Effect of Fly Ashes From Different Sources on the Performance of Concrete

by

Erdem Tandırlı, Özlem Akalın , Emin Arca

ABSTRACT

Fly ash is a waste product from coal based thermal power stations. About seven million tons of fly ash is being waste annually from power stations in Turkey. Therefore concerted efforts are needed to increase its use in the concrete industry.

In this research, fly ashes from different sources were compared. In the first test stage water-cementitious materials ratio was kept constant and each different source of fly ash sample was added to the mixture with an incremental rate starting from 0% to 25%. Slump, slump retention and compressive strength values at different ages were found from this stage. In the second stage one fly ash showed optimum performance in the first stage was tested to find the different water-cementitious materials ratios, with varying fly ash substitution rates. Both the fresh and the hardened concrete properties were measured. Equations were obtained empirically for each experimental stage by using linear multiple regression method. The actual compressive strength values were compared to the predicted values.

Keywords : concrete, fly ash, mineral admixture .

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INTRODUCTION

Fly ash is a by-product of the combustion of coal. It is hazardous and expensive to dispose of and hence is a threat as an environmental pollutant. However, the blends of fly ash with the cement supply economical and energy benefits. Physically, fly ash is composed of small, glassy, spherical particles. Both the chemical and physical nature of fly ash improves the quality of the blended portland cement concrete (1). Fly ash is also pozzolanic, so its chemical constituents react with free lime present in the portland cement concrete to produce an ultimately stronger concrete. The presence of fly ash in portland cement concrete has also been noted to decrease the overall heat of hydration, improve the workability, reduce concrete bleeding, and increase the concrete's resistance to chemical attack and corrosion. However, fly ash can result in a decreased early strength and air content problems when compared to conventional portland cement concrete. (2)

One of the most influential variables determining the chemical composition of fly ash is the type of coal burned to produce the fly ash. There are three primary types of coal used in electric generating plants. Each type depends on the content of burnable material and the energy-producing potential of the coal (3).

Fly ash is generally divided into two types: Class C and Class F. Ashes resulting from the burning of sub-bituminous and lignitic coals are high calcium (ASTM Class C) fly ash. This type of ashes possess relatively high concentrations of lime and are often self reactive in the presence of water. The low-calcium fly ashes (ASTM Class F) contain significantly less lime than ASTM Class C ashes, and have been used more often in the construction industry todate although both ashes show great promise for use in the cement and concrete industry. The type of fly ash used in the manufacture of cement will greatly alter the end result (4).

The chemical and mineral compositions of fly ash are directly related to the geologic and geographic factors of the coal burned (5).

EXPERIMENTAL PROGRAM

Materials

Cement The cement used was Turkish, Portland cement (PC 42,5) and conforms to ASTM C 150-89 Type 1 (6). The properties of cement are given in Table 1.

Fly Ashes Fly ashes were supplied from four different thermal power plants using lignite, namely Seyitömer, Çayırhan, Orhaneli and Çatalağzı. Their chemical compositions and physical properties are given in Table 2. (ASTM C 618-94) (7).

Chemical Admixtures Two types of chemical admixtures were used. One of them was lignosulphonate based normal plasticizer and the other was naphthalene-based superplasticizer They comply with ASTM C 494-98 Type A and Type F, respectively (8).

Aggregates The coarse aggregates were two kinds of crushed limestone maximum sizes of which were 20 mm. and 10 mm., while the fine aggregates were siliceous sand and manufactured sand, source of which was again limestone.

TEST MIXTURES

This experimental study was conducted at two following stages. At the first stage the water-cementitious materials ratio (cement and fly ash) was kept constant and fly ashes come from four different sources were added to concrete mixtures in varying dosages starting from 0% to 25% by 5% increments. Water-cementitious materials ratio was kept constant at 0.58 and concrete mixtures were prepared by using lignosulphonate based normal plasticizer at different dosages. For each mixture the air content and the slump loss were measured at every 15 minutes period up to 45 minutes. Hardened concrete samples were tested for the compressive strengths at 1 day, 3 days, 7 days, 28 days and 56 days. See Table 3 and Table 4 for the mixture content, fresh and hardened concrete properties, respectively. By using linear regression method, coefficients were obtained for choosing specific surface of fly ash and substitution percentage as variables and the results are given in Table 5. The actual and predicted values of the concrete strengths from these equations are given in Table 6 for different ages of concrete.

At the second stage of the study, Orhaneli fly ash was chosen as optimum test sample due to its better slump retention with higher compressive strength values from previous stage. In this mixture series lignosulphonate based normal plasticizer or naphthalene based superplasticizer admixture was used at 0.4 % and 1.5%, respectively depending on the water-cementitious materials ratio ratio. Mixture content of the series was given in Table 7 and fresh and hardened concrete properties were given in Table 8.

At the second stage water cement ratio and fly ash substitution percentage were taken as variables for linear regression method. The coefficients of the equations, and the actual and predicted values of the concrete strengths for different ages of concrete are given in Table 9 and Table 10 respectively.

TEST RESULTS

At the first stage of the program four different kinds of fly ashes were tested at the constant water-cementitious materials ratio ratio of 0.58. In this series only normal plasticizer based on lignosulphonate was used and the range of 0.4%-0.8% to adjust the initial slump value of the reference. The fly ash amount was increased starting from 10% to 25% by 5% increment steps. For each of the sample series reference mixtures were prepared without the fly ash.

In the first series of the experiment ' Seyitömer ' (se) fly ash was tested in the concrete mixture. In this series although the amount of the normal plasticizer was increased, initial slump was also decreased from 20 cm to 11cm respectively. Slump losses were reached to the value of 11 cm (for se4 series) from 16 cm (for se1 series) after 45 minutes. The compressive strength values of the series decreased while the fly ash addition was increased.

The fresh concrete properties and hardened concrete properties were given in Table 3 and 4, respectively.

The second fly ash sample was from 'Orhaneli ' (or) tested with the same method. The initial slump of the concrete mixtures was increased from 21 cm (or1 series) to 23 cm (or3 series) due to the effect of plasticizer used in the mixture when the fly ash dosage was increased in each series.

' Çatalağzı ' (ct) was the third fly ash sample in this program. The initial slump values increased when the fly ash substitution with cement was increased. The highest values for the initial slumps were found only in this series. The initial slump was 21 cm for the reference of this series. However, the initial slump was reached to 28 cm. at 25 % fly ash substitution. The slump losses were found as 4 cm. both of the reference and 25 % fly ash substitution.

The last fly ash sample supplied from ' Çayırhan ' (çy) and the initial slump increased from 21 cm to 23 cm when 25% fly ash was substituted in concrete mixture. Also the slump loss increased from 4 cm (for reference) to 7 cm (çy4 series) when 25% fly ash was added.

In the second part of the experimental program the 'Orhaneli' (or) fly ash sample was taken due to the its good performance in the concrete mixtures. The fly ash substitution rate and water binder ratio varied from 0 % to 25 % and 0.35 to 0.60, respectively while keeping the fly ash source constant. In this part of the experimental program two kinds of plasticizers were used. For the first two groups (A, B in Table 6) lignosulphonate based normal plasticizer and for the other groups (C and D in Table 6) naphthalene based superplasticizer were used as chemical admixture. The initial slump values were found as 18-19 cm for the series A, B and C. In Group D, the initial slumps were changed from 22 cm (for D1 series) to 28 cm (for D5 series). Moreover, the series D4 and D5 showed segregation due to decrease of the fineness.

DISCUSSION

In this study different sources of fly ash were tested for the substitution of cement in varying percentages. One of the sources (Seyitömer) caused slump loss due to the plero-spherical grains of the material while the others improved workability.

Increasing substitution ratio of fly ash worsened increase the slump loss especially in 45 minutes for Seyitömer and Çayırhan while the others kept their initial state.

Up to 25 % replacement of the fly ash gave reasonable results. Above the 0.60 water-cementitious materials ratio ratio with the high fly ash substitution (20% and 25%) caused to the segregation due to the decrease of the fineness.

Depending on the chemical and physical properties of the fly ashes the initial slump and slump loss were changed at the same fly ash substitution rate.

Multiple linear regression method was used to estimate the parameters of the equations by using the predicted and actual values were given in Table 5 and Table 8. The percent error between the predicted and actual values was changed in the range of 0 – 10 %.

CONCLUSION

As a result of this research almost seven million tons of fly ash can be replaced with cement in Turkey with regarding its source. Since the fly ash surface area is coarser than the cement, initial slumps got even higher with the increasing substitution rate.

The further slump loss value obtained from Seyitömer Fly Ash was due to the plero-spherical grains of the material is quite unstable microstructure (6).

As the substitution percentage of the fly ash got higher, the compressive strength values generally decreased, at constant water-cementitious materials ratio.

The equations obtained by applying the multiple regression may give some forecasting of the usage of fly ash in concrete before planning the new system based on the substitution of the fly ash.

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Table 1 . Properties of the Cement

Chemical Composition		
Components, %	PC 42.5	ASTM Type 1
SiO_2	21.16	
Al_2O_3	3.60	
Fe_2O_3	4.50	
CaO	64.90	
MgO	1.20	6 max.
SO_3	1.97	3 max.
$Na_2O + 0.658\ K_2O$	0.00	0.6 max.
Insoluble Residue	0.83	0.75 max.
Loss on Ignition	1.15	3 max.
Principal Compounds		
C_3S	64.27	-
C_2S	11.11	-
C_3A	1.93	-
C_4AF	13.69	-
Physical Properties		
Specific Gravity	3.12	-
Specific Surface, cm^2/gr	3268	2800 min.
Setting Times		
İnitial, minutes	195	45 min.
Final, minutes	216	375 max.
Mechanical Properties		
Compressive Strength, MPa		
1 day	16.6	
2 days	27.1	
7 days	44.2	19.3
28 days	-	27.6

Table 2. Properties of the Fly Ashes

Chemical Composition					
Components, %	Seyitomer (F1)	Orhaneli (F2)	Catalağzı (F3)	Cayırhan (F4)	ASTM C 618 Class C
SiO_2 , (S)	50.05	32.50	59.4	48.65	
Al_2O_3 , (A)	8.65	9.89	23.83	18.66	
Fe_2O_3 , (F)	5.85	11.88	2.33	6.34	
Total S+A+F	64.5	54.2	85.5	73.6	50.5 min.
CaO	23.65	35.05	7.84	19.18	-
MgO	2.83	1.55	1.34	1.77	5.0 max.
SO_3	-	0.41	0.46	-	5.0 max.
Na_2O + 0.658 K_2O	4.22	3.04	3.42	3.70	1.5 max.
Insoluble Residue	-	-	-	-	-
Loss on Ignition	3.87	1.85	1.38	0.78	6.0 max.
Physical Properties					
Specific Gravity,	1.99	2.65	1.93	2.27	
Specific Surface, cm^2/gr	3889	5952	1660	2990	
Amount retained on 45-µm sieve, %	36.5	35.2	55.3	51.1	34.0 max.
Mechanical Properties as Pozzolanic Activity, (of mortar with lime at 7 days)					
7 days, MPa	13.9	12.3	8.5	9.4	5.5

Table 3. The Mixture Content of the Series

Code	Source	water (lt.)	cement (kg)	fly ash (kg)	w/b	fly ash (%)	chemical admixture (%)
Reference		198	342	0	0,58	0	0,4
se1	Seyitömer	198	308	34	0,58	10	0,8
se2	Seyitömer	198	291	51	0,58	15	0,6
se3	Seyitömer	198	274	68	0,58	20	0,6
se4	Seyitömer	198	257	86	0,58	25	0,6
Reference		198	342	0	0,58	0	0,4
or1	Orhaneli	198	308	34	0,58	10	0,4
or2	Orhaneli	198	291	51	0,58	15	0,4
or3	Orhaneli	198	274	68	0,58	20	0,6
or4	Orhaneli	198	257	86	0,58	25	0,4
Reference		198	342	0	0,58	0	0,4
çt1	Çatalağzı	198	308	34	0,58	10	0,8
çt2	Çatalağzı	198	291	51	0,58	15	0,6
çt3	Çatalağzı	198	274	68	0,58	20	0,6
çt4	Çatalağzı	198	257	86	0,58	25	0,6
Reference		198	342	0	0,58	0	0,4
çy1	Çayırhan	198	308	34	0,58	10	0,4
çy2	Çayırhan	198	291	51	0,58	15	0,4
çy3	Çayırhan	198	274	68	0,58	20	0,6
çy4	Çayırhan	198	257	86	0,58	25	0,4

Table 4. The Fresh and Hardened Concrete Properties

Code	Source	slmp0' (cm)	slmp30' (cm)	slmp45' (cm)	Compressive Strength (Kgf/cm²)				
					1 day	3 days	7 days	28 days	56 days
Reference		20,0	17,0	16,0	192	274	359	451	513
se1	Seyitömer	15,0	13,0	11,0	162	263	373	470	532
se2	Seyitömer	15,0	11,0	10,0	146	207	347	450	522
se3	Seyitömer	13,5	10,0	8,0	134	201	290	482	505
se4	Seyitömer	11,0	7,0	0,0	122	187	267	443	468
Reference		20,0	17,0	16,0	192	274	359	451	513
or1	Orhaneli	21,0	19,0	18,0	159	194	281	401	455
or2	Orhaneli	20,0	17,0	15,5	152	180	263	392	450
or3	Orhaneli	23,5	21,0	20,0	126	165	243	386	440
or4	Orhaneli	19,0	16,0	15,0	112	150	232	339	429
Reference		21,0	19,0	17,0	135	219	338	427	512
çt1	Çatalağzı	24,0	22,0	21,0	127	170	358	448	489
çt2	Çatalağzı	25,0	20,0	19,0	133	180	325	430	469
çt3	Çatalağzı	24,0	21,0	19,0	104	200	274	377	422
çt4	Çatalağzı	28,0	25,0	24,0	72	150	237	332	400
Reference		21,0	19,0	17,0	135	219	338	427	512
çy1	Çayırhan	22,0	17,0	16,5	135	183	305	436	482
çy2	Çayırhan	23,0	19,0	17,5	118	155	278	388	443
çy3	Çayırhan	21,0	19,0	18,0	107	158	258	380	415
çy4	Çayırhan	23,0	18,0	16,0	115	135	234	351	383

Table 5. The Coefficients of the Equation for Different Fly Ash Series

	1 day	3 days	7 days	28 days	56 days
A	135,58	218,26	378,54	471,84	512,77
B	0,0086	0,0055	-0,0052	-0,0013	0,0019
C	-235,27	-311,35	-439,93	-356,01	-370

Y = A + B X1+ C X2

X1 = Specific surface of fly ash (m²/gr)
X2= Fly ash substitution percentage (%)

Table 7. The Mixture Content of the Series

Code	Source	water (lt.)	cement (kg)	fly ash (kg)	w/c	w/b	fly ash (%)
A1	Reference	190	424	0	0,45	0,45	0
A2	Orhaneli	186	390	44	0,48	0,43	10
A3	Orhaneli	186	372	68	0,50	0,42	15
A4	Orhaneli	199	348	92	0,57	0,45	21
A5	Orhaneli	205	328	114	0,63	0,46	26
B1	Reference	192	296	0	0,65	0,65	0
B2	Orhaneli	185	268	34	0,69	0,61	11
B3	Orhaneli	184	254	50	0,72	0,61	16
B4	Orhaneli	186	242	62	0,77	0,61	20
B5	Orhaneli	186	228	80	0,82	0,60	26
C1	Reference	166	515	0	0,32	0,34	0
C2	Orhaneli	169	448	56	0,38	0,35	11
C3	Orhaneli	163	434	80	0,38	0,33	16
C4	Orhaneli	166	414	106	0,40	0,33	20
C5	Orhaneli	167	388	132	0,43	0,34	25
D1	Reference	169	302	0	0,56	0,57	0
D2	Orhaneli	155	270	34	0,57	0,52	11
D3	Orhaneli	168	256	48	0,66	0,57	16
D4	Orhaneli	175	242	60	0,72	0,59	20
D5	Orhaneli	170	227	76	0,75	0,58	25

Table 8. The Fresh and Hardened Concrete Properties

Code	Source	slmp0' (cm)	slmp30' (cm)	Compressive Strength (Kgf/cm²)		
				3 days	7 days	28 days
A1	Reference	17,0	13,0	288	407	466
A2	Orhaneli	18,0	16,0	274	384	470
A3	Orhaneli	18,0	15,0	267	377	491
A4	Orhaneli	18,0	16,5	296	376	479
A5	Orhaneli	19,0	18,0	288	373	458
B1	Reference	19,0	17,0	201	269	361
B2	Orhaneli	18,5	17,0	195	265	355
B3	Orhaneli	18,0	16,0	200	244	346
B4	Orhaneli	-	-	195	252	330
B5	Orhaneli	19,0	17,0	165	218	305
C1	Reference	-	-	398	507	588
C2	Orhaneli	-	-	374	480	575
C3	Orhaneli	18,0	15,0	453	477	601
C4	Orhaneli	18,0	15,0	357	487	572
C5	Orhaneli	-	-	353	444	576
D1	Reference	22,0	19,0	228	247	402
D2	Orhaneli	23,0	21,0	223	303	393
D3	Orhaneli	23,0	21,0	218	259	384
D4	Orhaneli	27,0	27,0	214	218	328
D5	Orhaneli	28,0	28,0	188	170	301

Table 9. The Coefficients of the Equation for One Fly Ash Series

	3 days	7 days	28 days
A	629,37	820,49	908,98
B	-701,78	-915,82	-902,45
C	-97,09	-212,64	-169,12

Y = A + B X1+ C X2

X1 = water cement ratio
X2= Fly ash substitution percentage (%)

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