The Effect of Type and Amount of Fly Ash on the Mechanical Properties of Cement

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ABSTRACT

The aim of this research is to study the effects of different classes of fly ash and their substitution amounts on compressive strength, bending strength and unit weight of cement mortars. F class fly ash which is procured from Çayırhan thermal plant and C class fly ash which is procured from Orhaneli thermal plant are used in this study. In preparation of the specimens cement in the mixture is substituted with fly ashes from Çayırhan and Orhaneli thermal plants in 0 %, 5 %, 10 %, 15 % and 20 % ratios, then for each mixture 3 prism specimens having 40x40x160 mm dimensions are prepared. The amount of the water used for each group of mixture is determined by realizing flow table test according to the flow diameter specified in ASTM C230, C109 and C1437 standards. Unit weight, bending strength and compressive strength experiments are performed on the specimens. The results are evaluated with statistical analysis.

As a result, strength values of cement mortars with C class fly ash substitution are found to be smaller than those of cement mortars with F class fly ash substitution. With the increase of C class fly ash substitution ratio the compressive strength figures decline. However, in spite of this decrease it is found that the compressive strengths of cement mortars with fly ash substitution are still between standard values.

Keywords: Cement, fly ash, compressive strength, bending strength, substitution.

Uçucu Kül Tür ve Miktarının Çimento Mekanik Özelliklerine Etkisi

ÖZET

Bu araştırmanın amacı farklı sınıflardaki uçucu küllerin ve ikame miktarlarının çimento harçlarının basınç eğilme dayanımı ve birim alırlık üzerine olan etkilerini araştırmaktır. Bu amaçla, Çayırhan termik santralinden temin edilen F sınıfı uçucu kül ve Orhaneli termik santralinden temin edilen C sınıfı uçucu kül çimento numunelerinin hazırlanmasında kullanılmıştır. Numuneler hazırlanırken karışım içerisinde çimento ile %0, %5, %10, %15 ve %20 oranlarında Çayırhan ve Orhaneli termik santrallerinin uçucu külleri ikame edilerek, her bir karışım için 3 adet 40x40x160 mm boyutlarında prizma örnekleri hazırlanmıştır. Her bir grup için karışımda kullanılacak su miktarı ASTM C230. C109 ve C1437 standartlarında belirtilen akma çapına göre akma tablası deneyi gerçekleştirilerek belirlenmiştir. Numuneler üzerinde birim ağırlık, eğilmede çekme ve basınç dayanımı deneyleri gerçekleştirilmiştir. Sonuçlar istatistiksel analizlere tabi tutularak değerlendirilmiştir.

Sonuç olarak, C sınıfı uçucu kül ikameli çimento harçlarının dayanım değerleri, F sınıfı uçucu küllere göre daha düşük çıkmıştır. C sınıfı uçucu kül ikame miktarı arttıkça basınç dayanımı değerleri azalmıştır. Ancak bu azalmaya rağmen uçucu kül ikameli çimento harçlarının basınç dayanımlarının standart değerler arasında olduğu belirlenmiştir.

Anahtar kelimeler: Çimento, uçucu kül, basınç dayanımı, eğilme dayanımı, ikame.

1. INTRODUCTION (GİRİŞ)

Mineral admixtures such as fly ash, silica fume, natural pozzolans, blast furnace slag and rice husk ash, which are considered as both admixture and substitution materials in concrete, are widely used in cement and concrete sector due to their pozzolanic properties and ecological reasons [1-3]. These pozzolanic materials are utilized with admixture or substitution methods instead of cement [4, 5]. In addition to this high strength cement can be produced with the use of pozzolans such as fly ash and silica fume [6, 7]. Among these pozzolanic materials fly ash (FA) is one of the most-widely used materials due to its financial and ecological benefits [1].

FA is a waste product which is seized by the electro filters at the chimney exits after the burning of the coal for electricity generation in thermal plants. These flying ashes which have fine particles are called FA [8]. According to ASTM C 618 FAs are divided in to two groups which are F class (low lime FAs) and C class (High lime FAs). F class FAs have pozzolanic properties and their SiO_2+Al_2O_3+Fe_2O_3 (S+A+F) sum is higher than 70 %. C class FAs have, in addition to pozzolanic properties, inherent binding properties and their S+A+F sum is higher than 50 % [1, 8, 9].

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FA is used as an admixture or a substitution material in cement mortar or concrete. With the use of FA instead of cement natural resources are preserved, CO_2 emission is decreased and energy is saved [10, 11]. Also with the use of FA various advantages such as the control of alkaline aggregate growth, chemical resistance against environmental effects, decrease in hydration heat and concrete shrinkage, are realized [12-15]. FAs, which are widely used owing to these advantages, improve the strength and/or resistance properties of the concrete [16, 17].

In this study F class and C class FAs are used in the preparation of cement specimens. Unit weight, bending strength and compressive strength experiments are performed on the cement specimens that are produced with FA substitution and the results are assessed by using statistical analysis.

2. MATERIAL AND METHOD (Materyal ve Metot)

2.1. Material (Materyal)

Cement: CEM I 42.5 R cement (PC) produced by Ankara SET Cement factory is used (Table 1).

Table 1. Properties of cement

Chemical composition (wt. %)	
SiO_2	20.32
Al_2O_3	5.59
Fe_2O_3	3.09
CaO	62.50
MgO	1.74
SO_3	3.29
Na_2O	0.34
K_2O	0.91
Loss on ignition	1.18
Insoluble residue (%)	0.31
Free CaO	0.93
Physical properties	
Initial setting time (minute)	118
Final setting time (minute)	177
Expansion (mm)	2
Blaine (cm²/g)	3172
Mechanical properties	
Compressive strength (MPa)	
2 days	30.8
7 days	39.5
28 days	56.0

Fly ash: F class FA (FA1) which is procured from Çayırhan thermal plant and C class FA (FA2) which is procured from Orhaneli thermal plant are used (Table 2).

Table 2. Chemical composition of fly ash

Chemical composition (wt. %)	FA1	FA2
SiO_2 (S)	51.64	41.77
Al_2O_3 (A)	14.32	13.95
Fe_2O_3 (F)	9.31	4.84
CaO	6.54	17.95
MgO	4.02	7.04
SO_3	2.62	2.59
Na_2O	2.36	2.94
K_2O	2.27	2.14
S+A+F	75.27	64.56

Sand: In preparation of mortar specimens CEN reference sand which is produced by SET Trakya Cement Industry in compliance with TS EN 196-1 is used.

Mixing water: Network water of Ankara province Beşevler region is used.

2.2. Method (Metot)

2.2.1. Preparation of experiment specimens (Deney örneklerinin hazırlanması)

In preparation of the specimens cement in the mixture is substituted with fly ashes from Çayırhan and Orhaneli thermal plants in 0 %, 5 %, 10 %, 15 % and 20 % ratios then for each mixture 3 prism specimens having 40x40x160 mm dimensions are prepared. The amount of the water that will be used for each group of mixture is determined by realizing flow table test according to the flow table specified in ASTM C230, C109 and C1437 standards [18-20]. Water/cement (w/c) ratios used in mixtures are given in Table 3.

Table 3. Determined of water / cement ratios according to flow table test results

FA substitution ratio (%)	FA1		FA2	
	Water (ml)	Water/ cement ratio	Water (ml)	Water/ cement ratio
0	290	0.48	290	0.48
5	310	0.52	320	0.53
10	330	0.55	330	0.55
15	340	0.57	330	0.55
20	350	0.58	340	0.57

2.2.2. Determination of compressive and bending strength of the cement (Çimento başınç ve eğilme dayanımın belirlenmesi)

Cement compressive and bending strength experiments are performed on 2nd, 7th and 28th days on 3 separate specimens having dimensions 40x40x160 mm which are prepared for each group. Compressive and bending strength experiments are performed in compliance with the rules outlined in TS EN 196-1 standard [21].

Compressive strength R_c is calculated with the equation (1).

$$R_c = \frac{F_c}{1600} \tag{1}$$

Wherein;

R_c : Compressive strength (MPa),

F_c : Maximum load just before crushing (N),

1600: Specimen area (mm²).

Bending strength R_f, is calculated by using equation (2).

$$R_f = \frac{1{,}5xF_f xl}{b^3} \quad (2)$$

Wherein;

R_f : Bending strength, (MPa)

b : Edge length of the square cross section of the prism (mm),

F_f : The force applied when the prism breaks (N),

L : The distance between supporting cylinders (mm).

2.2.3. Unit weight (Birim ağırlık)

Masses of the specimens prepared in 40x40x160 mm dimensions are measured before they are subjected to bending and compressive strength experiments and thus their respective unit volume weight figures are calculated.

2.2.4. Statistical method (İstatistiksel metot)

Descriptive statistics pertaining to the data obtained through experimental studies are given. For three different experiment types variance analysis is used in testing the differences between the groups. In order to investigate the differences between the groups Bonferroni multiple comparisons test is used. The possibility of error in comparison test is assumed to be α= 0.05. Furthermore the obtained results are visualized with column graphs [22].

3. FINDINGS and DISCUSSIONS

(BULGULAR VE TARTIŞMA)

3.1. Compressive and Bending Strength

(Basınç Dayanımı ve Eğilme Dayanımı)

Descriptive statistics pertaining to compressive strength data obtained from experiments performed on cement specimens on 2nd, 7th and 28th days are given in Table 4 whereas descriptive statistics pertaining to bending strength data are given in Table 5.

When compressive strength values are examined it is observed that for all specimen ages and FA substitution ratios FA1 substituted cement specimens have larger average compressive strength values than FA2 substituted specimens. Moreover it is determined that for all specimen ages the compressive strength values decrease as FA substitution ratio increases.

When bending strength values are examined it is observed that for all specimen ages and FA substitution ratios, as in the case of compressive strength, FA1 substituted cement specimens have larger average bending strength values than FA2 substituted specimens. Moreover it is determined that for all specimen ages the bending strength values decrease as FA substitution ratio increases. The compressive strength and the bending strength figures of the both FA types for all ages and FA substitution ratios are given in Figure 1 and Figure 2, respectively.

Table 4. The descriptive statistics of the compressive strength values

			FA1		FA2	
Age (days)	FA substitution ratio (%)	N	Average compressive strength (MPa)	Std. error	Average compressive strength (MPa)	Std. error
2	0	3	28.5133	0.30208	28.5133	0.30208
	5	3	25.5900	0.40374	23.7900	0.43059
	10	3	23.3183	0.21302	20.2850	0.32374
	15	3	22.8883	0.07446	18.2150	0.25482
	20	3	22.4883	0.12956	17.2967	0.11410
7	0	3	39.4200	0.26424	38.6067	1.07058
	5	3	37.6283	0.05932	34.0250	0.52288
	10	3	36.6817	0.28715	32.5650	0.07767
	15	3	34.7383	0.42773	31.6017	0.22595
	20	3	33.1583	0.46995	29.9300	0.69409
28	0	3	50.0667	0.62140	50.0667	0.62140
	5	3	47.0817	0.19417	44.6183	0.07474
	10	3	46.2900	0.18644	44.2700	0.09579
	15	3	45.4150	0.25986	43.8233	0.10651
	20	3	44.1817	0.41754	42.0650	0.30029

Table 5. The descriptive statistics of the bending strength values

			FA1		FA2	
Age (days)	FA substitution ratio (%)	N	Average bending strength (MPa)	Std. error	Average bending strength (MPa)	Std. error
2	0	3	4.9567	0.07720	4.7550	0.02386
	5	3	4.6380	0.01222	3.9813	0.08772
	10	3	4.5783	0.00754	3.5477	0.03254
	15	3	4.3780	0.12368	3.3053	0.08980
	20	3	3.9443	0.07766	3.1477	0.02783
7	0	3	6.2780	0.00603	5.8167	0.06822
	5	3	6.1740	0.04678	4.9653	0.05710
	10	3	5.9767	0.04891	4.7480	0.09640
	15	3	5.8543	0.03717	4.5277	0.01272
	20	3	5.3803	0.15648	4.4010	0.05659
28	0	3	7.4333	0.05855	7.2423	0.09613
	5	3	7.1843	0.03689	6.4657	0.01288
	10	3	6.8667	0.09992	6.2420	0.05750
	15	3	6.5953	0.02500	5.8293	0.05505
	20	3	6.4367	0.03610	5.5987	0.05569

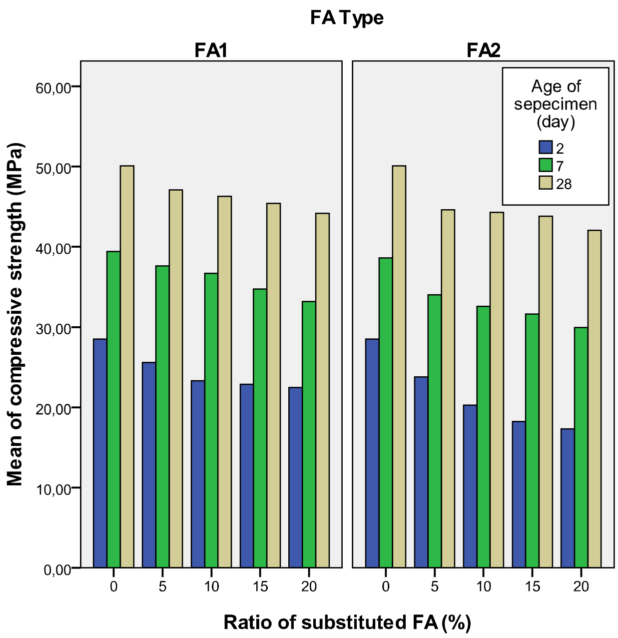

Figure 1. The graphic of average compressive strength values

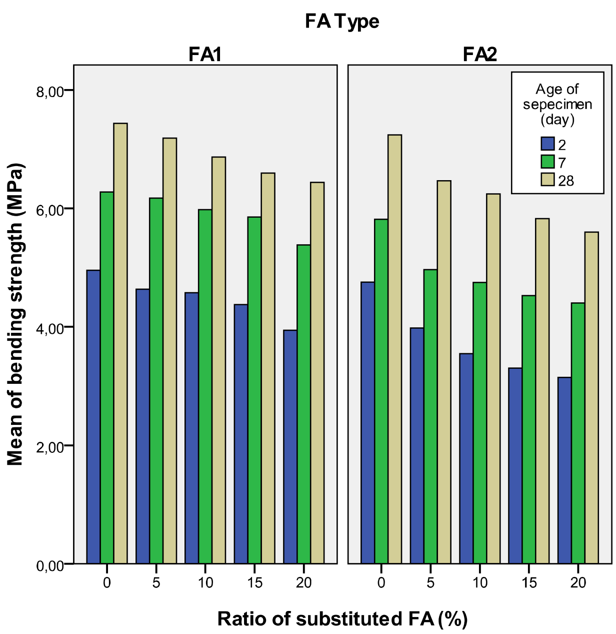

Figure 2. The graphic of average bending strength values

In order to test whether there is any difference between FA substitution ratios on 28-days strength values for both FA types for compressive and bending strength values variance analysis is performed. As a result of the analysis done it is observed that at $p \leq 0.05$ significance level there is a significant difference between FA substitution ratios along with compressive and bending strength values of both FA types. In other words strength values differ depending on FA substitution ratio. In order to compare all groups Bonferroni multiple comparison test is used. The results of multiple comparison results obtained for compressive strength are given in Table 6 whereas the results obtained for bending strength are presented in Table 7.

Table 6. The results of Bonferroni multiple comparison test for compressive strength values

FA type	FA substitution ratio (%)	FA substitution ratio (%) 0	5	10	15	20	Compressive strength (MPa)
FA1	0		f*	f*	f*	f*	50.0667
	5	f*				f*	47.0817
	10	f*				f*	46.2900
	15	f*					45.4150
	20	f*	f*	f*			44.1817
FA2	0		f*	f*	f*	f*	50.0667
	5	f*				f*	44.6183
	10	f*				f*	44.2700
	15	f*				f*	43.8233
	20	f*	f*	f*	f*		42.0650

According to comparison test results it is seen that from compressive strength point of view the reference specimen is different from substituted groups for both FA types, in FA1 the specimens having 15 % and 20 % substitution are not different, yet they are different than others, in FA2 the specimens having 20 % substitution are different than the rest of the groups.

It is observed that among FA1 substituted specimens the reference specimen, which has the highest compressive strength, has 12 % higher compressive strength than the specimens with 20 % substitution, which have the lowest compressive strength while for FA2 substituted specimens the reference specimen has 16 % higher compressive strength than the specimens with 20 % substitution.

Table 7. The results of Bonferroni multiple comparison test for bending strength values

FA type	FA substitution ratio (%)	FA substitution ratio (%) 0	5	10	15	20	Bending strength (MPa)
FA1	0			f*	f*	f*	7.43
	5			f*	f*	f*	7.18
	10	f*	f*			f*	6.86
	15	f*	f*				6.59
	20	f*	f*	f*			6.43
FA2	0		f*	f*	f*	f*	7.24
	5	f*			f*	f*	6.46
	10	f*			f*	f*	6.24
	15	f*	f*	f*			5.82
	20	f*	f*	f*			5.59

When Table 7 is examined, according to the test results it can be observed that for FA1 the reference specimen is different than all substituted groups except for the specimens with 5 % substitution and for FA2 the reference specimen is different than all groups. Furthermore for both FA types it is found that the groups with 15 % and 20 % substitution are not statistically different.

It is observed that among FA1 specimens the reference specimen, which has the highest bending strength, has 13 % higher bending strength than the specimens with 20 % substitution, which have the lowest strength while for FA2 specimens the reference specimen has 23 % higher bending strength than the specimens with 20 % substitution.

3.2. Unit Weight (Birim Ağırlık)

Descriptive statistics pertaining to data obtained from unit weight experiment which is performed on cement specimens on 2nd, 7th and 28th days are given in Table 8.

Table 8. The descriptive statistics of the unit weight values

Age (days)	FA substitution ratio (%)	N	FA1 Average unit weight (g/cm^3)	FA1 Std. error	FA2 Average unit weight (g/cm^3)	FA2 Std. error
2	0	3	2.1893	0.00133	2.1990	0.00231
	5	3	2.1890	0.00153	2.1837	0.00033
	10	3	2.1830	0.00058	2.1777	0.00033
	15	3	2.1747	0.00333	2.1683	0.00176
	20	3	2.1477	0.00784	2.1487	0.00441
	Total	15	2.1767	0.00439	2.1755	0.00455
7	0	3	2.2223	0.00033	2.2113	0.00067
	5	3	2.2190	0.00058	2.2073	0.00120
	10	3	2.2157	0.00067	2.2017	0.00088
	15	3	2.2120	0.00058	2.1990	0.00000
	20	3	2.2083	0.00033	2.1937	0.00067
	Total	15	2.2155	0.00134	2.2026	0.00168
28	0	3	2.2633	0.01284	2.2447	0.00273
	5	3	2.2423	0.00240	2.2363	0.00088
	10	3	2.2350	0.00000	2.2277	0.00033
	15	3	2.2287	0.00088	2.2233	0.00133
	20	3	2.2230	0.00000	2.2180	0.00265
	Total	15	2.2385	0.00435	2.2300	0.00263

When the unit weight figures are examined it is observed that for all specimen ages and FA substitution ratios FA1 substituted cement specimens have larger average unit weight figures than FA2 substituted specimens. Also it is found that for all specimen ages unit weight figures decrease as FA substitution ratio increases. Unit weight figures of both FA types at different ages and for different FA substitution ratios are shown in Figure 3.

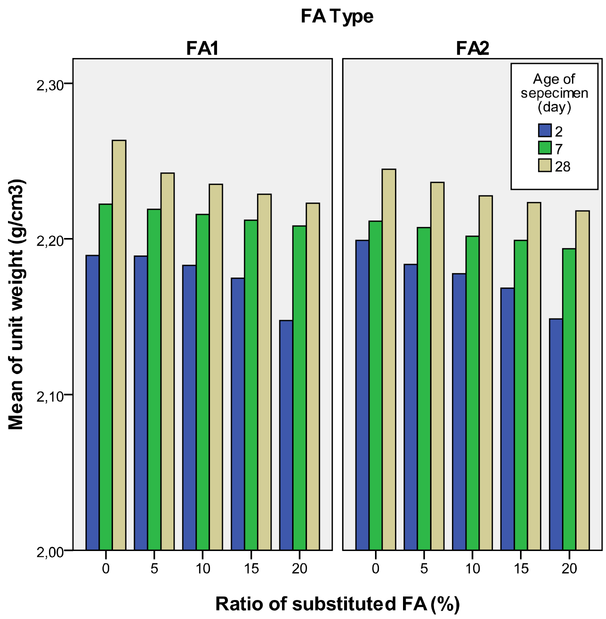

Figure 3. The graphic of average unit weight values

In order to test whether there is any difference between FA substitution ratios on 28-days figures for both FA types from unit weight point of view variance analysis is performed between the groups. As a result of the analysis done it is observed that at $p \leq 0.05$ significance level, from statistical perspective, there is a significant difference between FA substitution ratios and unit weight values of both FA types. In other words unit weight differs significantly depending on FA substitution ratio. In order to compare all groups Bonferroni multiple comparison test is used. The results of multiple comparison results obtained for unit weight are given in Table 9.

Table 9. The results of Bonferroni multiple comparison test for unit weight values

FA type	FA substitution ratio (%)	FA substitution ratio (%) 0	5	10	15	20	Unit weight (g/cm^3)
FA1	0				f^*	f^*	2.263
	5						2.242
	10						2.235
	15	f^*					2.229
	20	f^*					2.223
FA2	0			f^*	f^*	f^*	2.245
	5				f^*	f^*	2.236
	10	f^*				f^*	2.228
	15	f^*	f^*				2.223
	20	f^*	f^*	f^*			2.218

When Table 9 is examined, according to the test results it can be observed that from unit weight values point of view, for FA1 the reference specimen is different than specimens with 15 % and 20 %

substitution where as it is identical to specimens with 5 % and 10 %, for FA2 the reference specimen is different than all substituted groups except for the specimens with 5 % substitution

It is observed that among FA1 specimens the reference specimen, which has the highest unit weight, has 2 % higher unit weight than the specimens with 20 % substitution, which have the lowest unit weight while for FA2 specimens the reference specimen has 2 % higher bending strength than the specimens with 20 % substitution, which have the lowest unit weight.

4. **CONCLUSION** (SONUÇLAR)

In the scope of the research F class FA1 which is procured from Çayırhan thermal plant and C class FA2 which is procured from Orhaneli thermal plant are substituted into cement specimens in 0 %, 5 %, 10 %, 15 % and 20 % weight ratios then on 3 prism specimens prepared for each mixture unit weight, bending strength and compressive strength experiments are performed. As a result of statistical evaluations realized on the results obtained, it is observed that for all specimen ages and FA substitution ratios, *compressive strength, bending strength and unit weight* values are

- higher for F-class FA1 coded cement specimens than C-class FA2 coded specimens,
- 12 %, 13 % and 2 % higher, respectively, for reference specimens than F class FA substituted specimens ,
- 16 %, 23 % and 2 % higher, respectively, for reference specimens than C class FA substituted specimens ,
- when compared to reference specimen there is very little decrease in strength and unit weight figures in F class FA substituted specimens with 5 % or 10 % substitution ratios.

According to the figures obtained in this study at the end of 28-days period the cements obtained from FA substituted cement mortars have compressive strength values larger than the minimum strength (42.5 MPa) specified by TS EN 197-1 CEM 1 42.5 R standard. However in 20 FA2 coded cement mortar this value is 42.06 MPa which is 99 % of the standard value (which is very close to the standard value). Especially when it is considered that in addition to strength is resistance is also important it is thought that with FA substitution to high strength cements (PC) in suitable amounts cements with high resistance can be produced without compromising from the strength that is set by the standards. Also in the study performed FA substituted cements are assessed up to 28 days age from compressive strength experiment perspective. If the compressive strengths of FA substituted cements for older ages it is anticipated that due to FA's pozzolanic property strength will increase. As a result when it is considered from sustainability point of view it is thought that the use of FA's in cement and concrete will contribute to waste recycle and environment pollution while, at the same time, cement and concrete mortars having the desired properties from mechanical perspective can be obtained.

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