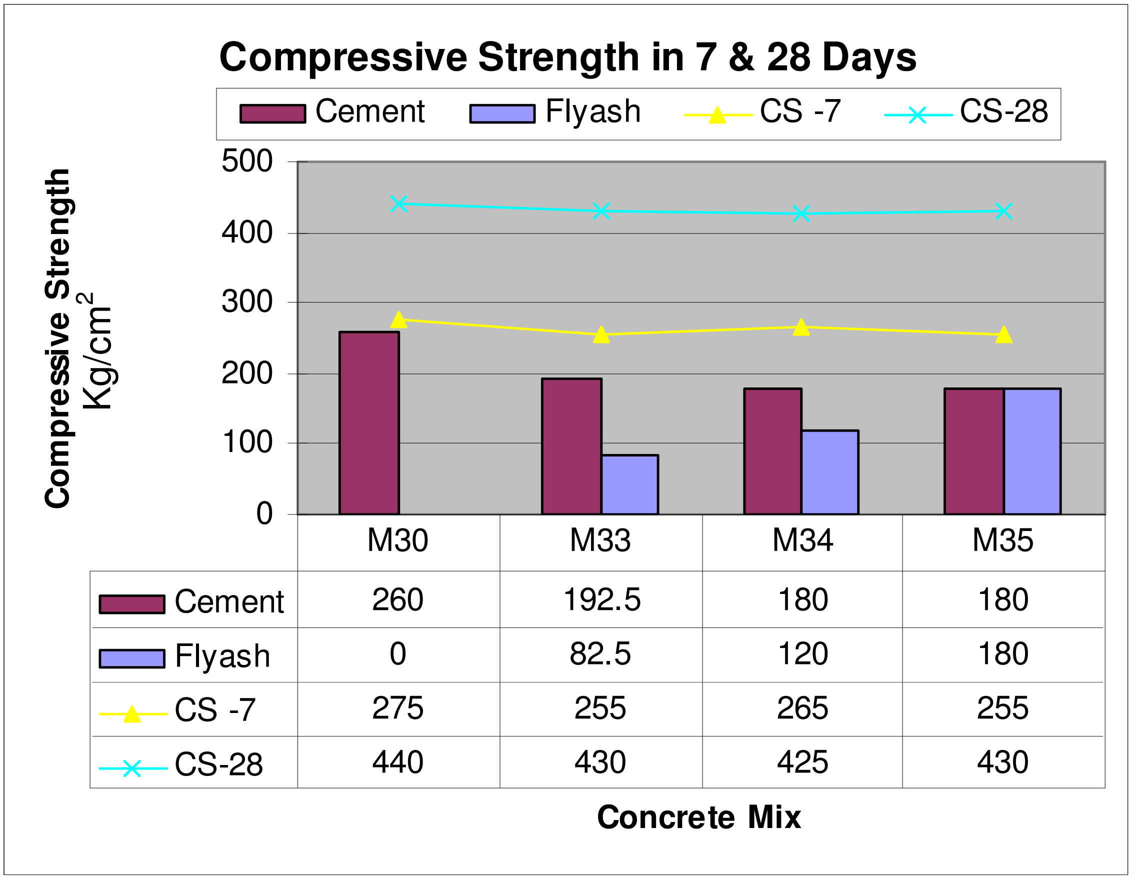


Figure -2 X-Ray of Dadri Fly Ash



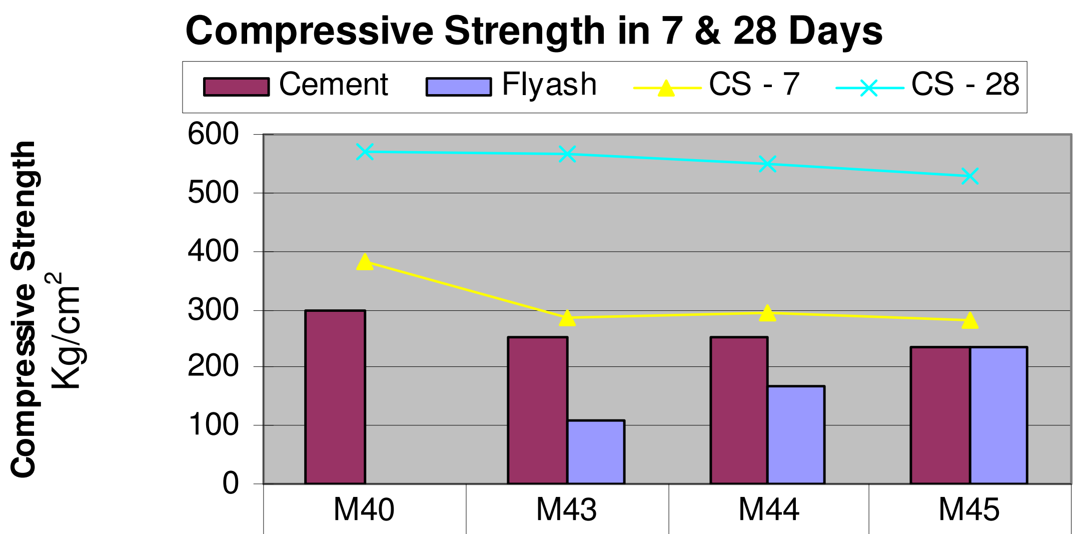
	M20	M23	M24
cement	235	196	180
flyash	0	84	120
CS-7	195	175	165
CS-28	360	340	325

Figure –3 Compressive Strength of M20 grade Concrete With 30%, 40% and Without Fly ash



	M30	M33	M34	M35
Cement	260	192.5	180	180
Flyash	0	82.5	120	180
CS -7	275	255	265	255
CS-28	440	430	425	430

Figure -4 Compressive Strength of M30 grade Concrete with 30%, 40%, 50% and Without Fly ash



	M40	M43	M44	M45
Cement	300	252	252	235
Flyash	0	108	168	235
CS - 7	380	285	295	280
CS - 28	570	565	550	530

Concrete Mix

Figure -5 Compressive Strength of M40 grade Concrete with 30%, 40%, 50% and Without Fly ash

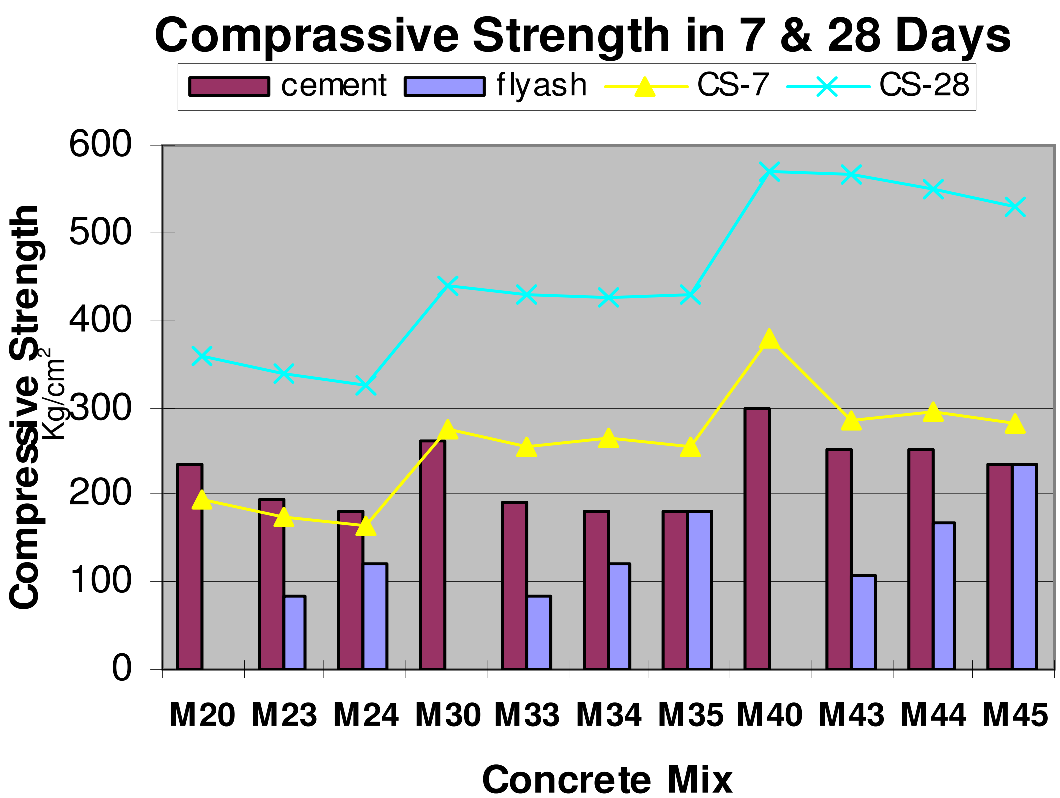


Figure -6 Compressive Strength of M20, M30 and M40 grade Concretes with Various Percentages of Fly ash

Discussion

M20 grade of concrete is lowest grade of concrete, which IS: 456-2000 recommends for use in reinforced concrete construction even for mild exposure condition. Higher grade of concrete is used either due to higher strength requirement or due to worse exposure conditions.

It is clear from the controlled test results shown in Table – 13 that M20, M30 and M40 grade plain concrete (i.e. without fly ash) can be produced with less cement content than the minimum as suggested in IS: 456-2000 in its table 5. In such situations, one has to either overlook the codal provisions or use higher cement content. Higher compressive strength values may be due to high grade of cement used and better controlled conditions in the laboratory. Similarly in case of M30 and M40 grade, compressive strength has been achieved with lower cement content. Replacing a suitable percentage of cement by fly ash can fulfill minimum cement content requirement.

The replacement of cement by fly ash in all the three grades of concrete shows that 28 day strength can be achieved when compared to control concrete.

Fly ash concrete of all grades in Table - 13 has shown improved resistance to chloride ion penetration and reduced water permeability. The use of fly ash influences the physico – chemical effects associated with pozzolanic and cementitious reactions that result in pore size reduction and grain – size reduction phenomena. This affects the rheological behavior of fresh concrete and the strength and durability of hardened concrete. Thus the resistance to chloride ion penetration and reduced permeability can be derived from the use of fly ash as supplementary cementing material.

Cost of fly ash concretes shown in Tables 14 - 16 are lower than the cost of respective plain concrete. Thus, addition of fly ash in concrete, helps in achieving the codal provisions improves durability and reduces the cost of the product.

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