The Effects of Fly Ash and Silica Fume Content on the Compressive, Flexural, Splitting Tensile Strength and Water Absorption of Concrete

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Abstract— **High performance concrete is concrete that meets a particular combination of performance and uniformity requirements. This paper compares the compressive, flexural, and splitting strengths of three types of concrete with different proportions of fly ash and silica fume at 180 days of age and their water absorption at 90 days of age. The result shows that the effect of silica fume concrete is greater than that of fly ash concrete and the combination of fly ash and silica fume in the same concrete mix gives the average values. Moreover, fly ash concrete has the lowest water absorption value.**

Keywords—fly ash; silica fume; high-performance concrete; concrete properties

I. Introduction

Cement substitutes are frequently used in concrete technology. Several researchers have studied high performance concrete after the addition of mineral admixtures, but more research is needed to determine the optimum dosage of these materials, such as fly ash and silica fume. This paper compares the mechanical properties (compressive strength, flexural strength and splitting tensile strength) of three types of concrete at 180 days of age and water absorption at 90 days of age. The study is based on laboratory experiments and the methodology is described in the part III. The result showed that the effect of adding 12% silica fume as a substitute for cement in the concrete mix was greater than the effect of adding 20% fly ash. Moreover, the effect of combination between fly ash and silica fume slightly improved the strength of concrete. The results are presented in the part IV. The results presented in this paper will increase the interest of those who want to improve the use of mineral intermediate mixes in HPC.

II. Preliminaries

High performance concrete (HPC) is characterized by massive compressive strength and excellent durability compared to other types of concrete, which can be improved by the use of additives such as fly ash and silica fume. HSC has become a widely used material and is widely used in construction. A superplasticizer is also required in the admixture to achieve the required properties; in addition, various types of additives are typically added to reduce the porosity.

Silica Fume (SF) is a by-product of processing plain silicone or silicone alloys in an electric arc furnace. During the reduction of high purity quartz to silicon, silica fume is formed at about 2000 °C, which changes its physical state at low temperatures and becomes silica fume. Silica fume has a solid surface and extremely fine average particle sizes of 0.1-0.3 m [1]. To improve workability, the early slump of fresh concrete is increased. The effect of silica fume on rheological products has shown to reduce bleeding [2, 3]. The results of the tests showed that silica fume plays a minor role in the development and stabilization of the air avoidance system.

Fly ash (FA) is characterized by the presence of small carbon-burned fragments and is used in a variety of ways. Fly ash, which is produced when coal is burned in power plants, causes significant environmental and economic problems in several countries. It has been used to improve the effectiveness of Acid Mine Drainage (AMD) caused by the oxidation of sulfide rich mining wastes [4]. It is a very popular mineral mixture available only in states with coal-fired power plants. J. Junak et al [5] used different types of waste materials including coal fly ash in their laboratory experiments and found significant improvement in compressive strength of concrete. B. V. Kavyateja et al [6] studied the effect of fly ash (25%) and Alccofine (0, 5, 10, 15%) as a replacement material in reinforced self-compacting concrete beams. Compared to a standard concrete beam, fly ash and alccofine increased the bearing capacity and strength of the beam.

In order to understand the effect of silica fume and fly ash additives on HPC and to test the mechanical properties of this type of concrete, a test program was carried out in which silica fume, fly ash and both with percentage (12%, 20% and 12% + 20%) were added to HPC mix. The flow fish test of fresh concrete, compressive strength, flexural strength, split tensile test after 180 days and water absorption test after 90 days were part of the study.

TABLE I. CHEMICAL ARRANGEMENTS OF MATERIALS [8]

Materials	Chemical Arrangements of Materials (%)						
	SiO_2	***Al_2O_3***	***Fe_2O_3***	***Cao***	***MgO***	***NaO_2^{Eq}***	***Clinker***
Cement CIM I 52.5 N	20.50	4.40	2.30	63.30	2.10	0.66	97.00
Fly ash	52.00	25.00	7.00	5.00	-	-	-
Silica fume	93.45	0.17	0.69	0.03	-	-	-

III. THE PROPOSED METHOD

A. Materials

A type CEM I 52.5 N [7] Cement with a specific gravity of 3.13 g/cm3 and Blaine fineness of 410 kg/m2 was used in the test mix. Silica fume is a powdered concrete admixture containing highly effective fine particles to produce high-performance concrete. Table I shows that the specific gravity of silica fume is 2.2 g/cm3. Microsite20 fly ash was used in the experiment, which is an excellent latent hydraulic cement admixture type II for the production of high-quality concretes and mortars. Microsite20 is classified as an aluminosilicate because it is mainly composed of SiO2 and Al2O3.

The maximum aggregate size is 16 mm, the specific gravity for fractions 4-16 mm is 2.61 g/cm^3, and the aggregate has water absorption of 0.6%. The aggregate was sieved, which aided distinguish two sizes of fractions, 4-8 mm, and 8-16 mm, with percentages of 24.7% and 39.2%, respectively. The percentage of good-round natural fine aggregate used was 36.1% as a sand 0-4 mm with specific gravity 2.62 g/cm^3 and water absorption of 0.2%. All the grain size distribution curves are shown in Fig. 1. The superplasticizer (SP) was Sika ViscoCrete-5-500, a third-generation superplasticizer used to produce soft plastic concrete as well as state-of-the-art Self-Compacting Concrete (SCC). The superplasticizer-specific gravity ranged between 1.07 g/cm^3 and 1.07 g/cm^3 depending on the dose rate.

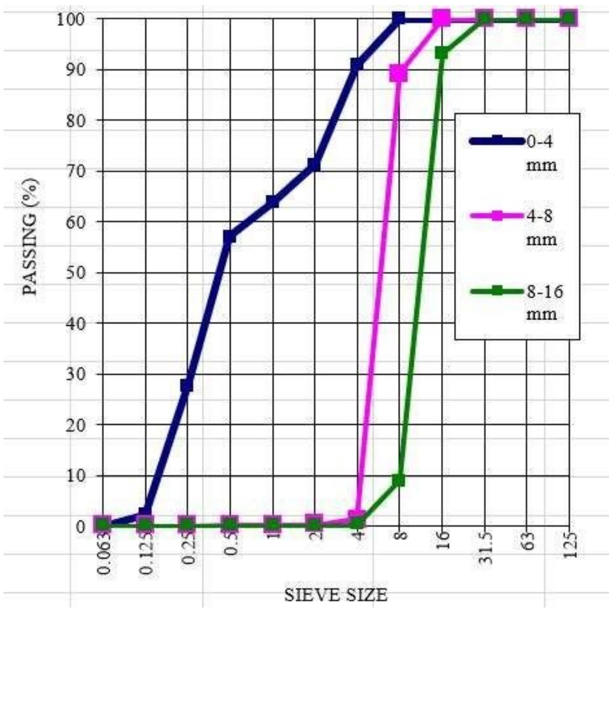

TABLE II. CONCRETE ADMIXTURE PROPORTIONS [8]

Criterion	Concrete Admixture Proportions		
	Mix 1	***Mix 2***	***Mix 3***
Cement (360 kg/m^3)	288	317	245
Coarse aggregate (kg/m^3)	1209	1209	1209
Fine aggregate (kg/m^3)	686	686	686
Water (kg/m^3)	144	144	144
Silica fume (kg/m^3)	-	43	43
Fly ash (kg/m3)	72	-	72
Superplasticizer (% binder)	1.0	1.2	1.1

B. Mix amount

Three different types of concrete, each with different admixtures, were prepared to test the compressive strength, flexural strength, and splitting tensile strength of concrete after 180 days. Nine specimens from each mix were used for these tests. In addition, water absorption at 90 days of age was tested. Mixture 1 contained 20% fly ash by weight of cement, mixture 2 contained 12% silica fume by weight of cement, and mixture 3 contained 20% fly ash and 12% silica fume by weight of cement. The water to cement ratio (W/C) remained constant at 0.4 while the cement weight was fixed at 360 kg/m3. As shown in Table II, these cement quantities were selected after experimenting with different mixes with different W/C values to achieve a concrete with superior performance and high strength.

C. Speciemens preparation and method of test

After a minute, the water has precisely added to the dry materials, and once the admixture began to mix, the superplasticizer has added to provide a perfect concrete mix. The next step was a flow table test to evaluate the consistency of fresh concrete and determine its workability. The cube, cylinder, and prism molds were prepared for casting the concrete. After that, the specimens were kept in the room for 24 hours, then cured in water for 7 days before being returned to the room until the day of testing. The specimens' manufacturing processes are shown in Fig. 2.

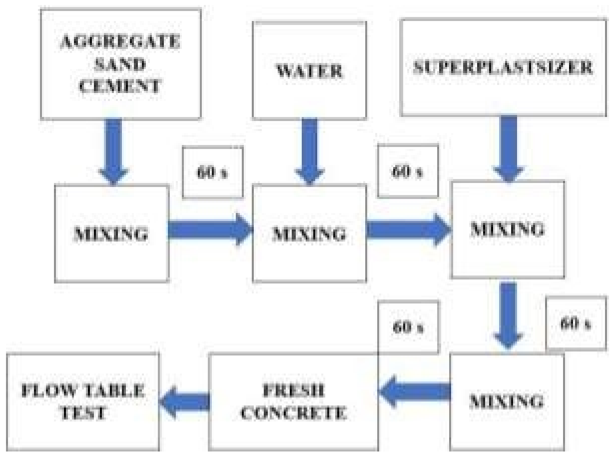

Fig. 2. Manufactoring process of speciemens [8]

Fig. 3. Compressive strength test in progress [8]

D. Compressive strength test

The compressive strength test used three cubical specimens for each mixture, for a total of 9, with a size of 150×150×150 mm. Three samples were tested per mixture at 180 days, following the MSZ EN 12390-3:2019 standard [9] (Fig. 3).

E. Flextural strength test

The flexural strength test was performed using three prismatic specimens per mixture with a size of 70×250×250 mm at 180 days, in accordance with the MSZ EN 12390-5:2006 standard [10] (Fig. 4).

F. Splitting tensile strength test

Three plus cylindrical specimens with a size of 150×300 mm were prepared for the splitting tensile test per mixture at the age of 180 days, in accordance with the MSZ EN 12390-6:2001 standard [11] (Fig. 5).

G. Water absorption test

Three cubical specimens for each mix have been used, with a size of 150×150×150 mm. The samples were tested at age of 90 days, following the MSZ EN 772-11: 2011 standard [12].

Fig. 4. Flexural strength test in progress [8]

Fig. 5. Splitting tensile strength test in progress [8]

IV. RESULTS AND DISCUSSION

All the tests of the research program have been performed with the three types of admixtures, which included the flow table test of fresh concrete, the compressive strength, flexural strength, and splitting tensile strength tests of the specimens at 180 of age, separately. In addition, the water absorption test had carried out at 90 days of age. In the following, the results of the tests will be presented, compared with the results of parallel research found in the literature.

A. Fresh concrete properties

The slump test was used to evaluate all concrete admixtures to achieve F3 (420-480 mm) class plastic consistency according to MSZ EN 12350-5:2019 standard [12] by adding different amounts of SP. As a result, the flow table test range was set at 420-430 mm for all concrete mixes. During the process, the SP amount varied depending on the concrete mix type; the concrete mix with 20% fly ash as cement replacement had a lower SP than the concrete mix with 12% silica fume. Other researchers, [13] and [14], have confirmed this result. According to their result, the excessive adsorption of SP is caused by the large surface zone of the silica fume particles, which reduces the volume in solution on the outer surface of the cement particles and thus the liquidity of the cementitious mixtures.

B. Compressive strength (CS)

The results of the compressive strength test for all mixes after 180 days are shown in Fig. 6. The range of this test was 83.3-89.6 MPa for all types. Mix 2 (89.6 MPa) with 12% silica fume gave the highest CS result. The second highest CS value at 180 days was for Mix 1 (85.0 MPa) made with a 20% replacement of cement with fly ash, and the lowest value (83.3 MPa) was for the concrete containing a combination of silica fume and fly ash. While the results of CS at 28 and 90 days of age showed that the concrete containing the combination of fly ash and silica fume had the second value of CS [8].

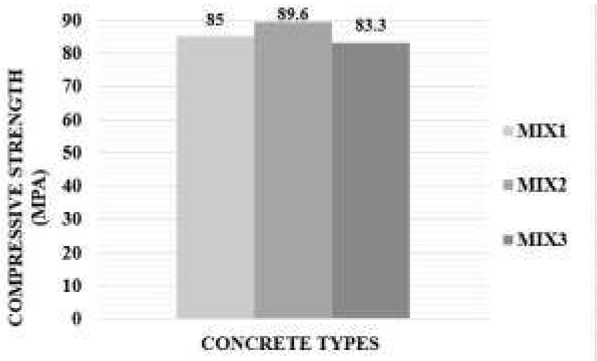

Fig. 7. Compressive strength results at age 180 days

C. Flexural strength (FS)

Continuously, for the FS results at 28 days and 90 days of age [8], the concrete mixes had the same behavior at 180 days of age. Compared to the concrete with 20% fly ash, the concrete with 12% silica fume showed the greater value (10.8 MPa), while the average value of FS for the concrete with 12% silica fume plus 20% fly ash was 8.9 MPa. Moreover, fly ash had a slightly negative effect on FS in Mix 1 compared to Mix 3, as shown in Fig. 7.

D. Splitting tensile strength (STS)

The STS for all concrete mixes were 4.88, 4.3, and 4.5 MPa for Mix1, Mix2, and Mix3, respectively. Concrete containing 20% FA had the highest value of 4.88 MPa in STS. Therefore, according to the results, fly ash could be a good admixture material to increase the splitting tensile strength of concrete at both ages of 180 days. When the results at 28 and 90 days of age were compared [8], the concrete mixes at 180 days of age showed the same behavior although the values were very close. Whereas the fly ash concrete still showed the highest number. As shown in Fig. 8.

E. Water absorption

Water absorption was measured for all concrete admixtures by the covering of three 150×150×150 mm cubes in water until the samples were fully saturated. The specimens were then dried in an over at 50-60 °C until completely dry. Relative masses were recorded for obtaining the water absorption after

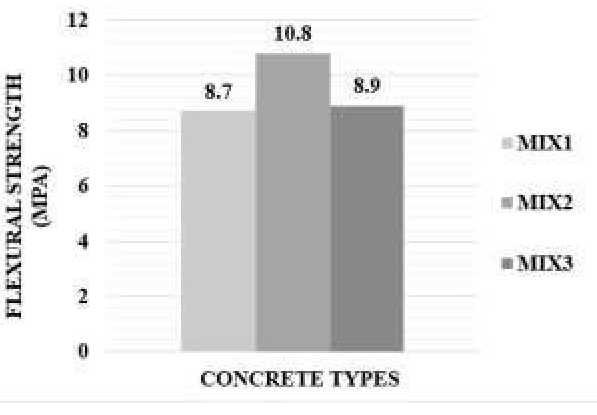

Fig. 9. Flexural strength results at age 180 days

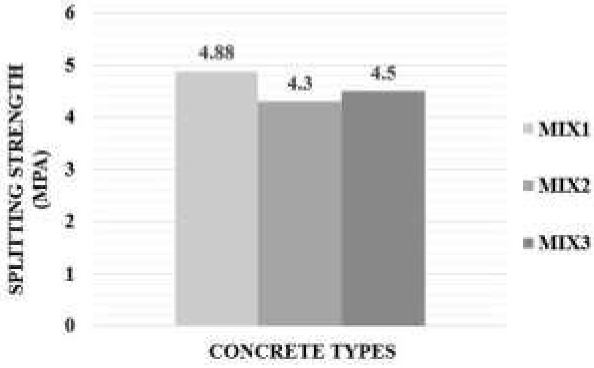

Fig. 6. Splitting tensile strength results at age 180 days

90 days. The conducted test had certain limitations in that it could only measure the volume of accessible pores and thus did not represent the porosity of the concrete. Figure 9 shows that the fly ash concrete has the lowest value of water absorption, compared to the silica fume concrete. This behaviour could be related to the grading particle distribution of fly ash, which aided in filling the pores inside the concrete.

V. CONCLOUSIONS

This paper presents an experimental program to describe the effect of treating conditions on the high-performance concrete with two percentages of fly ash and silica fume to determine the best mix of FA, SF, or their combination in terms of concrete. Compressive strength, flexural strength, splitting tensile strength, and water absorption were the main tests in this paper. Based on the findings, the following conclusions can be drawn:

- Compressive strength had the top value (89.6 MPa) at the age of 180 days in the concrete type that contains 12% silica fume, where the impact of 20% of fly ash as supplementary material in the concrete admixture provided the smallest values. However, a combination of minerals with the same percentages had improved the compressive strength compared with Mix 1.
- For the superplasticizer demand, concrete containing 20% fly ash was lower than concrete containing 12% silica fume. The large surface area of silica fume

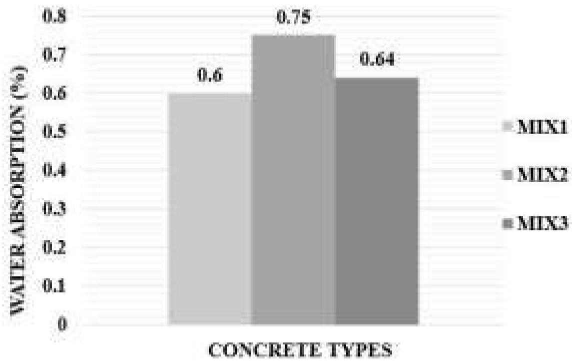

Fig. 8. Water absorption results at age 90 days

particles is responsible for this result.

- The perfect grading distribution of fly ash particles provided the lowest value of the water absorption test, unlike the silica fume particles, which had the greatest value.
- This research examined the flexural strength of three different types of concrete. At 180 days, the results confirmed that the effect of concrete containing 12% SF is superior to concrete containing 20% FA.
- At the age of 180 days, the splitting tensile test showed different results according to the concrete type. The highest value (4.88 MPa) was concrete which contained 20% FA while adding 12% silica fume in Mix 2 caused a slight reduction (4.32 MPa) compared with the first type. Meanwhile, the combination between the two supplementary materials in Mix 3 improved (STS) with a value 4.5 MPa.

REFERENCES

[1] D. K. Panesar, "Supplementary cementing materials," Developments in the formulation and reinforcement of concrete, 2nd ed., S. Mindess, ed., pp. 55–85, 2019.

[2] S.M. Levy, "Calculations relating to concrete and masonry," Construction Calculations Manual, pp. 211–264, 2012.

[3] M. Pigeon, and R. Cantin, "Flexural properties of steel fibre-reinforced concretes at low temperatures," Cement and Concrete Composites, vol. 20, no. 5, pp. 365–375, 1998.

[4] R. Pérez-López, J.M. Nieto, and G.R. de Almodóvar, "Utilization of fly ash to improve the quality of the acid mine drainage generated by oxidation of a sulphide-rich mining waste: Column experiments", Chemosphere, vol. 67, no. 8, pp. 1637–1646, 2007.

[5] J. Junak, N. Stevulova, and M. Ondova, "Concrete samples prepared with different types of wastes," Pollack Periodica, vol. 9, supl. 1, pp. 95–104, 2014.

[6] B.V. Kavyateja, J.G. Jawahar, C. Sashidhar, and N.R. Panga, "Moment carrying capacity of RSCC beams incorporating alccofine and fly ash", Pollack Periodica, vol. 16, no. 1, pp. 19–24, 2021.

[7] T. Perraki, E. Kontori, S. Tsivilis, and G. Kakali, "The effect of zeolite on the properties and hydration of blended cements," Cement and Concrete Composites, vol 32, no. 2, pp 128–133, 2010.

[8] M. Shmlls, D. Bozsaky, and T. Horváth, "Compressive, flexural, and splitting strength of fly ash and silica fume concrete," Pollack Periodica, 2021., in press. doi:10.1556/606.2021.00448

[9] MSZ EN 12390-3: 2019, Examination of hardened concrete, Part 3: Compressive strength of specimens, Hungarian Standard Committee, 2019.

[10] MSZ EN 12390-5: 2006, Examination of hardened concrete, Part 5: Flexural tensile strength of specimens, Hungarian Standard Committee, 2006.

[11] MSZ EN 12390-6: 2001, Examination of hardened concrete, Part 6: Tensile strength of specimens, Hungarian Standard Committee, 2001.

[12] MSZ EN 772-11: 2011, Test methods for masonry units. Part 11: Determination of the capillary-based water uptake of admixture concrete, aerated concrete, artificial stone and natural stone masonry units and the initial water uptake value of fired clay masonry units, Hungarian Standard Committee, 2011.

[13] F.A. Sabet, N.A. Libre, and M. Shekarchi, "Mechanical and durability properties of self-consolidating high-performance concrete incorporating natural zeolite, silica fume and fly ash," Construction and Building Materials, vol. 44, pp. 175–184, 2013.

[14] C.K. Park, M.H. Noh, and T.H. Park, "Rheological properties of cementitious materials containing mineral admixtures," Cement Concrete Research, vol. 35, no. 5, pp. 842–849, 2005.