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A review of enhancing the properties of concrete containing silica fume along with fibers

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Abstract

It is well known that there is a serious shortage of raw materials for construction and the production of building materials causes environmental pollution and must be stopped immediately. Therefore, waste materials such as silica fume, slag, various fibers, etc. can be used to replace some of the raw materials that are not easily available. The use of these waste materials will ultimately reduce the cost of construction while improving many strength properties. It is necessary to review some of the literature on the improvement of concrete properties by adding fiber steel and silica fume to examine the effect of incorporating silica fume alone and subsequently adding silica fume together with fibers to replace the weight of cement and improve the properties of the reference mix prepared using locally available materials.

Keywords: Concrete; Cement; Fiber; Silica Fume

1. Introduction

Nowadays, the amount of waste generated is increasing, which poses a problem for its disposal. Therefore, emphasis has been placed on using waste materials to partially replace concrete mixers. Pierre Richard started developing reactive powder concrete (RPC), commonly known as ultra-high strength concrete[1]. This work was completed by Marcel Cheyrezy and Nicolas Roux in 1993[2], while they were employed by the French construction company Bouygues. Reactive powder concrete (RPC) is the latest and most important development in concrete technology and has attracted a lot of attention worldwide in recent years due to its excellent mechanical properties[3]. It has a low weight compaction ratio, does not contain coarse aggregate, fibers, fine sand or crushed quartz and a large amount of cement, which makes it excellent in corrosion and wear resistance[4]. RPC is rapidly becoming an excellent alternative to conventional concrete in many important structural applications, especially power plants, industrial facilities and bridges. It is an extremely strong concrete. Silica fume remains the most successful and widely used material in concrete and cement technology due to the significant improvement in concrete properties[5,6]. If these materials are used as substitutes, the durability and strength of concrete will be improved and the heat release rate will be reduced.

1.1. Need and objective

From the previous studies, various properties of aerosilicic concrete have been studied, but the studies on the bond strength of aerosilicic concrete with synthetic fibers are few and poor. Therefore, this study plans to evaluate the "improvement of compressive strength and bond strength of concrete by silica fume and fiber".

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2. Material

2.1. Fibers

High performance monofilament polypropylene fibers were used in this study. Table (1) shows the typical properties of the polypropylene fibers (1) used.

Table 1 Characteristics of Steel fiber

Conformation	Condition	Assets
	Hooked	Explanation
	30 mm	Length
	0.375 mm	Diameter
	7800 kg/m3	Mass
	1800 MPa	Tensile capacity
	200GPa	elasticity
	80	aspects Ratio (Lf/Df)

2.2. Silica Fume

Grey compacted silica fume (a by-product of silicon or ferrosilicon metal production) imported from Sika was used. Silica fume is an extremely fine powder with particles hundreds of times smaller than cement particles. It is always used in small proportions as a partial replacement for cement or as an additive (as in the present work) to improve concrete properties. The chemical composition of the silica fume used in this study is shown in Table (2). It should be noted that the silica fume used complies with the requirements of ASTM C1240-04 (2).

Table 2 Chemical properties of silica fume

Oxide composition	Extreme Requirement for Conditions	Oxide Satisfied (%)
Silica(SiO2)	85.0 (min)	94.86
Iron oxide(Fe2O3)	-	0.08
Alumina(Al2O3)	-	1.17
Lime(CaO)	-	0.22
Sulfate(SO3)	-	0.24
Magnesia(MgO)	-	0.021
Oxygenated potassium(K2O)	-	0.47
Moisture level	3.0(max)	0.47
Ignition injury(L.O.I.)	6.0(max)	2.86

2.3. Cement

The cement used in the previous study was Ordinary Portland Cement (Taasluja) type (I). It was stored in sealed plastic containers to protect it from different weather conditions. The cement was tested and validated according to ACI Committee 211.1-91 [8]. The chemical and physical properties of the cement are shown in Tables (3) and (4).

Table 3 Chemical composition of the cement

Compound composition	Chemical composition	Percentage by weight	Limits of IOS 5:1984
Lime	CaO	62.00	_
Silica	SiO_2	21.00	_
Alumina	Al_2O_3	5.26	_
Iron Oxide	Fe_2O_3	3.00	_
Magnesia	MgO	2.70	<5
Sulfate	SO_3	2.10	<2.8
Loss on Ignition	L.O.I	1.10	<4
Insoluble residue	I.R	0.49	<1.5
Lime saturation factor	L.S.F	0.92	0.66-1.02
Main Compounds (Bogue's equation) percentage by weight of cement			
Tricalcium silicate (C_3S)		47.11	
Dicalcium Silicate (C_2S)		30.81	
Tricalcium Aluminate (C_3A)		8.87	
Tetracalcium Aluminoferrite (C_4AF)		9.12	

Table 4 Physical properties of the cement

Physical Properties	Test result	Limit of IOS 5:1984
Fineness using Blaine air permeability apparatus (m^2/kg)	312	≥230
Setting time using Vicat's instruments		
Initial (hrs:min.)	2:10	≥45 min
Final (hrs:min)	4:00	≤10 hrs
Compressive strength		
3 days (MPa)	20.5	≥15
7 days (MPa)	28.8	≥23

2.4. Fine Aggregate

The size and amount of fine aggregate are important factors in concrete. Natural sand is used. Table (5) gives the size of fine aggregate and the limits of ACI Committee 211.1-91 [8]. Table (6) shows the physical properties of the fine aggregate used. The fineness modulus of the fine aggregate is 2.63.

2.5. Coarse Aggregate

Use gravel with a maximum size of (5 - 20) mm. The coarse aggregate size is given in Table (7). Table (8) shows the specific gravity, sulphate and chloride content and absorption rate of the coarse aggregate materials used..

Table 5 Grading of fine aggreagate

No.	Sieve size (mm)	% Passing by weight	
		Fine aggregate	Limits of IOS No. 45/1984-Zone 2
1	10	100	100
2	4.75	99	90-100
3	2.36	90	75-100
4	1.18	75	55-90
5	0.60	53	35-59
6	0.30	17	8-30
7	0.15	2	0-10

Table 4 Physical properties of the fine aggreagate

Physical Properties	Test results	Limits of IOS No.45/1984
Specific gravity	2.65	-
Sulfate content(SO3) %	0.33	$\leq$ 0.5
Absorption %	1.1	-
Loose bulk density kg/m3	1645	-

Table 7 Grading of the coarse aggregate

No.	Sieve size mm	Passing (%) by weight	
		Coarse aggregate	**Limits of IOS No.45/1984**
1	20	100	100-95
2	14	80	-
3	10	37	30-60
4	5	2	0-10

Table 8 Properties of the coarse aggregate

Physical properties	Test results	Limits of IOS No.45/1984
Specific gravity	2.65	-
Sulfate content(SO3)	0.073 %	≤ 0.1 %
Chloride content(Cl)	0.092 %	≤ 0.1 %
Absorption	.65 %0	-
Loose bulk density kg/m3	1500	-

2.6. Water

Ordinary tap water is used without any additives for mixing, casting and curing.

3. Experimental work

3.1. Concrete Mixes

The reference concrete mix used by the researchers was developed according to ACI 211.1 -91 (8) and achieved a minimum compressive strength of 25 MPa after 28 days without additives as shown in Table (9). The mix ratio was 1:1.19:1.8 by weight and the water-cement ratio was 0.50.

Table 9 Concrete mix materials

Cement	**390 kg/m3**
Water	195 kg/m3
Fine aggregates	610.10 kg/m3
Coarse aggregates	1073.43 kg/m3
Water cement ratio	0.50

3.2. Mixing of Concrete

The mixing process was carried out in a pan mixer of (0.1 m3) capacity. The inner surfaces of the mixer were cleaned and wetted before changing the materials. The dry components (silica fume and fibers) of the reference concrete mix were added to the mixer and mixed for about 1.5 minutes to obtain a homogeneous dry mix. The required amount of water was then added and all the mixed components were mixed for about 2 minutes until a homogeneous concrete mix was obtained.

For high performance concrete, the required amount of silica fume was mixed with cement before adding it to the mixer to ensure uniform distribution of silica fume. The dry ingredients (cement, silica fume, sand and gravel) were added to the mixer and mixed for about 1.5 minutes to obtain a homogeneous dry mix. For the fiber reinforced concrete mix, the same mixing procedure was followed except that after all the mixed materials were thoroughly mixed, the fibers were added manually and mixing was continued for (2-3) minutes to ensure uniform fiber distribution throughout the concrete mix(24).

4. Mechanical Properties of Hardened Tests

In order to evaluate the mechanical properties of all types of concrete used in the previous article, control samples were cast with the same mix as the concrete. Four mechanical properties were allowed: cylindrical compressive strength (f'c) [9], [10], splitting tensile strength (ft) [11], modulus of rupture (fr) [12] and modulus of elasticity (Ec) [13]. Three samples were provided for each property test and the average of the three results was taken..

4.1. Compressive Strength of SCC (f'c)

The compressive strength test was carried out in accordance with BS 1881: Part 116 [9]. Cubes of (150 × 150 × 150) mm were tested using a hydraulic press of (2000) kN. The specimens were cast without any compaction. The average of three specimens at the age of the specimen was taken. The tests were carried out at 7 days of age, 28 days of age and at the time of specimen testing.

4.2. Flexural Strength Test of Concrete(f_r)

The flexural strength test (modulus of rupture) was conducted using a prism (100 x 100 x 500 mm) with a load span of 450 mm using a two-point hydraulic press with a capacity of 2000 kN. The test was conducted according to ASTM C78-02 [10] using three concrete prisms and the average of the three results was used. The modulus of rupture was calculated as follows:-

$$f_r = PL/bd^2$$

where:-

f_r: modulus of rupture, MPa.
P: maximum load, N.
L: clear span length, mm.
b: width of specimen, mm.

4.3. Tensile Splitting Strength of Concrete (f_t)

The splitting tensile strength test was conducted on (150 × 300) mm concrete cylinders according to ASTM C496-04 [11]. Three cylinder samples were tested at 28 days of age and the average value of these samples was determined and recorded. The following formula was used to determine the splitting tensile strength of the cylinder.:

$$f_t = 2P/\ \pi\ D\ L \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

f_t: splitting tensile strength, (MPa).
P: Maximum applied load, (N).
D: diameter of specimens, (mm).
L: length of the specimens, (mm).

4.4. Static Modulus of Elasticity Test(E_c)

To measure the static elastic modulus (Ec) according to ASTM C469-02[12], concrete cylinders with dimensions of 150 × 300 mm were cast. The test was performed using the same testing machine as the compression strength test. The elastic modulus was determined from the stress-strain diagram using a compression gauge. To avoid damaging the test equipment, all samples were tested at a pressure of approximately 0.5 f'c. The slope of the line drawn from the origin to the 0.4 f'c point represents the elastic modulus and can therefore be calculated using the following formula:

$$E_c=(S_2 - S_1)/(\varepsilon_2 - 0.00005) \ \ldots\ldots\ldots\ldots\ldots$$

Where:

E_c= static modulus of elasticity, MPa
S_2 = stress corresponding to 40 % of ultimate load, MPa
S_1 = stress corresponding to a longitudinal strain (0.00005), MPa and
ε_2= longitudinal strain produced by stress $S2$.

5. Experimental Results of Concrete

Experimental program of structural behavior consists of casting and testing specimens

Table 10 Variation of hardened properties with age 28 day (cement replaced by Silica Fume and Fibers)

Mix No.	% Replacement by Silica Fume	% Replacement by Fibers	f_{cu} MPa	f′c MPa	f_t MPa	f_r MPa	E GPa
M(0)	0	0	25	20	1.94	2.874	21.019
M(1)	20	0	28	22.40	2.172	3.218	22.224
M(2)	40	0	31	24.80	2.405	3.563	26.168
M(3)	40	0.20	36	28.80	2.793	4.138	25.222
M(4)	40	0.25	39	31.20	3.026	5.604	26.252
M(5)	40	0.30	42	33.60	3.259	4.828	27.243
M(6)	40	0.35	44	35.20	3.414	5.058	27.884
M(7)	40	0.50	51	40.80	3.957	5.862	30.021

5.1. Literature review of adding silica fume and fibers

The investigation of effects two fiber types (steel fibers SF and polypropylene fibers PPF) on flexural behavior and some key characteristics (compressive and splitting) of reactive powder concrete in comparison to regular strength concrete (NSC) was conducted by Jinan[13], however, examined the impact of that addition by [14], [15], [16], [17] and [19]. By comparing the effects of two distinct methods—fly ash silica-fume plain concrete (FA-SPC) and fly ash silica-fume coconut fiber reinforced concrete (FA-SCFRC)—Khan [18] found that the second kind had generally better qualities than the first. K. H. Hoang found that Specially shaped steel fiber can be added to UHPC (Ultra-high performance of concrete) to efficiently increase its compressive and flexural strength[20]. Some researchers blended silica fume and recycled steel fibers to improve the characteristics of concrete[21], the others used Reactive Powder with fibers on beams[22]. The unit weight, compressive strength, slump, and compaction factor tests are the ones taken into consideration for the study of S. M. Dumne[23], the findings demonstrate that, given a constant water-to-cement ratio, adding more superplasticizer to self-compacting concrete results in both a little decrease in unit weight and an improvement in self-compaction ability. Additionally, the compressive strength is marginally higher than that of a typical concrete mix. T. Park et al., [25] studying the orientation and distribution of steel fibers on concrete properties and found that In the direction of the primary vertical reinforcement steel embedded in the HPC column, and discovered that the steel fibers were generally oriented perpendicular to the main axis

6. Conclusion

The following conclusions can be drawn from this study:

- With increasing silica fume cement replacement, an increase in compressive strength is observed.
- Fumed silica concrete containing up to 40% silica fume cement replacement has sufficiently high compressive strength for use in most structural applications.
- When fibers are added to silica fume in concrete mixes, only a slight increase in compressive strength is observed.
- With increasing cement replacement in silica fume, the performance improves. However, the addition of fibers improves the properties of hardened concrete. Further analytical studies can also be done to attitude a comparative records between silica fume and fiber steel with additional ratio when adding to concrete mixer.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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