

Capillary Water Absorption and Strength of Concretes with Binary and Ternary Blends of SF and FA

Kasım Mermerdaş

Harran University, Faculty of Engineering
Department of civil engineering
Şanlıurfa, Turkey
kasim.mermerdas@harran.edu.tr

Farman Khalil Ghaffoori

Hasan Kalyoncu University, Faculty of Engineering
Department of civil engineering
Gaziantep, Turkey
farman_gh@yahoo.com

Abstract— The aim of the paper is to compare the strength and capillary water absorption (sorptivity) performances of the concretes incorporating various replacement levels of silica fume (SF) and fly ash (FA). The study was carried out on water cured and air cured concretes produced by w/b ratio of 0.45 with total binder content of 400 kg/m³. Total 9 different concrete mixtures with binary and ternary blends of SF and FA were produced. The results indicated that incorporation of SF significantly improved both strength and sorptivity of concretes while FA had an adverse effect on strength.

Keywords- Silica fume, fly ash, sorptivity, strength, curing regimes.

I. INTRODUCTION

Being an index of moisture transport into unsaturated cement based materials; sorptivity has been recognized as an important indication of concrete durability. The value of sorptivity illustrates the water mass uptake by concrete from the bottom surface based on water flowing into the concrete through large connected pores. The test method used generally reflects the way how water penetrates into concrete transporting harmful agents. Specifically, it is a good measure of the quality of near surface concrete, which governs durability of reinforced concrete in relation to reinforcement corrosion. The sorptivity coefficient is essential to predict the service life of concrete as a long lasting structural material [1]. It is a property associated with capillary effects. Sorption means water ingress into pores under unsaturated conditions due to capillary suction. The sorptivity test measures the ability of concrete to absorb water. Equation 1 is used to express sorptivity index which is derived from the relationship between the volume of water absorbed per unit of cross-section (i) and the square root of time (t)

$$S = \frac{i}{\sqrt{t}} \quad (1)$$

Where i is the depth of penetrated water at different time intervals (mm).

Fly ash is a by-product of the combustion of coal in thermal power plants, which is capable of reacting with $\text{Ca}(\text{OH})_2$ at room temperature. The pozzolanic activity of fly ash depends on the presence of SiO_2 and Al_2O_3 in the amorphous form [2-4]. The use of fly ash in concrete technology dates back 1930s [5]. It is estimated that about 450 million tons of fly ash is produced worldwide annually, but only 6% of the total available is used as pozzolan in blended cements or in concrete mixtures [2].

Silica fume is a by-product resulting from the reduction of high-purity quartz with coal or coke and wood chips in an electric arc furnace during the production of silicon metal or ferrosilicon alloys. The silica fume, which condenses from the gases escaping from the furnaces, has a very high content of amorphous silicon dioxide and consists of very fine spherical particles [6].

For the experimental study, nine different concrete mixtures with w/b ratios of 0.45 were designed. The mineral admixtures used to obtain binary and ternary system mixes are fly ash (FA) and silica fume (SF). Two different curing regimes namely, water curing and air curing were adopted to monitor 28-day compressive strength and sorptivity of the concretes.

II. EXPERIMENTAL STUDY

A. Materials

CEM I 42.5 R type Portland cement having specific gravity of 3.14 and Blaine fineness of 327 m²/kg was utilized for preparing the concrete production for compressive strength and sorptivity testing. The chemical composition of the cement is shown in Table 1.

Fly ash (FA) used was a class F type according to ASTM C 618 [7] was supplied from Ceyhan Sugözü thermal Power Plant. It had a specific gravity of 2.25 and the Blaine fineness of 287 m²/kg. A physical and chemical property of the fly ash is given in Table 1.

A commercial grade silica fume (SF) obtained from Norway was utilized in this study. It had a specific gravity of 2.2 and the specific surface area (Nitrogen BET Surface Area) of 21080 m²/kg. In Table 1, both the chemical analysis and physical properties of SF is provided.

The coarse aggregate (medium aggregate) used was river crushed stone gravel with a nominal size between of 2 and 16 mm. As fine aggregate, a crushed limestone was used with a maximum size of 4 mm. The coarse aggregate (medium aggregate) had a specific gravity of 2.65. The specific gravity of crushed limestone was 2.45. The particle size gradation obtained through the sieve analysis of the fine and coarse aggregates are presented in Figure 1. Fuller parabola [8] was used as reference for adjusting proper grading. Eq. 2 is the mathematical expression of Fuller’s curve.

$$dp_i = 100 \times \sqrt{\frac{d_i}{d_{max}}} \quad (9)$$

Where dp_i percent passing from sieve size of i is, d_i is sieve size, d_{max} is the maximum aggregate size (16 mm for this study).

A sulphonated naphthalene formaldehyde type superplasticizer (SP) with a specific gravity of 1.19 and pH of 5.7 was used in all mixtures and used to achieve the target workability.

TABLE I. CHEMICAL COMPOSITIONS AND PHYSICAL PROPERTIES OF PORTLAND CEMENT, FLY ASH AND SILICA FUME.

Analysis Report (%)	Cement	Fly ash	Silica fume
CaO	62.58	4.24	0.45
SiO ₂	20.25	56.2	90.36
Al ₂ O ₃	5.31	20.17	0.71
Fe ₂ O ₃	4.04	6.69	1.31
MgO	2.82	1.92	0
SO ₃	2.73	0.49	0.41
K ₂ O	0.92	1.89	1.52
Na ₂ O	0.22	0.58	0.45
Loss on ignition	3.02	1.78	3.11
Specific gravity	3.14	2.25	2.2
Fineness (m ² /kg)	327(Blaine)	287(Blaine)	21080(Bet)

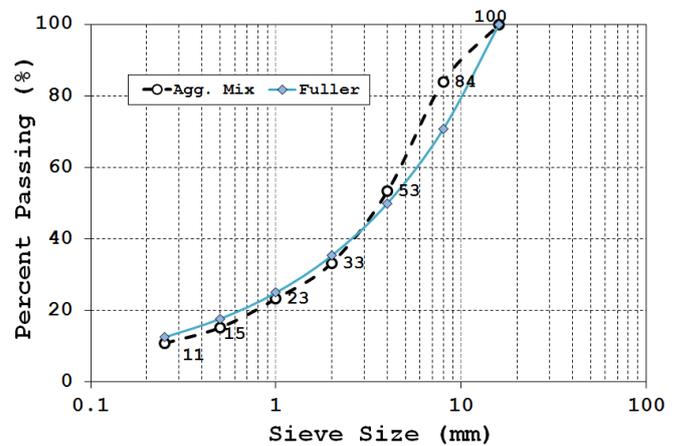


Figure 1. Grading of aggregate mix and reference curves.

B. Mix proportions

A total of 9 mixtures were designed at water/binder ratio (w/b) of 0.45. In the design of the concrete mixtures, the total cementitious materials content was 400 kg/m³. In the production of such concretes the mineral admixtures used were FA and SF. Table 2 indicates the mix proportions used in the study. The mixture SF0FA0 in Table 2 was designated as the control mixture which included only ordinary Portland cement as the binder while the remaining mixtures incorporated binary [(SF=0%, FA=10%), (SF=0%, FA=20%), (SF=5%, FA=0%), (SF=15%, FA=0%)] and ternary [(SF=5%, FA=10%), (SF=5%, FA=20%), (SF=15%, FA=10%), (SF=15%, FA=20%)] blends of SF and FA.

C. Specimen Preparation and Curing

All concretes were mixed in accordance with ASTM C192 [9] standard in a power driven rotating pan mixer with a 20 l capacity. All samples were poured into the steel molds in two layers, each of which being vibrated for a couple of seconds.

After casting the molded specimens were protected with a plastic sheet and left in the casting room for 24 hr. Thereafter, the samples were demolded and cured in water and air until the testing age. The testing age was selected as 28 days. Although longer time may be better to monitor the effectiveness of the minerals on the properties of the concretes, due to the high pozzolanic reactivity of SF 28 days of moist curing was decided to be enough.

D. Test Methods

The compression test was carried out on the specimens by a 3000 kN capacity testing machine. Compressive strength test was conducted at the ages of 28 days on three 150 mm cube samples for each concrete mixture. The test was conducted per ASTM C39 [10].

The sorptivity test measures the rate at which water is drawn into the pores of concrete. For this, three test specimens having a dimension of 100x100x100 mm are employed. The

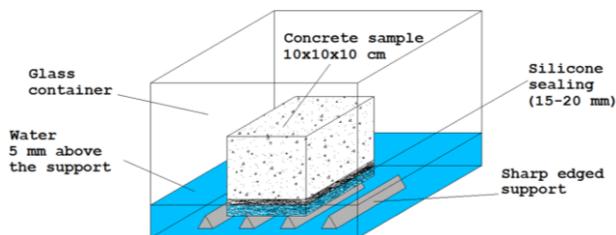
TABLE II. CONCRETE MIXTURE PROPORTIONING AT A W/B RATIO OF 0.45 (KG/M³)

Materials	Mixture designations								
	SF0FA0	SF0FA10	SF0FA20	SF5FA0	SF5FA10	SF5FA20	SF15FA0	SF15FA10	SF15FA20
Cement	400	360	320	380	340	300	340	300	260
FA	0	40	80	0	40	80	0	40	80
SF	0	0	0	20	20	20	60	60	60
Water	180	180	180	180	180	180	180	180	180
Fine Aggregate	970.8	962.9	954.4	965.4	956.9	949	957.3	949.8	942.8
Coarse aggregate	812.7	806	798.9	808.1	801	794.3	801.3	795.1	789.2
Superplasticizer	4.4	3.2	2.4	6.4	5.6	4.4	8	6.4	4.4

III. EXPERIMENTAL RESULTS

specimens are dried in an oven at about 80 °C until constant mass and then allowed to cool to the ambient temperature in a sealed container. Afterwards, the sides of the specimens are coated by silicone and as shown in Fig. 2, the sorptivity test is carried out by placing the specimens on sharp edged rods in a tray such that their bottom surface up to a height of 5 mm is in contact with water. This procedure is considered to allow free water movement through the bottom surface. The total surface area of water within the tray should not be less than 10 times that of the specimen cross-sectional area. The specimens are removed from the tray and weighed at different time intervals up to 1 hour to evaluate mass gain. The volume of water absorbed is calculated by dividing the mass gained by the nominal surface area of the specimen and by the density of water. These values are plotted against the square root of time. The slope of the line of the best fit is defined as the sorptivity coefficient of concrete. For each test, the measurements are obtained from three specimens and the average values are reported. The test was conducted at the age of 28 days.

The data concerning the variation of compressive strength with curing condition and mineral admixture were graphically indicated in Figure 3. The strength values of the plain air cured and water cured concretes are 66.44 and 78.53 MPa, respectively. The highest compressive strength of concretes for air and water curing are 75.37 and 87.5 MPa, respectively. These values were observed for SF5FA0 concrete. Figure 3 indicated that there was an increase in compressive strength with the increase in SF content. This is more pronounced for concretes subjected to water cured concretes than that of air cured ones. However, addition of FA to concrete mixes decreased compressive strength systematically.



a



b

Figure 2. a) Sorptivity test set up, b) Photographic view of the test set up

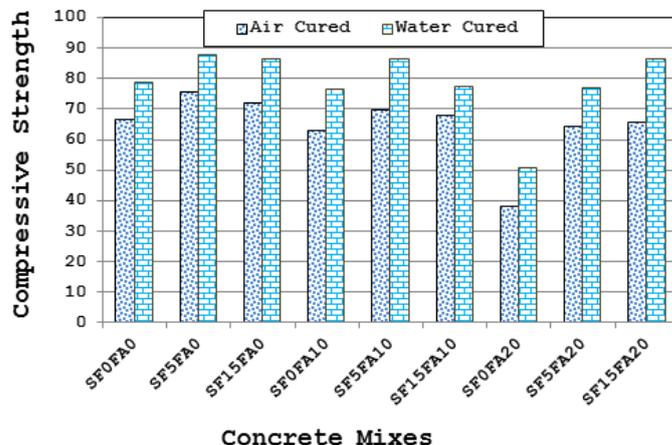


Figure 3. Compressive strength results for air and water cured.

The change in sorptivity values of water cured and air cured concretes with various replacement levels of SF and FA the age of 28 days is illustrated in Figure 4. From the figure it can be noted that the sorptivity of SF5FA10 concrete is lowest while SF0FA10 has highest value for water cured concretes. For air cured concretes, the lowest and highest sorptivity values were measured for SF5FA20 and SF0FA20 concretes, respectively. These variations can be attributed to the pozzolanic behaviors and amounts of FA and SF in concrete mixtures. Utilization of binary and ternary mix compositions of FA and SF to improve the performance of the cementitious composite has been proved to be an acceptable practice [11].

REFERENCES

[1] S.A. Al-Sheikh, "Study of sorptivity of self-compacting concrete with different chemical admixtures," Concrete Research Letters, 2013, pp. 639-655.

[2] M. Baker, (). "Evaluation on the utilization options, combustion by products utilization manual" EPRI report no. CS-3122, 1984.

[3] M. Gesoğlu, E. Özbay, (). "Effects of mineral admixtures on fresh and hardened properties of self-compacting concretes: binary, ternary and quaternary systems" Materials and Structures, 2007, DOI 10.1617/s11527-007-9242-0.

[4] T.R. Naik, S.S. Singh, "Influence of fly ash on the setting and hardening characteristics of concrete systems". ACI Material Journal, 1997, pp.355-360.

[5] Ö. Şengül, "Effects of pozzolanic materials on the mechanical properties and chloride diffusivity of concrete" PhD thesis, Istanbul Technical University, Istanbul, Turkey, 2005.

[6] E. Özbay, "Effects of mineral admixtures on the fresh and hardened properties of self-compacting concretes: binary, ternary and quaternary systems" PhD thesis, Gaziantep University, Turkey, 2007.

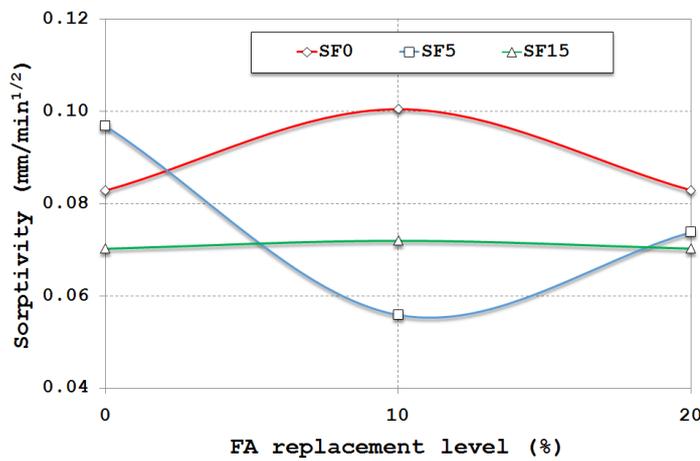
[7] ASTM C618-08, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. American society for testing and materials," Annual book of ASTM standards, vol. 04.02, West Conshohocken, PA: ASTM, 2008.

[8] A.M. Neville "Properties of Concrete," 4th and final ed. Addison Wesley Logman, England, 1996.

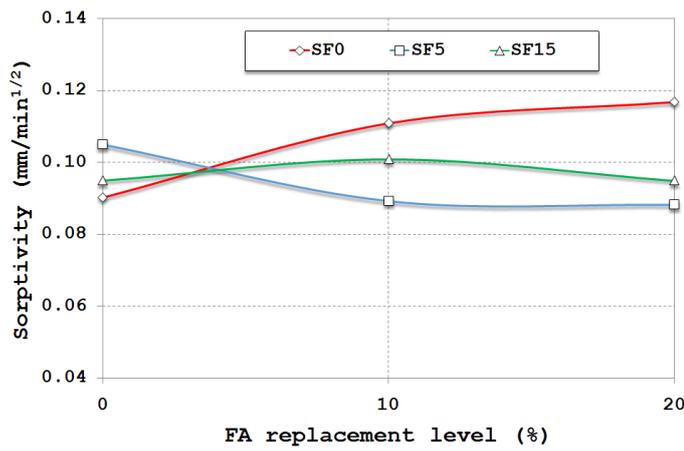
[9] ASTM C192-14. "Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. American society for testing and materials," Annual book of ASTM standards, vol. 04.02, West Conshohocken, PA: ASTM, 2014.

[10] ASTM C39, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. American society for testing and materials," Annual book of ASTM standards, vol. 04.02. West Conshohocken, PA: ASTM, 2012.

[11] K. Türk "Viscosity and hardened properties of self-compacting mortars with binary and ternary cementitious blends of fly ash and silica fume" Construction and Building Materials 2012, pp. 326-334



a)



b)

Figure 3. Sorptivity values of a) water cured, b) air cured concretes

IV. CONCLUSIONS

- Experimental study indicated that utilization of silica fume and fly ash effects the sorptivity behaviors of concretes significantly.
- When considering silica fume incorporated concretes produced in experimental stage, 5% silica fume and 0% replacement of fly ash was found to be the most effective substitution level for improving the concrete strength for 28 days for water-curing.
- Sorptivity test results revealed that 10 and 20% replacement of fly ash with 5% replacement of silica fume at 28-day testing in air-cured condition revealed the lowest values. But for water-curing case, due to 10% replacement of fly ash with 5% replacement of silica fume significantly lower sorptivity value was measured.