Green Concrete Produced by Fly Ash and Silica Fume

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Abstract- In the detailed study presented in this paper, an experimental study was conducted to investigate the fresh concrete and compressive strength of concrete when fly ash and silica fume were used. For compressive strength, concrete specimens at three water - binder ratios, namely 0.35, 0.50, 0.70 made with various combinations of Portland cement, fly ash, and silica fume were tested at 7, 28 days, and 1 year. The effects of fly ash, silica fume, water - binder ratio, and age were studied on produced 12 mixtures. From the test results, it was concluded that the more effective variable on concrete's performance was the water - binder ratio; it decreases the compressive strength and unit weight of the concrete.

Keywords Green concrete, Fly Ash, Silica Fume, Environmentally friendly concrete, Cementitious materials.

1. Introduction

Industrial and residential areas are needed for human being and it is a must to protect the environment while meeting these needs. Reinforced concrete structures are mostly used for this demand of human. Concrete, as the most common building material, is the main contributor of reinforced concrete, and the cement is binder material in concrete. The production of cement is very energy intensive and releases large amount of CO_2 into the atmosphere which is approximately 6 to 7 percent of all CO_2 produced worldwide [1]. Pozzolanic and cementitious materials, such as fly ash, granulated blast-furnace slag, natural pozzolans, silica fume, rice-husk ash and metakaolin, are becoming increasingly important to enhance the environmental friendliness of Portland cement concrete and to improve workability, durability, and other properties of the material [2]. Once the environmental effect of concrete industry could be reduced by using partial replacement of Portland cement by other pozzolanic and cementitious materials, the economic and environmental benefits may emerge, and thus environmentally friendly green concrete can gain more importance. Both fly ash and silica fume are by-products of industrial processes; fly ash is being produced during the generation of electricity in coal-burning power plants [3] and silica fume is by-product of resulting from the reduction of high-purity quartz with coal in electric arc furnaces in the manufactures of silicon and ferrosilicon alloys [4]. Therefore, a great deal of research aimed at understanding the properties of Portland cement and cementitious materials, such as fly ash and silica fume systems from past [5-8] to today [9-13].

In this work, an experimental study was conducted on fresh concrete and compressive strength as the basic engineering property of the concrete produced with and without fly ash and silica fume. Totally, 12 concrete mixtures were cast at water - binder ratios of 0.35, 0.50 and 0.70.

2. Experimental Details

2.1. Materials

Portland cement, fine aggregate, coarse aggregate, fly ash and silica fume were used in this study to produce concrete mixtures. ASTM Type I Portland cement PC42.5, density of 3107 kg/m^3 with an average compressive strength at 28 days of 50 MPa, was used in all concrete mixtures. Natural river sand was used as fine aggregate while crushed basalt stone was used as coarse aggregate. The maximum particle size of sand was 4 mm whereas it was 10 mm for No I crushed stone and 20 mm for No II crushed stone. The physical properties of the aggregates and grading are given in Table 1. The class C fly ash from Soma Thermal Power Plant, SiO_2 content of 49.1%, was used in concrete as cement replacement. The silica fume from Antalya Ferro-Chromium Plant, SiO_2 content of 91%, was used in concrete as additive to cement. The chemical analysis of the fly ash and silica fume is given in Table 2.

Table 1. Sieve analysis and physical properties of the aggregates

Sieve size (mm)	Sand	No. I Basalt	No. II Basalt
16.0	100	100	100
8.0	100	66.0	2.2
4.0	97.6	23.5	0.80
2.0	75.8	0.60	0.10
1.0	62.6	0.30	0.10
0.50	43.2	0.20	0.10
0.25	9.0	0.20	0.10
Fineness modulus	2.12	5.09	5.97
Specific gravity	2.55	2.92	2.91

Table 2. Chemical analysis of the silica fume and fly ash

Analysis Report	Silica Fume	Fly Ash
SiO_2 (wt. per cent)	91.00	49.10
Al_2O_3 (wt. per cent)	0.58	22.98
Fe_2O_3 (wt. per cent)	0.24	5.41
CaO (wt. per cent)	0.71	13.61
MgO (wt. per cent)	0.33	1.44
SO_3 (wt. per cent)	1.06	1.54
Cl^- (wt. per cent)	0.0879	0.0192
Na_2O (wt. per cent)	0.38	0.30
K_2O (wt. per cent)	4.34	1.13
H_2O (wt. per cent)	1.00	----
$CaCO_3$ (wt. per cent)	2.25	16.50
Insoluble Residue	----	----
Loss of Ignition (wt. per	1.84	2.10

2.2. Concrete Mixture Proportions

A total of 12 mixtures were produced at the laboratory. Concretes having different water/binder ratios and cementitious material content were casted. These twelve mixtures could be categorized into three groups with respect to the water to binding ratios (w/b). In the first group the w/b ratio was 0.35, and it was 0.50 and 0.70 for the second and third group, respectively. The mix proportions of concretes are given in Table 3, PC refers to Portland cement, SF refers to silica fume and FA refers to fly ash. In each group, first batch (A, E and I) was the control mix; neither fly ash nor silica fume was used in this control mix. In the second batch of each group (B, F and J) silica fume was added as an additive in amount of 10% of cement by weight. 15% of cement by weight was replaced by fly ash in the third batch of each group (C, G and K). In the fourth batch of each group (D, H and K) both silica fume and fly ash were used; silica fume was added as an additive in amount of 10% of cement weight and also 15% of cement by weight was replaced by fly ash. Concrete mixes in first and second group were designed to provide a slump of 15 ± 1 cm. For this reason superplasticizer was added to the first and second group concrete mixes to provide a sufficient slump value. In the third group batches having a w/b ratio of 0.70, superplasticizer was not used, since sufficient amount of slump was provided by water itself.

2.3. Properties Measured

The fresh concrete properties unit weight and slump were measured by ASTM C138 [14] and ASTM C143 [15], respectively. Compressive strength test was conducted on the 150 x 300 mm cylindrical specimens in accordance with ASTM C 39 [16], at the age of 7, 28 days and 1 year. In order to prevent stress concentration during the test, the specimens were capped with a sulphur-containing compound prior to the compressive test. Compressive strength tests were performed on a 2000 kN capacity testing machine in uniaxial compression up to the failure with a pace rate of 3.5 kN/s.

3. Experimental Results

3.1. Fresh Concrete Properties

Measured slump values and unit weight of the concrete specimens are given in Table 4. The required slump values were obtained for all mixes except batches K and L in the third group, which had slumps 19, and 21 cm, respectively. The slump results showed that using a superplasticizer could very well control workability of concrete. The mixes with a w/b ratio of 0.70, on the other hand, had higher and more variable slump values. The unit weights ranged from 2315 to 2499 kg/m^3. The unit weights of concrete specimens decreased with increasing w/b ratio as shown in Fig. 1.

Table 3. Mix proportions of concretes

Batch	A	B	C	D	E	F	G	H	I	J	K	L
w/b	0.35				0.50				0.70			
w/c	0.35	0.38	0.41	0.45	0.50	0.55	0.59	0.65	0.70	0.77	0.82	0.91
PC/SF/FA	100/0/0	100/10/0	85/0/15	85/10/15	100/0/0	100/10/0	85/0/15	85/10/15	100/0/0	100/10/0	85/0/15	85/10/15
Water	158.2	174.1	158.2	174.3	177.1	195.4	177.0	194.9	217.0	238.7	217.0	238.7
Cement	452.1	452.3	384.1	384.7	354.2	355.3	300.9	301.3	310	310	263.5	263.5
Silica fume	0	45.2	0	45.3	0	35.5	0	35.4	0	31	0	31
Fly ash	0	0	67.8	67.9	0	0	53.1	53.2	0	0	46.5	46.5
Sand	697.4	663.5	690.5	657.3	722.9	691.4	715.9	684.5	683.6	661.3	680.1	643.4
Basalt # I	691.4	657.9	684.6	651.7	716.7	685.5	709.7	678.7	677.7	655.7	674.2	637.7
Basalt # II	492.2	468.3	487.3	463.9	510.2	488	505.2	483.1	482.5	466.8	480.2	454.3
Superplasticizer	7.95	5.3	7.91	5.23	3.72	2.74	4.96	2.73	0	0	0	0

Table 4. Slump values and unit weights of the mixes

Batch	PC/SF/FA	w/b	Slump (cm)	Unit Weight (kg/m^3)
A	100/0/0	0.35	16	2499
B	100/10/0	0.35	14	2467
C	85/0/15	0.35	16	2480
D	85/10/15	0.35	14	2450
E	100/0/0	0.50	15	2485
F	100/10/0	0.50	14	2454
G	85/0/15	0.50	16	2467
H	85/10/15	0.50	15	2434
I	100/0/0	0.70	17	2371
J	100/10/0	0.70	17	2364
K	85/0/15	0.70	19	2362
L	85/10/15	0.70	21	2315

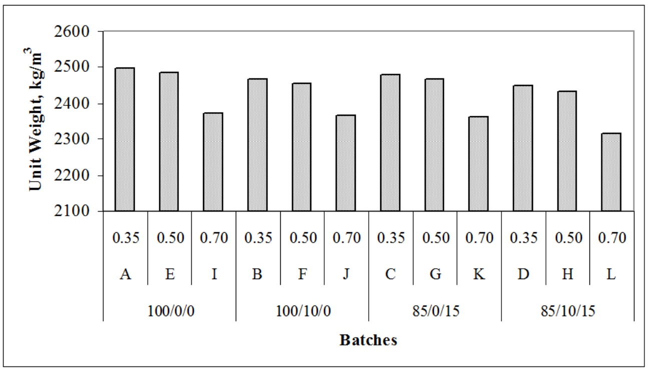

Fig. 1. Unit weight of concretes having a w/b ratio of 0.35, 0.50, and 0.70 and incorporating various combinations of cementitious material

3.2. Compressive Strength

The average compressive strength values of the concrete specimens at 7, 28 days and 1 year are given in Table 5. By taking the compressive strength values at 28 days as unity, the effect of age on compressive strength of concrete specimens and percent changes in the compressive strength are listed in Table 6 and depicted in Figs. 2, 3, and 4. The results show that compressive strength of the concrete specimens increased with time. Percent increase with time in compressive strength of concrete specimens made with both silica fume and fly ash cements was more than plain, fly ash, and silica fume concrete specimens at all w/b ratios. In plain concrete specimens the change in compressive strength with time was not as much of fly ash and silica fume concrete specimens. At w/b ratio of 0.35 the compressive strength of concrete specimens at one year were about 50 percent higher than the compressive strength of concrete specimens at seven days, on the other hand at w/b ratio of 0.50 and 0.70 the compressive strength of concrete specimens at one year were about 80 and 150 percent higher than the compressive strength of concrete specimens at seven days, respectively. These results indicated that reaction in the cement paste continues when water exists. They also showed that lower the w/b ratio, higher the early strength.

The effect of w/b ratio on compressive strength at 7, 28 days and 1 year is shown in Fig. 5. These results showed that decreasing the water content in the concrete specimens was improving the compressive strength of the concrete specimens. In plain and fly ash concretes the compressive strength of concrete specimens at w/b ratio of 0.50 and 0.70 were about 39 and 70 percent lower than the compressive strength of concrete specimens at w/b ratio of 0.35, respectively. In batches containing both silica fume and fly ash the compressive strength of concrete specimens at w/b ratio of 0.50 and 0.70 were about 33 and 69 percent lower than the compressive strength of concrete specimens at w/b ratio of 0.35, respectively. In silica fume concretes the compressive strength of concrete specimens at w/b ratio of 0.50 and 0.70 were about 20 and 55 percent lower than the compressive strength of concrete specimens at w/b ratio of 0.35, respectively. Among all types of concrete specimens tested for compressive strength silica fume concrete specimens were less affected by the decrease of w/b ratio.

Table 5. Compressive strengths of concretes at 7, 28 days and 1 year

Batch	PC/SF/FA	$f_{c,7days}$ (MPa)	$f_{c,28days}$ (MPa)	$f_{c,1year}$ (MPa)
A	100/0/0	52.9	71.3	73.6
B	100/10/0	46.8	66.0	69.2
C	85/0/15	53.3	72.4	76.1
D	85/10/15	47.9	60.6	80.0
E	100/0/0	34.0	43.4	45.1
F	100/10/0	35.5	53.6	56.5
G	85/0/15	28.4	44.6	49.7
H	85/10/15	28.8	45.2	54.1
I	100/0/0	13.6	20.9	24.8
J	100/10/0	16.2	35.0	43.3
K	85/0/15	10.3	21.1	26.4
L	85/10/15	11.4	20.7	26.9

Table 6. Effect of age on compressive strength of concretes and percent change with respect to the reference concretes at 28 days

Batch	PC/SF/FA	$f_{c,7days}$	$f_{c,28days}$	$f_{c,1year}$
A	100/0/0	-26%	1	3%
B	100/10/0	-29%	1	5%
C	85/0/15	-26%	1	5%
D	85/10/15	-21%	1	32%
E	100/0/0	-22%	1	4%
F	100/10/0	-34%	1	5%
G	85/0/15	-36%	1	11%
H	85/10/15	-36%	1	20%
I	100/0/0	-35%	1	19%
J	100/10/0	-54%	1	24%
K	85/0/15	-51%	1	25%
L	85/10/15	-45%	1	30%

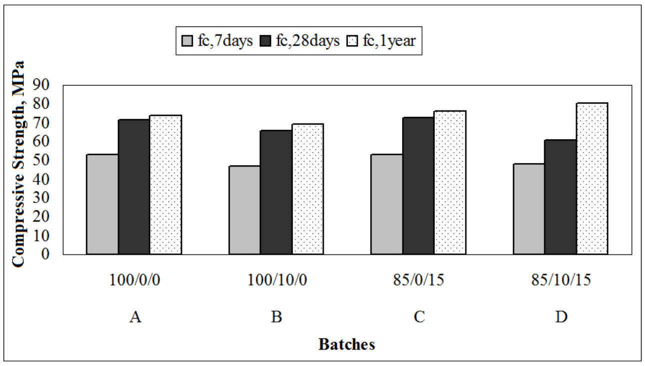

Fig. 2. Effect of age on compressive strength of concretes at 7, 28 days and 1 year having a w/b ratio of 0.35 and incorporating various combinations of cementitious material

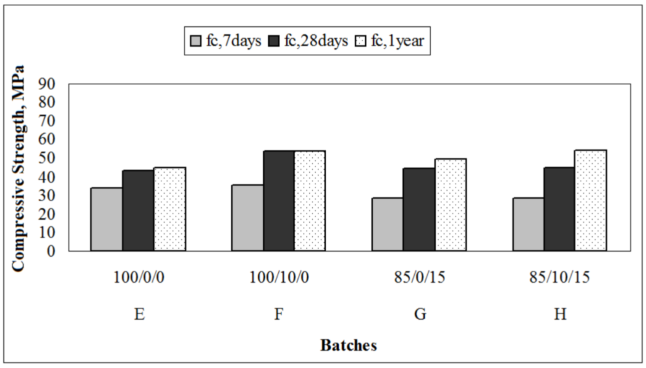

Fig. 3. Effect of age on compressive strength of concretes at 7, 28 days and 1 year having a w/b ratio of 0.50 and incorporating various combinations of cementitious material

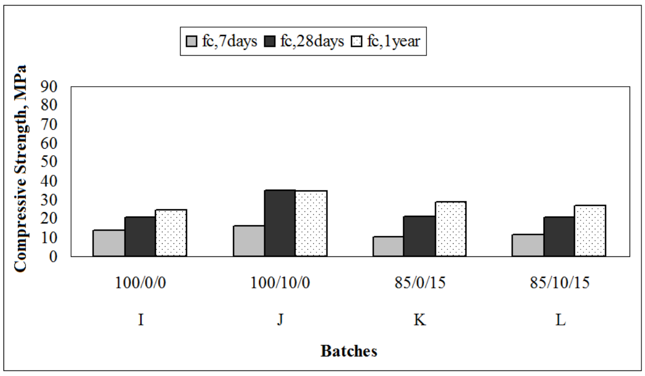

Fig. 4. Effect of age on compressive strength of concretes at 7, 28 days and 1 year having a w/b ratio of 0.70 and incorporating various combinations of cementitious material

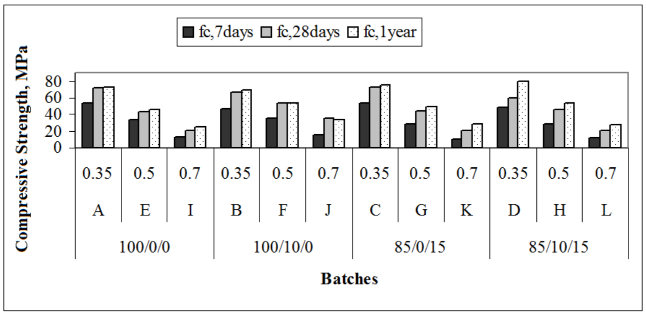

Fig. 5. Effect of w/b ratio on compressive strength of concretes at 7, 28 days and 1 year and incorporating various combinations of cementitious material

By taking the A, E, and I batches as reference batches, the effect of binding material on compressive strength of concrete specimens and percent changes in the compressive strength are listed in Table 7 and depicted in Figs. 6, 7, and 8. While at 7 days the compressive strength of concrete specimens made with fly ash was lower than the plain concrete specimens, at 28 days and one year it was higher. The positive effect of silica fume on the compressive strength of concrete specimens could be observed especially in higher w/b ratios. Using both silica fume and fly ash in concrete gave a higher compressive strength values at later ages. Similar results were reported by other authors [5, 6].

Table 7. Effect of binding material on compressive strength of concretes and per cent change with respect to the reference concretes named A, E, and I

Batch	PC/SF/FA	$f_{c,7days}$	$f_{c,28days}$	$f_{c,1year}$
A	100/0/0	0%	0%	0%
B	100/10/0	-12%	-7%	-6%
C	85/0/15	1%	2%	3%
D	85/10/15	-9%	-15%	9%
E	100/0/0	0%	0%	0%
F	100/10/0	5%	24%	19%
G	85/0/15	-16%	3%	10%
H	85/10/15	-15%	4%	20%
I	100/0/0	0%	0%	0%
J	100/10/0	18%	68%	39%
K	85/0/15	-24%	1%	16%
L	85/10/15	-16%	-1%	8%

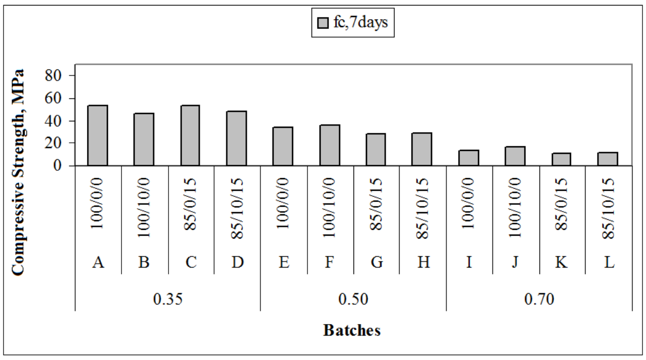

Fig. 6. Effect of binding material on compressive strength of concretes at 7 days and incorporating various w/b ratios

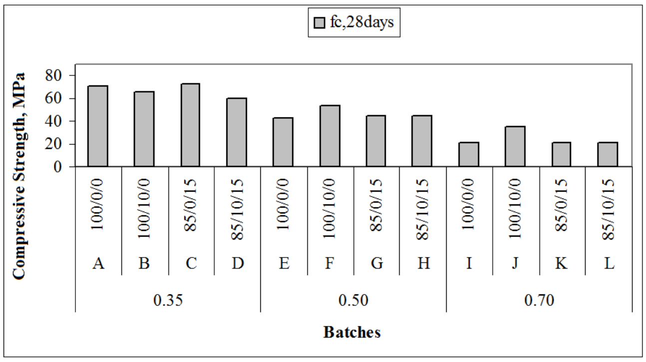

Fig. 7. Effect of binding material on compressive strength of concretes at 28 days and incorporating various w/b ratios

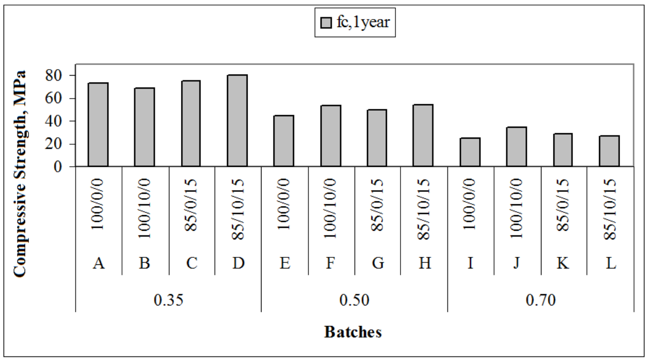

Fig. 8. Effect of binding material on compressive strength of concretes at 1 year and incorporating various w/b ratios

4. Conclusion

The conclusions from this study are:
1. Rising in water-binder ratio decreased the unit weight of the concrete.
2. Compressive strength of all the concrete specimens continued to increase up to one year. Strength gain in concrete specimens made with silica fume and fly ash cements are more than plain, fly ash, and silica fume concrete specimens, comparatively.
3. The reduction in compressive strength of the concrete specimens was primarily due to increased water binder ratio.
4. A relatively higher compressive strength was observed in silica fume concrete specimens compared to that noted in concrete specimens made with Portland cement, fly ash cement, and fly ash and silica fume cements.

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