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International Journal of Current Research
Vol. 8, Issue, 11, pp.40944-40948, November, 2016

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

EFFECTS OF FLY ASH AND BLAST FURNACE SLAG AS THE POZZOLAN MATERIAL IN CONCRETE PRODUCTION

[1,*]Can Burak Sisman and [2]Yusuf Yılmaz

[1]Namık Kemal University, Agricultural Faculty, BiosystemEngineering Department
[2]Sultanbeyli Technical andIndustry Vocational High School

ARTICLE INFO

Article History:
Received 17th August, 2016
Received in revised form
09th September, 2016
Accepted 23rd October, 2016
Published online 30th November, 2016

Key words:

Concrete,
Fly Ashe,
Blast Furnace Slag,
Additive.

ABSTRACT

In this study, the effects of ash and slag on the physical and mechanical properties of the concrete were investigated experimentally, and the change in the cost of concrete was examined. For this purpose, concrete samples containing a series of standard concrete, 3 series of ash and 2 series of slag were poured. As a result of the study, ash and slag generally increased the beginning and ending of setting times. It was observed that both pozzolan materials increased the workability of fresh concrete and decreased the hydratation heat.In concrete compressive strength, it was observed that the ash and slag replacement decreased the strength at early ages and caused a higher concrete strength at older ages.

Citation: Can Burak Sisman and Yusuf Yılmaz, 2016. "Effects of fly ash and blast furnace slag as the pozzolan material in concrete production", *International Journal of Current Research*, 8, (11), 40944-40948.

INTRODUCTION

Natural resources are largely used and consumed in the production of concrete which is the most commonly used material in the construction industry. This utilization also leads to various environmental problems (Yılmaz 2013). In recent years, different waste materials have begun to be used in concrete production especially because of the environmental problems arising in cement production.Nowadays, especially pozzolanic materials are used widely in the production of concrete, and concrete with different properties can be produced for its intended uses.Pozzolans are the materials with a binding feature that are used in different ratios as cement-displacement in the concrete.It usage rates range from 15% to 40%(Şimşek 2004, Gündeşli 2008, Şişmanand Gezer 2011).

In concrete, the use of pozzolan; (Bilgen et al. 2010)

- improves workability,
- increases the resistance against sulfate effect,
- reduces the heat of hydration,
- decreases the harmful effect of alkali - aggregate reaction,
- decreases the thermal shrinkage,
- decreases the cost.

Corresponding author: Can Burak Sisman,
Namık Kemal University, AgriculturalFaculty, Biosystem Engineering Department.

Pozzolans are divided into two as natural and artificial. Natural pozzolans are the materials that have basically undergone changes in some degree and are usually composed of sedimentary rocks of volcanic origin. The fly ashes (FA) releasing from thermal power plants, slag (BFS), silica fume and rice husk ash occurring in steel production can be given as the examples of artificial pozzolans (Cil 2003). Nowadays, especially fly ash (FA) and blast furnace slag (BFS) among pozzolan materials are used in almost all concrete productions. Fly ashes (FA) are micron-sized ash particles that are entrained with the flue gasses by the combustion of low-calorie lignite coals burned during the production of electricity in thermal power plants and the exit to theatmosphere of which is prevented by keeping with the help of electro filters, and are industrial wastes.The composition and physical properties of the FAs vary depending on the characteristics and composition of the coal burned in the thermal power plant, combustion temperature and collection method (Tokyay 2013).As a result of the oil crisis that began in the 1970s in the world, studies for the use of FAs have increased and are still continuing. When physical, chemical and mineralogical properties of FA are examined, it is seen that they can easily be used in the construction industry, and hence the economy is ensured in the material and energy production, and also the prevention of environmental pollution and protection of the ecological balance are possible (Unal and Uygunoglu 2004).

Table 1. Physical properties of FAs

Diameter (µm)	Shape	Color	SpecificGravity (gr/cm^3)	Finess
1-200	Circular	Grey	2.2-2.7	SametotheCement

Blast furnace slag (BFS) is waste generated during steel production. The iron oxide (mineral ore, pellets, sinter), flowability regulators (limestone, dolomite), and fuel (coke) are used in furnaces at high temperatures used in iron-steel production. As a result of the production process, molten iron collected in the lower part of the furnace and the blast furnace slag floating on the molten iron are obtained. Today, it is used as a by-product with an economic value that occurs during steel production. BFS composition is affected by the mineral ore poured into the blast furnace, flowable stone and purity in coke (Okyayand Akkaya 2011).An average of 250 kg, namely the slag by the ratio of 25% is obtained from a ton of steel production. In this study, an attempt to determine the effects of the use of FA and BFS that emerge as an industrial waste as the pozzolan material in concrete production on the physical and mechanical properties of the concrete and the effect of the use of these materials on the cost of concrete was made.

MATERIALS AND METHODS

Materiel

In this study, FA and BFS that are the industrial wastes of the factories making production in different regions of our country, and the concrete samples produced using cement, coarse and fine aggregates and tap water constituted the research material. In the study, FA which was used as the pozzolan material and constituted the research material was provided from Çatalağzı, Çayırhan, Tunçbilek thermal power plants, and BFS was provided from the plants of Ereğli Iron and Steel Factory (Oyak) and KarabükKarçimsa Cement Industry and Trading Inc.The physical properties of the FA and BFS are given in Table 2 and Table 3, respectively. CEM I 42,5 R-Portland cement produced by Nuh Cement Factory was used as a binder in concrete production. The properties of the cement are presented in Table 4.

The experiments on aggregate were carried out in accordance with TS EN 12620 standards (Anonimous 2009). The tap water of Istanbul province was used in mixtures.AYDOSPER NY 300 superplasticizer additive constant rate was used as aplasticizer in all concretes produced. Table5. Sieve analysis results and physical properties of the aggregate

Method

6 series of samples were poured in the experimental study (2 series of slag, 3 series of ash and 1 series of reference concrete) and the fresh and hardened concrete properties in these were determined by the methods specified in the standards. A total of 90 samples with 3 replications were poured in each series. In this study, the ratios of FA and BFS, which were obtained from 5 different plants and facilities, in concrete mix as pozzolan were selected as 19% for FA and 22% for BFS by considering the previous studies and the ratios used in the concrete industry.

In this study, the test specimens were coded as following.

A : C30 Reference concrete B_1 : C30 Tunçbilek ash reinforced concrete
B_2: C30 Çatalağzıash reinforced concrete
B_3: C30 Çayırhanash reinforced concrete
C_1: C30 Oyakslag reinforced concrete
C_2 : C30 Karçimsaslag reinforced concrete

In this study, it was aimed to produce C 30 class concretes. The mixing water and air amounts specified in TS 802 were taken.15x15x15 cm^3 standard cubic samples were used during the tests (Anonimous 1985). The workability of the fresh concrete samples produced was measured by the Slump test (Anonimous 2010a), and the air content was measured by the technique of pressure vessel (Anonimous 2010b).In addition, the unit weight and temperature of the fresh concrete were measured using the methods specified in the standards. The unit weight in the hardened concrete samples was determined in accordance with the TS EN 12390-6 (Anonimous 2010c).

Table 2. Physical properties of the FAs

Properties	FA		
	Çatalağzı	Çayırhan	Tunçbilek
Blainespecificsurface(cm^2/g)	2340	2754	2812
Specificgravity (gr/cm^3)	2,51	2,42	2,24
Amount on the45µmsieve (%)	23,0	25,8	27,1
Activity on 7th day	-	-	60,7
Activity on 28th day	78,8	76,4	77,1
Diameter (µm)	1-200	1-200	1-200
Color	Grey	Grey	Grey
Shape	Circular	Circular	Circular
Free lime (%)	-	0,74	-
Weightperliter (gr/lt)	-	1,06	-

The crushed sand, number 1 and 2 crushed aggregate, which are used in Istanbul region, were used as aggregate. The results of the sieve analysis of the aggregate are presented in Table 5. The largest particle size was selected as 31.5 mm.

Besides, the concrete samples produced were subjected to uniaxial compression test for 3-7-28-60 and 90 days, respectively.

Table 3. Physical properties of the BFS

Physical properties	GranuleBFS	
	Oyak	Karçimsa
Blainespecificsurface(cm^2/g)	1160	1240
Specificgravity (gr/cm^3)	2,88	2,75
Consistency (Water/çement, (%)	-	-
Amount on the 90 µmsieve (%)	23,4	24,1
Amount on the45µmsieve (%)	60,8	61,2

The compressive strength was performed in accordance with the TS EN 12390-3 standard (Anonimous 2003). Within the scope of the study, the cost analysis of 1 m^3 of each series of concrete produced was also performed.During the cost analysis, the quantities of the raw materials used in the mixture were calculated, and the cost of 1m^3 concrete was calculated using the unit prices of Istanbul province in 2014. The unit prices of the material are given in Table 6.

RESULTS AND DISCUSSION

The physical properties of the fresh concrete samples produced are given in Table 7.As it can be seen in the table, the highest slump value occurred (20 cm) on B_3 (Çayırhan FA).On the contrary, the least slump occurred in reference concrete during the slump tests performed in T_{30} time.This situation was due to the fact that the amount of fine material (FA and BFS) which was used on matters outside reference was more. When the unit weights of the fresh concrete are examined, values which are almost close to each other are seen. The highest unit weight was determined as 2375 kg/m^3 on C2 (Karabük slag).The air contents in the fresh concrete were increased by the use of thepozzolanic material. The highest values were achieved especially on B3 and B2 matters in which Çatalağzı and Çayırhan FAs were used by 2.3% and 2.4%. The times of initial setting and completion of thesetting are presented in Figure 1.

Table 4. The mechanical properties of the cement

Properties	Cement CEM I 42,5 R	
Blainespecificsurface(cm^2/g)	3444	
Specificgravity (gr/cm^3)	3,16	
Consistency (Water/çement,,%)	27,1	
Amount on the 90 µmsieve (%)	0,3	
Amount on the45µmsieve (%)	12,7	
Setting time(min)	Initial	185
	Final	236
Compressivestrength (MPa)	2th day	26,4
	7thday	44,8
	28thday	60,5

Table 5. Sieve analysis results and physical properties of the aggregate

Agregate	Sieve size (mm)								Specificgravity (gr/cm^3)	Waterabsorption %
	31,5	16,0	8,0	4,0	2,0	1,0	0,5	0,25		
The crushed sand(0,3)	100	100	100	97	92	83	63	27	2,68	1,4
The crushed sand	100	100	100	96	55	30	19	14	2,67	1,6
The crushed aggregateNo:1	100	100	70	10	3	2	0	0	2,71	0,3
The crushed aggregate No:2	100	58	1	0	0	0	0	0	2,71	0,3
Gradation of themixture	100	88	66	52	37	28	20	10		

Table 6. 2015 (Istanbul) unit prices for the cost analysis

Cement ($/ton)	Water (TL/ton)	Sand TL/ton	Crushed aggregate Num:1	Crushed aggregate Num:2	AdmixtureTL/ton
41	2,6	3,8	3,8	3,8	0.25

	Reference	B_1 TunçbilekTL/ton	B_2 Çatalağzı TL/ton	B_3 Çayırhan TL/ton	C_1OyakTL/ton	C_2 Karabük TL/ton
Mineral Additive	-	13	13	12,4	31,7	32,7

Table 7. Fresh concrete properties produced according to concrete class C30/37

Properties/ Sampleseries	A	B1	B2	B3	C1	C2
Slump T 0 (cm)	18,0	18,0	18,0	20,0	19,0	19,0
Slump T 30 (cm)	15,0	17,0	18,0	18,0	18,0	18,0
Unitweight (kg/m^3)	2359	2358	2360	2355	2361	2375
Aircontent (%)	1,8	2,1	2,3	2,4	2,0	2,1
Temperature (°C)	20,5	19,0	19,1	19,5	19,1	19,0
Ambienttemperature(°C)	22,5	22,5	22,5	22,5	22,5	22,5

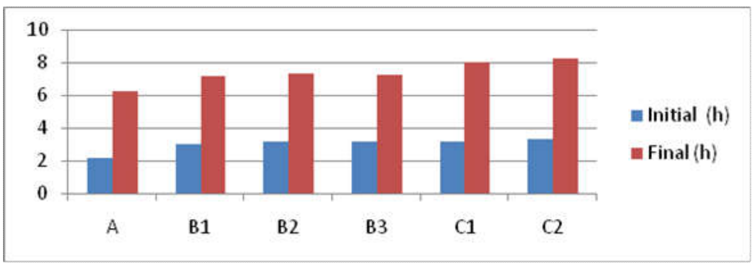

Figure 1. Setting times

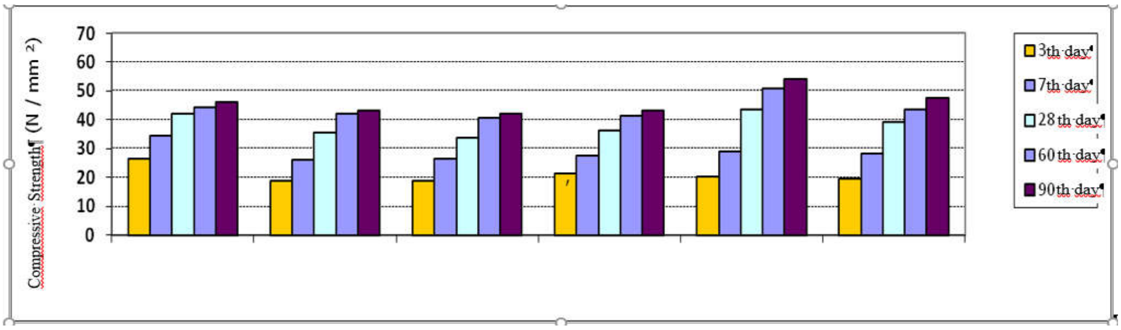

Figure 2. Compressive strength of the hardened concrete

Table 8. Cost analysis of the concrete produced

Samples		Material								
		Cement	Mineral Additive	Water	Natural Sand	Crushed Sand	Crushed aggregate Num:1	Crushed aggregate Num:2	Admixture	Cost $
A	Amount (Kg)	320	0	176	411	558	378	529	4,16	22,88
	$/ton	41	0	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	13,24	0	0,47	2,55	2,12	1,43	2	1,07	
B_1	Amount (Kg)	260	60	182	403	547	370	518	4,16	20,87
	$/ton	41	13,1	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	10,75	0,78	0,34	2,5	2,07	1,4	1,96	1,07	
B_2	Amount (Kg)	260	60	182	403	547	370	518	4,16	20,86
	$/ton	41	12,9	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	10,75	0,77	0,34	2,5	2,07	1,4	1,96	1,07	
B_3	Amount (Kg)	260	60	182	403	547	370	518	4,16	20,83
	$/ton	41	12,41	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	10,75	0,74	0,34	2,5	2,07	1,4	1,96	1,07	
C_1	Amount (Kg)	250	70	182	407	553	1,4	1,96	4,16	22,78
	$/ton	41	31,7	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	10,34	2,22	0,34	2,52	2,09	1,41	1,98	1,07	
C_2	Amount (Kg)	250	70	182	407	553	1,4	1,96	4,16	22,04
	$/ton	41	32,7	2,6	6,2	3,8	3,8	3,8	0,25	
	$/m³	10,34	2,29	0,34	2,52	2,09	1,41	1,98	1,07	

The shortest times of the initial setting and completion of the setting were measured as 02:15-06:30 in the reference concrete (A).When the times of the completion of setting were examined, the longest completion of setting was determined as 08:30 on theC_2matter.It is seen that the use of pozzolan generally extended the setting times. Aruntaş (2006) stated that the use of mineral additive increased the setting time. In the study, it was aimed to produce C30 concrete and that 28-day compressive strength was at least 37 N/mm^2 according to standards.

The change of 3, 7, 28, 60 and 90-day compressive strengths of the concrete samples produced is presented in Figure 2. As it is seen in the figure, samples C_1 and C_2, as well as the reference concrete (A), ensured the compressive strength required in 28 days.It was seen that especially the use of FA decreased the compressive strengths compared to the reference concrete but reached values close to the reference concrete in late strengths (60-90 days). On the contrary, it was determined that the use of BFS (C1 and C2) did not affect the 28-day compressive strength but exceeded the reference concrete, especially in late strengths. This situation was due to the fact that the specific gravities of the BFSs were higher than FAs. Figure 2 shows that the late strengths increased in all concrete in which FA and BFS were used. This situation is a natural consequence of the reduction in the heat of hydration by the pozzolan materials and the reduction in the strength gain speed. The cost analyses of the concrete produced in the study are presented in Table 8. When the concrete costs calculated using the unit prices of 2015 of Istanbul province are examined, m^3 costs were reduced by approximately 3-9% along with the use of pozzolan material except for distance and transport costs.

Conclusion and Suggestion

The results of the experimental studies carried out can be summarized as following. When the unit weights of the fresh concrete were examined, values which were almost close to each other were obtained in the samples in which FA and BFS were used. It was observed that workability increased with FA and BFS substitution, and mineral additives increased the amount of air in fresh concrete.In addition, the highest temperature in fresh concrete was measured in the reference concrete sample, and the use of FA and BFS as a pozzolan decreased the heat of hydration. Tokyay (2013) stated that blast furnace slag replacement decreased the maximum concrete temperature and reduced the time of reaching this maximum temperature by reducing the heat of hydration. Similarly, it was stated that FAs are used in controlling the high temperatures that occur in mass concretes.

FA and BFSs increased the times of initial setting and completion of setting of the cement paste. It was determined that Çatalağzı FA and Karabük BFS had more effects on the setting time. It was observed that FA replacement decreased the strength at early ages and required a longer curing time compared to normal concrete. It was observed that BFS replacement caused relatively low concrete strength at early ages and higher concrete strength at older ages in the concrete.This situation is a result of the fact that the pozzolan materials decreased the heat of hydration.When the 28-day compressive strengths in the concrete produced were taken into account, it was seen that BFS-reinforced concrete ensured the desired strength, but FAs remained inadequate.

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