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USE OF FLY ASH AS CEMENTITIOUS MATERIAL IN CONCRETE

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ABSTRACT

Fly ash or pulverized fuel ash is one of the mineral admixtures in concrete, widely used throughout the world. However, very little attention has been paid to the material in Pakistan, though large quantities of it are being wasted in the thermal power stations. The aim of this research was to study the cementitious properties of fly ash sample collected from coal fire station Lakhra District Hyderabad Sindh.

The chemical analysis of fly ash revealed that various constituents are falling in the favourable limits recommended by the American Concrete Association. The effect of cement substitution by fly ash in concrete was studied both in compression and flexure. The level of substitution, a typical primary school with mass construction all over Pakistan was considered. The research has revealed that the compressive strength of concrete has been decreased by merely 15% with half of the cement replaced by fly ash whereas there is an overall saving of 12% in the cost of construction. The behavior of reinforced fly ash added concrete also reflected very slight reduction in the flexural strength of concrete. The results necessitate further research about the various aspects of fly ash available at different thermal Power Stations.

INTRODUCTION MATERIAL

Fly ash: Fly ash or pulverized coal fire ash is collected as by product from the flues of thermal power stations where powdered coal is used as fuel. The sample of fly ash was collected from Lakhra Coal fire power station Sindh.

The chemical analysis of the material was carried out at Lucky Cement factory D.I. Khan as shown in Table 1. The General specification of fly ash are covered by ASTMC-618, where fly ashes have been classified into Category C & F. The fly ash sample has been compared with both these categories as shown in Table 2. The American Concrete Institute has recommended ceratin favourable limits of various ingredients for fly ash to yield high strength. It is interesting to note that most of the constituents of fly ash sample are falling in these limits.

Cement: Ordinary Portland Cement (OPC) of type-I conforming to ASTMC-150 has been used which has been compared with the fly ash in Table 4.

Aggregate: Crushed aggregate has been used from Margalla Hills quarry with sizes between 3/8" to 3/4" whereas sand from Lawrencepur has been used with fineness modulus between 2.5 to 3.0. The gradation of aggregate has been shown in Table 2.

TESTING PROGRAM

Preliminary testing: The initial testing of material both as cement substitute and additive was carried out at Material Testing Laboratory of Communication and Works Department Abbottabad. In these tests 50% and 75% of cement was replaced by fly ash and the results were compared with the controlled mix having no fly ash. The ratios of cementitious material, fine and coarse aggregate was kept as 1:2:4 in all these cases. The 50% replacement of cement by fly ash led to a reduction of merely 15% in the 28 days strength of concrete. Hence detailed investigation was initiated.

Mix Proportioning of fly ash added concrete: Six batches of concrete were prepared such that the

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Table 1. ASTM C-618 Chemical & Physical Properties of Class C & F fly ash

PROPERTIES	CLASS "C"	CLASS "F"
Chemical Properties		
$SiO_2+Al_2O_3+Fe_2O_3$ (Min %)	50	50
Cao (Mm%)	----	----
Mgo (Mm%)	5	4
Available Alkalies as NO_2 (Max%)	-	-
SO_3 (% Max)	5	5
Loss on ignition (%)	6	6
Moisture (Max %)	6	12
Physical Properties		
Fineness (Max % retained on 45 micron sieve)	34	34
Autoclave Expansion (Max %)	0.80	0.80
Pozzalonic Activity Index with Portland Cement 28 days	75	75
Water Requirement (% of controlled Mix)	105	105
Drying Shrinkage (Max %)	0.03	0.03

Table 2. Gradation of course and fine aggregates

COARSE AGGREGATE	
Sieve number	Cumulative Percentage Retained
19 mm	0
12.7	32
9.5	68
4.75	100
Fine Aggregate	
4.75	0.30
2.36	2.60
1.18	5.82
600 micron	28.74
300 micron	68.60
150 micron	92.30
Pan	100

Table 3. Chemical and Physical Properties of fly ash of Lakhra Station compared with ASTM specification and recommendation favorable range

Constituent	Fly ash	ASTM	Favorable range
SiO_2	32 %	-	24.1%-43.1%
Al_2O_3	30.5 %	-	14.3%-27.5%
Fe_2O_3	9.3 %	-	4.2%-9.5%
CaO	12.47 %	-	16.8%-29.5%
MgO	1.04 %	5 % max	3.70%-8.5%
Loss on ignition	14 %	12 %	-
$SiO_2+Al_2O_3+Fe_2O_3$	71.8 %	70 % min	47.9%-27.4%

controlled mix with ratio 1:2:4 had no fly ash. The remaining batches of concrete were prepared in the nominal ratios as 1:2:4, 1:2:3, 1:2:2, 1:1-1/2:3, and 1:1-1/2:2 but in all these mixes 50% of cement was replaced by fly ash. The water to cementitious material ratio in all cases was kept as 0.5 as hand mixing

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Table 4. Comparison of chemical properties of cement and fly ash of Lakhra Station

Constituent	Fly ash	ASTM
SiO_2	20.57 %	32 %
Al_2O_3	5.25 %	30.5 %
Fe_2O_3	3.53 %	9.3 %
CaO	64.03 %	12.47 %
MgO	2.31 %	1.04 %
$SiO_2+Al_2O_3+Fe_2O_3$	29.35 %	71.80%min

was done. Concrete cylinders of 15 cm x 30 cm were prepared and tested at 7, 14 and 28 days. The details of mix proportioning and compressive strength of these various mixes of concrete are shown in Table 5 and Fig. 1.

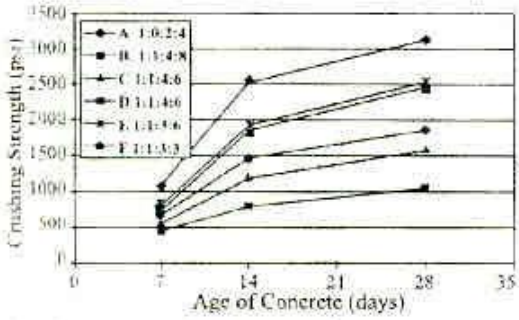

Fig.1 Graph showing the variation in the compressive strength of fly ash added concrete for different mixes

Testing of fly ash added concrete in flexure: Based on the results of mix proportioning of fly ash added concrete the nominal ratio of 1:2:4 was adopted to study the material in flexure. Six beams of 15 cm X 30 cm (6" x 12") area, and length 210 cm (7'-0") with reinforcement of 6-1/2" diameter bars were prepared. The concrete ratio was kept as 1:2:4 but in three beams 50% of cement was replaced by fly ash. the beams were tested after 28 days under concentrated loads that were gradually increased to 10 KN and the corresponding deflections were also observed. The details of loads and deflection for all six beams are shown in Figs. 2 & 3.

Cost implication of using fly ash added concrete: The saving in the cost of concrete with 50% replacement of cement by fly ash comes directly as the cost replaced cement. To study the saving in the cost of construction with the use of fly ash in concrete, a typical Govt. Girls Primary School was taken and the bill of quantities of all items is shown in the Figure.

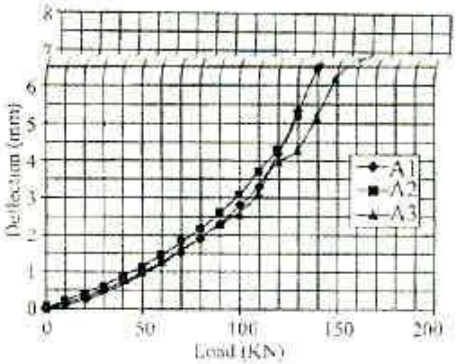

Fig.2 Load deflection curves for plain concrete beams

From all items of work where cement is used, its quantity is determined with the help of WAPDA schedule of Material and labour. With 50% replacement the quantity and cost of cement is calculated as shown in Table 7 & 8. It reveals that an overall saving in the cost of construction is about 12% i.e. for every 100 schools we can get 12 additional schools as free of cost.

OBSERVATIONS AND DISCUSSIONS

The 28 days compressive strength of concrete 1:2:4 with no fly ash comes to 21.64MPa (3131 psi) which decreases with the 50% replacement of cement by fly ash to 16.76MPa (2433psi) i.e. only 22%. The 28 days compressive strengths for other fly ash added mixes i.e. 1:1-1/2:3, 1:3:3, 1:2:2 and 1:1-1/2:2 comes out to be 17.445MPa (2532psi), 13.118MPa(1904psi), 10.49MPA (1588psi), 7.241MPa (1051psi), and 12.815MPa (1860psi) respectively. The strength of 1:1-1/2:3 fly ash added concrete is slightly more than 1:2:3 and 1:2:2 the strength has been considerably decreased though the quantity of cementitious material is the same. Thus sufficient coarse aggregate must be available in the mass of concrete.

The reinforced concrete beams with no fly

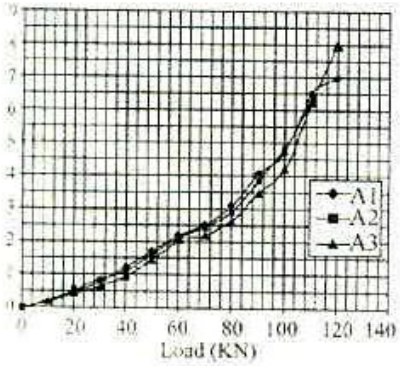

Fig.3 Load deflection curves for fly ash added Concrete Beams

ash failed at concentrated loads of 130, 160 & 142 KN against the theoretical capacity of 112KN whereas the fly ash added reinforced concrete beams failed at 112, 115, and 110KN against the theoretical values of 102KN. The load deflection tables show that the deflections of fly ash added beams are more for equal loads when compared with other beams. The load deflection curves show that the linearity is best exhibited in the range from 33% to 80% of failure load

CONCLUSIONS AND RECOMMENDATIONS

- A large volume of literature is available about the various aspects of fly ash used as additive and substitute of cement but in PAKISTAN very little attention has been paid to this material. The material is abundantly available throughout the country but its successful use, as concrete admixture requires developing local specification and standardization for material. Hence extensive research is required to be carried out about various types and forms of fly ashes available at different coal fire stations.

- The current research aimed at addressing this problem and fly ash sample was col-

Table - 5. Mix proportioning of fly ash added concrete.

BATCH	A	B	C	D	E	F
Cement (Kg/m³)	345	172.5	201	241	219	268
Fly Ash (Kg/m³)	0	172.5	201	241	219	268
% Replacement of cement	0	50	50	50	50	50
Fine Aggregate (Kg/m³)	690	690	805	966	658	895
Coarse Aggregate (Kg/m³)	1380	1380	1206	966	1316	1074
Water Cement Ratio	0.5	0.5	0.5	0.5	0.5	0.5
Slump (in)	3"	2.5"	2.75"	2.5"	2.5"	2.75"
Cement: Fly ash: Sand: Aggregate	1:0:2:4	1:1:4:8	1:1:4:6	1:1:4:4	1:1:3:6	1:1:3:4
(Cement Mat): Sand: Aggregate	1:2:4	1:2:4	1:2:3	1:2:2	1:1 1/2:3	1:1 1/2:2
Cylinder Strength (psi) 7 days	1056	752	541	427	797	641
14 days	2524	1825	1177	778	1904	1452
28 days	3141	2433	1588	1051	2532	1860
% Reduction in the compressive strength	0	22	49	66	19	41

Table - 6. Comparison of deflection for equal loads in plain and fly ash added concrete beams

Load (KN)	Plain Concrete Deflections (mm)				Fly Ash Added Concrete Deflections (mm)			
	Beam A1	Beam A2	Beam A3	Avg.	Beam B1	Beam B2	Beam B3	Avg.
0	0	0	0	0	0	0	0	0
10	0.16	0.18	0.14	0.16	0.20	0.17	0.15	0.17
20	0.31	0.38	0.31	0.33	0.49	0.54	0.43	0.48
30	0.51	0.62	0.52	0.55	0.78	0.82	0.65	0.75
40	0.75	0.88	0.77	0.80	1.20	1.07	0.95	1.07
50	1.02	1.16	1.00	1.06	1.7	1.60	1.43	1.58
60	1.28	1.48	0.31	1.36	2.20	2.10	2.05	2.12
70	1.55	1.82	1.71	1.69	2.50	2.43	2.19	2.40
80	1.93	2.18	2.03	2.04	3.08	2.91	2.65	2.88
90	2.30	2.63	2.30	2.41	4.05	3.85	3.45	3.78
100	2.84	3.11	2.60	2.85	4.70	4.80-	4.20	4.57
110	3.32	3.71	3.16	3.39	6.50	6.32	6.25	
120	4.20	4.35	4.00	4.28	7.00(112)		8.00(115)	
130	5.30	5.22	4.30	5.14				
140	-	6.50	5.20	-				
150	-		6.20	-				
160	-		6.80	-				
169	-		6.80	-				

lected from coal fire power station lakhra Sind. The research gave very good initial results for use as both additive and cement substitute.

- The chemical analyses of fly ash shows that almost all the ingredients fall in the favourable range recommended by American Concrete Institute for successful use of fly ash. The fly ash substitution of cement by fly ash for concrete 1:2:4 is materialized. The 28 days strength of fly ash concrete comes in the range of 362.844MPa or 2500psi which is regarded as a suitable value for structures where the strength of the concrete is not of prime importance.

- The behavior of fly ash added concrete was analyzed in flexure and it is very interesting to note that the actual failure loads are falling very closed to the theoretical values. It is safely concluded that the formula for the flexure capacities of ordinary cement concrete can be easily applied to the fly ash added concrete. However further research is required for studying the shear and torsional

Table - 7. Bill of quantities of the construction of a girl primary school under primary education Programme (1995-2000)

S. No	DESCRIPTION	QTY	RATE	AMOUNT (RS)
1	Excavation in Foundation	92.91 m	19.94	1853
2	PCC 1:4:8 as in foundation	24.43 m	550	13437
3	B.B masonry in cement mortar 1:6	62.97 m	790	49746
4	Providing DPC 1-1/2" thick	63.05 m	80	5044
5	Random Rubble stone masonry	57 m	530	30210
6	B.B. masonry in super structure in mortar	70.55 m	810	57145
7	R.C.C (1:2:4) in slab & beams	20.70 m	1415	29293
8	Supply & Fabrication of Steel	1.78 T	20000	35663
9	Cement Plaster (1:4)	457.83 m	26	11904
10	Cement pointing	418.4 m	25	10406
11	P.C.C (1:4:8) under floors	9.66 m	550	5313
12	Floor stopping (1:2:4) 2" thick	98.79 m	90	8891
13	Joinery steel of approved design	21 m	1062	22302
14	Notice board in cement mortar 1:3	4.46 m	123	549
15	P.C.C 1:3:6 as in plinth protection	7.07 m	710	5020
16	White washing 3 coats	457.83 m	5	2289
17	Leveling and Dressing	92.75 m	31.66	3000
18	Roof insulation of brick tiles grouted	106.5 m	140	14910
19	S & F of steel gate of approved design	4.46 m	1063	4740
			Total	Rs 311815/-
	Add 75% above the schedule rates:	Rs: 233861/-		
	Total Cost of main Building	Rs 545676/-		

capacities for flay ash added concrete structures.

- The saving in the cost of construction with the substitution of cement by fly ash reflects that the material can be easily used in the far-flung areas in the construction of education and health buildings in the vicinity of the coal fire power stations.

RECOMMENDATIONS

- For successful use of fly ash available at different power stations, it is recommended that stage wise extensive study about all the fly ashes available in the country may be adopted to develop the local standards and classification of materials.
- The saving in the cost of construction with

Table - 8. Quantity of cement in various items of work in a typical Girls Primary School

S.No	DESCRIPTION	QTY	Cement Bags	Total (Bags)
1	Excavation in Foundation	92.91 m		
2	PCC 1:4:8 as in foundation	24.43 m^3	3.4/m^3	83.00
3	B.B masonry in cement mortar 1:6	62.97 m^3	1.26/m^3	79.34
4	Providing DPC 1-1/2" thick	63.05 m^2		
5	Random Rubble stone masonry	57 m^3	1/m^3	57.00
6	B.B. masonry in super structure in mortar	70.55 m^3	1.26/m^3	88.90
7	R.C.C. (1:2:4) in slab & beams	20.70 m^3	6/m^3	124.20
8	Supply & Fabrication of Steel	1.78 T		
9	Cement Plaster (1:4)	457.83 m^2	13%/m^2	59.52
10	Cement pointing on brick wall	418.4 m^2	3%/m^2	12.55
11	P.C.C (1:4:8) under floors	9.66 m^3	3.4/m^3	32.84
12	Floor stopping (1:2:4) 2" thick	98.79 m^2	20%/m^2	19.76
13	Joinery steel of approved design	21 m^2		
14	Notice board in cement mortar 1:3	4.46 m^2	17%/m^2	0.75
15	P.C.C 1:3:6 as in plinth protection	7.07 m^3	4.4/m^3	31.11
16	White washing 3 coats	457.83 m^2		
17	Leveling and Dressing	94.75 m^2		
18	Roof insulation of brick tiles grouted	166.5 m^2		
19	S & F of steel gate of approved design	4.46 m		
20	Total No. if cement bags			589 Bags
	Total cost cement @ Rs 225/ bag			Rs 132585
	With 50% replacement by fly ash saving = Rs 66292			
	% Saving in cost of construction = 66292/545676 = 12 %			

the use of fly ash necessitate the study of materials for use in low cost housing schemes which are being launched in the social sector so that shelters is provided to the Non-privileged segment of society.

- With initial data available from the research about the flexure strength of fly ash added concrete it is required to study the materials in flexure shear and torsion under various categories of loads.
- The Nation Building departments, which are closely associated with the construction of basic buildings for education, health care, women development are required to use the materials in the construction of these units. In this connection care needs to be taken till

necessary alternations in the specification for different works are being formalized by various concerned departments.

- Further research is also recommended to bring more economy in the cost of construction by studying the combination of fly ash added concrete with brickbats and other cheap materials.

- In hydel power generation, where construction of small hydel dams seems to be the ultimate solution to fight the energy crisis. The Small Hydel Dams Authority (SHYDA) responsible for the construction of such dams is required to study the use of material in mass concrete required for the construction of gravity structures.

- The material can also be used as additive with cement and clay to improve the lining of irrigation canals. Due to its cementitious properties, erosion of canals can be subsided to greater extent thus increasing its efficiency.

- Though the fly ash has shown some cementitious properties when used as admixture in concrete, yet the long term effect on cohesion or mortar paste is required to be studied.

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