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ABRASION RESISTANCE ESTIMATION OF HIGH STRENGTH CONCRETE

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ABSTRACT

This study gives the results of a laboratory investigation undertaken to determine the relationship between mechanical properties (compressive and flexural strengths) and abrasion resistance of 65-85 MPa high strength concretes incorporating silica fume, fly ash and silica fume-fly ash mixtures as supplementary cementing materials. A series of six different concrete mixtures including a control high strength concrete mixture (C1), and five high strength concrete mixtures (C2, C3, C4, C5, C6) incorporating supplementary cementing materials, were manufactured. The compressive strength, flexural strength, and abrasion resistance were determined for each mixture at 28-days. Mathematical expressions were suggested to estimate the abrasion resistance of concrete regarding their compressive strength and flexural strength.

Key Words : High strength concrete, Abrasion resistance, Fly ash, Silica fume.

YÜKSEK DAYANIMLI BETONDA AŞINMA DİRENCİNİN TAHMİNİ

ÖZET

Bu çalışmada, silis dumanı ve/veya uçucu kül içeren basınç dayanımı 65-85 MPa olan yüksek dayanımlı betonların, aşınma direnci ile mekanik özelikleri (basınç ve eğilme dayanımı) arasındaki ilişkiyi belirleyebilmek amacıyla yapılan deneysel çalışma sonuçları sunulmuştur. Bir adet yüksek dayanımlı beton kontrol karışımı (C1) ve beş adet katkı içeren yüksek dayanımlı beton karışımı olmak üzere (C2, C3, C4, C5, C6), toplam altı adet beton karışımı hazırlanmıştır. Tüm karışımların 28 günlük basınç dayanımları, eğilme dayanımları ve aşınma dirençleri belirlenmiştir. Betonların basınç ve eğilme dayanımına bağlı olarak aşınma direncini tahmin eden matematiksel eşitlik önerilmiştir.

Anahtar Kelimeler : Yüksek dayanımlı beton, Aşınma direnci, Uçucu kül, Silis dumanı.

1. INTRODUCTION

The abrasion resistance of concrete is of importance in various types of concrete construction. For example, in pavements, floors and hydraulic structures such as tunnels and dam spillways, the concrete should withstand destructive wearing forces, which may include abrasion and impact. Compressive strength and tensile strength are major factors controlling the abrasion resistance of concrete (Mindess and Young, 1985).

Abrasion resistance of concrete depends a great deal on the hardness of the aggregates used. High strength concretes with low W/C ratio is less dependent on aggregate type and the use of a low w/c ratio can provide a dense, strong concrete which is resistant to abrasion (Mindess and Young, 1985). High strength is made possible by reducing porosity, in-homogeneity and micro cracks in concrete and the transition zone. This can be achieved by using super plasticizers and supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag and natural pozzolan (Hague and Kayalı, 1998; Shannag, 2000).

In this research, the effect of compressive strength and flexural strength on abrasion resistance of concrete was taken into consideration. Besides, an expression predicting loss on abrasion including the parameters mentioned above was proposed.

2. EXPERIMENTAL STUDY

2. 1. Materials

In this study, an ordinary portland cement (PC), a silica fume (SF), and a fly ash (FA) were used as a cementitious materials. Also, fly ash was used as an aggregate in some concrete mixtures. The chemical composition and some physical properties of portland cement, silica fume and fly ash are given in Table 1. The silica fume used in this study is a by-product of Antalya ferrosilicon chrome Factory. The Class C fly ash was obtained from Soma power plant in Manisa. The coarse aggregate was crushed basalt with maximum size of 16 mm, and the fine aggregate was natural sand. Saturated-surface-dry (SSD) specific gravities of coarse and fine aggregates were 2.70 and 2.63, respectively. The absorption capacity of coarse and fine aggregates is 0.8% and 1.1%, respectively. Coarse aggregate was separated into two different size fractions as 4/8 mm (CAI) and 8/16 mm (CAII) and then recombined to a specified uniform grading during mixing. The blend consisted of 50 % CAI, 23 % CAII and 27 % natural sand (NS). The blend conforms to ASTM C33 aggregate grading standard. A melamine sulfonate polymer type (brown, density of 1.2 kg/l) high range water reducing admixture (HRWRA), was used in all mixtures in constant value accept for first mixture within the limits proposed by the manufacturer.

Table 1. Chemical Compositions of Cements and Mineral Admixtures.

Chemical Analysis (%)	PC	SF	FA
SiO_2	19.7	94-95	42.4
Al_2O_3	5.1	0.4-1.35	27.6
Fe_2O_3	2.6	0.4-1.0	5.5
CaO	64.2	0.6-1.0	23.0
MgO	1.4	1-1.5	2.0
SO_3	2.4	---	---
Insoluble Residue	0.4	---	---
Loss on Ignition	1.8	0.85	1.5
Na_2O	0.3	2.27	0.5
K_2O	0.8	0.59	0.9
Physical Analysis			
Specific Gravity Fineness: Blaine Specific Surface, cm^2/g	3.06 3470	2.24	2.33
Compound Composition			
C_3S	59.35		
C_2S	11.71		
C_3A	9.22		
C_4AF	7.79		

2. 2. Preparation and Casting of Specimens

The proportioning and description of the concrete mixtures are summarized in Table 2. Six series of high strength concrete (HSC) mixtures were prepared to have a slump of 50 ± 15 mm. Mixture C1 is a normal HSC. C2 and C3 were prepared for 30 % SF and 25 % FA replacement of cement, respectively. C4, C5, and C6 mixtures consist of 30 % SF replacement of cement and 5, 10 and 15 % FA replacement with aggregate.

In the experiment, six batches were prepared for each concrete mixture. From each batch three specimens were prepared in order to use same batch at following three tests. The compressive strength tests were determined on 100 x 200 mm cylinders at 28-days according to ASTM C39. Before testing in compression, specimens were capped with a sulphur-graphite based mixture to maintain a uniform stress distribution. Flexural strength tests were performed 100 x 100 x 600 mm prismatic specimens at 28-days according to ASTM C293.

Cube samples of 71±1.5 mm were used for the determination of abrasion resistance at 28-days according to Turkish Standard Specifications TS 699-1987 "Methods of Testing for Natural Building Stones". Although this standard is highly recommended for the abrasion of natural stones, this standard is applied on concrete specimens as an alternative of ASTM C779 "Test Method for Abrasion Resistance of Horizontal Concrete Surfaces". Many other researchers used this method and obtained reliable results (Oymael and Yeğinobalı, 1996; Arslan, 2001). In compliance with TS 699, the abrasion system had a steel disc, which had a diameter of 750 mm and rotating speed of 30±1 cycle/min, a counter and a lever, which could apply 300±3 N on the specimens. In the test procedure, 20±0.5 g of abrasion dust was spread on the disc, the specimens were then placed, the load was applied to the specimen and the disc was rotated for 4 periods, while a period was equal to 22 cycles. After that, the surfaces of the disc and the sample were cleaned. The above mentioned procedure repeated for 20 periods (totally 440 cycles) by rotating the sample 90° in each period. The volume decrease was measured in cm^3/cm^2 due to abrasion.

Table 2. Mix Proportions and Description of Concrete Mixtures.

Mixture Code	Mixture Description	Batch Weight (kg/m³)							
		Binder			Water	Aggregate			HRWRA
		PC	SF	FA		CAI	CAII	NS	
C1	HSC	550	0	0	123	905	416	477	13.75
C2	HSSFC	385	165	0	135	860	396	454	16.50
C3	HSFAC	413	0	137	130	867	399	457	16.50
C4	HSSFFAC	385	165	28	153	821	377	433	16.50
C5	HSSFFAC	385	165	55	175	776	357	409	16.50
C6	HSSFFAC	385	165	83	194	732	337	386	16.50

* : Aggregates were used in saturated-surface dry (SSD) condition in the concrete mixtures.

3. RESULTS AND DISCUSSION

Avarega compressive strength test results are presented in Figure 1. Reported values are the average of six specimens. The mean compressive strength values ranged from 68.4 to 82.7 MPa. The 28-day maximum compressive strength, 82.7 MPa was obtained in C2 mixture where 30 % of cement was replaced with SF. It is recognized that SF can contribute significantly to the compressive strength development. This is because of the pore refining effect and excellent pozzolanic properties of the material which causes a stronger zone at the paste-aggregate interface (Anon., 1987a; Khayat and Aïtcin, 1992; Malhotra et al., 1992).

The minimum 28-day compressive strength, 68.4 MPa, was found for the 25 % FA replacement concrete (C3), which is typical behavior of FA concrete at 28-days. The use of 25% FA as replacement for cement can decrease the 28-day compressive strength of the concrete. It is known that fly ashes generally may have negative effects on the concrete strength, particularly at early ages (Carette and Malhotra, 1983; Anon., 1987b; Bilodeau et al., 1989). But after 28-days, the strength of FA concrete increases more rapidly due to the pozzolanic reaction.

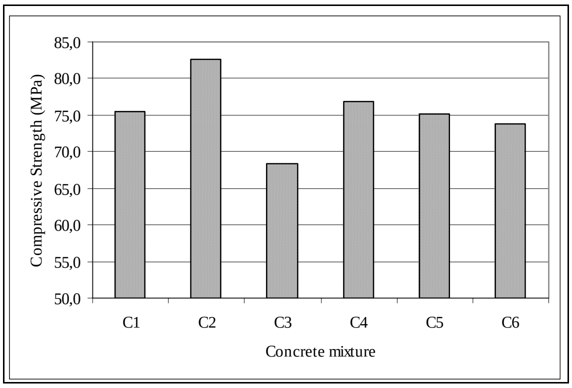

Figure 1. 28 day compressive strength test results.

Compressive strength results indicated that gain in strength of SF-FA mixtures (C4, C5, and C6) were in the same trend with the normal HSC concrete (C1) whereas the compressive strength of the C4, C5, C6 mixtures is higher than C3 mixtures and lower than C2 mixtures. This case is more possibly due to the following reasons:

i. The $Ca(OH)_2$ resulted from the hydration of cement is reacted with SF and no $Ca(OH)_2$ remained to react with FA,
ii. The use of FA as an aggregate replacement leads to using high W/Binder ratio and this

produces a significant reduction in compressive strength,

iii. Testing period (28-days) seems to be insufficient for the FA contribution to the strength.

The center point flexural strength test results are shown in Figure 2. Flexural strength values ranged from 7.9 to 9.0 MPa. The maximum flexural strength, 9.0 MPa, was obtained in the mixture containing 30 % SF (C2). The lowest 28-day flexural strength, 7.9 MPa, was found for the 25 % FA replacement concrete (C3). It seems that this gain was partly due to pore refining effect of SF. The results of this test indicated that the flexural strength of the concrete incorporating SF and/or FA varies in the same manner as compressive strength.

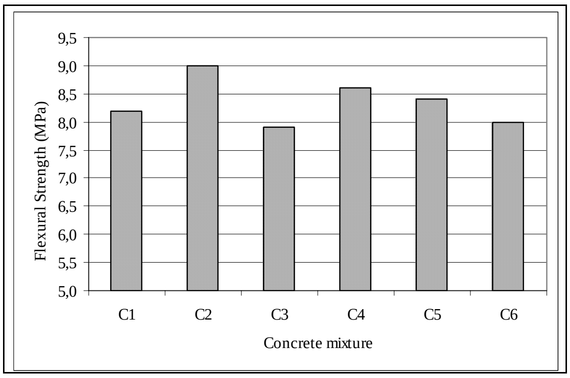

Figure 2. 28 day flexural strength test results

As shown in Figure 3, the lowest (7.01 $cm^3/50cm^2$) and maximum (10.28 $cm^3/50cm^2$) loss of volume on abrasion were obtained in C2 and C3 mixture, respectively. The abrasion resistance values of other high strength concretes ranged from 7.73 to 8.14 $cm^3/50cm^2$. Test results showed that resistance to abrasion of concrete increased as the strength increased. In addition, the abrasion resistance of high strength concretes was improved by the use of SF but decreased proportionally with the FA content in the mixtures. Same results were obtained by other researchers (Siddique, 2004; Naik et al., 1994). Siddique reported that abrasion resistance of concrete mixtures containing fly ash was lower than that of control mixture and decreased with increasing fly ash content (Siddique, 2004). Also, Naik et al. determined lower abrasion resistance values for high-volume fly ash concrete systems compared to that of non-fly ash concrete (Naik et al., 1994).

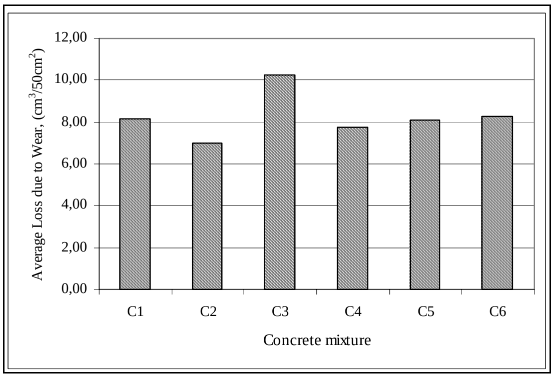

Figure 3. 28 day loss on abrasion test results

The average results of compressive strength, flexural strength and abrasion loss values as well as the stand ard deviation for each concrete mixture are summarized in Table 3.

Table 3. Statistical Parameters of Test Results For Each Concrete Mixtures.

Mixture Code	Statistical Values	Compressive Strength (MPa)*	Flexural Strength (MPa)*	Loss on Abrasion ($cm^3/50cm^2$)*
C1	Average, (MPa)	75.5	8.2	8.14
	Standard Deviation	1.2	1.6	1.26
C2	Average, (MPa)	82.7	9.0	7.01
	Standard Deviation	2	1.5	1.40
C3	Average, (MPa)	68.4	7.9	10.28
	Standard Deviation	3	1.5	1.55
C4	Average, (MPa)	76.8	8.6	7.73
	Standard Deviation	2.4	1.5	1.46
C5	Average, (MPa)	75.2	8.4	8.07
	Standard Deviation	2.2	1.4	1.28
C6	Average, (MPa)	73.8	8.0	8.26
	Standard Deviation	2	1.3	1.57

* : Each value is the average of six specimens.

4. STATISTICAL EVALUATION OF TEST RESULTS

The compressive strength, flexural strength and abrasion loss values are given in Table 4. A multiple regression analysis was applied to obtain the following relationship among compressive strength, flexural strength and loss on abrasion values.

$$LOA = 29.3507 - 0.2795 f_c - 0.0034 f_{fl} \qquad \text{(Eq. 1)}$$

Where,

LOA : 28-day abrasion loss value of concrete, ($cm^3/50cm^2$),

f_c : 28-day compressive strength of concrete, (MPa),

f_{fl} : 28-day flexural strength of concrete, (MPa).

Table 4. Measured and Estimated Abrasion Loss Values.

Concrete Code	Batch No	28-day Loss on Abrasion Values ($cm^3/50cm^2$)		Concrete Code	Batch No	28-day Loss on Abrasion Values ($cm^3/50cm^2$)	
		Estimated	Measured			Estimated	Measured
C1	1	7.99	6.84	C4	1	8.47	8.24
	2	8.16	8.10		2	8.66	9.96
	3	8.47	9.81		3	7.94	8.43
	4	8.37	8.21		4	7.75	7.21
	5	8.62	9.23		5	7.44	6.69
	6	7.72	6.63		6	6.87	5.85
C2	1	5.97	7.21	C5	1	7.60	6.95
	2	5.79	5.72		2	8.11	8.22
	3	6.71	9.36		3	7.74	7.65
	4	7.10	7.63		4	8.48	6.69
	5	5.85	5.62		5	8.70	8.76
	6	5.82	6.54		6	9.20	10.16
C3	1	9.06	8.49	C6	1	8.30	6.92
	2	10.15	11.32		2	8.79	8.25
	3	10.9	9.36		3	8.50	7.46
	4	9.37	8.86		4	9.09	9.95
	5	10.74	11.96		5	9.54	10.35
	6	11.01	11.70		6	7.97	6.63

The comparison of experimental and est imated loss on abrasion values (obtained from Eq. 1) as well as 95 % confidence intervals is shown in Figure 4. The estimated values are in good agreement with the experimental values obtained in this study. The coefficient of correlation between estimated and experimental values is 80 %. In the other words, with a few exceptions, the differences between calculated and experimentally obtained values are within a range of ±2.65.

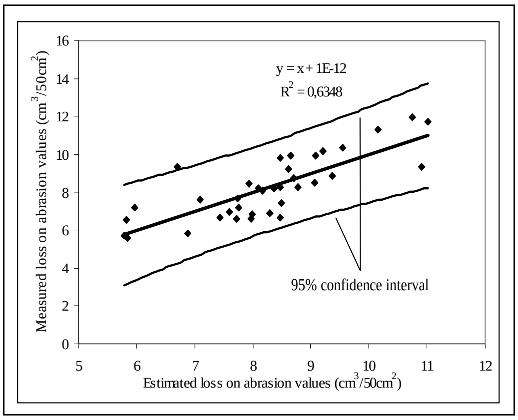

Figure 4. Comparison of experimental and calculated loss on abrasion values

5. CONCLUSIONS

1) The abrasion loss of high strength concrete can be estimated from compressive and flexural strength results. The proposed equation has a sufficient reliability.
2) The 30 % SF replacement of cement provided improvement in the mechanical properties and abrasion resistance of the concrete.
3) The presence of 25 % FA, as partial replacement for cement, caused significant reduction in strength values and abrasion resistance.
4) High strength concrete mixtures consist of 5, 10 and 15 % FA as an aggregate replacement (C4, C5, and C6), generally exhibited same mechanical properties and abrasion resistance with normal HSC (C1). Strength reduction of these mixtures (C4, C5, and C6) can be attributed entirely consumption of calcium hydroxide by SF and increase in W/Binder ratio by reason of raise in water requirement due to FA which is replaced with aggregate.

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