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Mechanical properties of self-compacting concrete incorporating quarry dust powder, silica fume or fly ash

H.A.F. Dehwah *

King Fahd Univesity of Petroleum & Minerals, Dhahran 31261, Saudi Arabia

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ABSTRACT

This paper presents the results of a study conducted to evaluate the mechanical properties of self-compacting concrete (SCC) prepared using quarry dust powder (QDP), silica fume (SF) plus QDP or only fly ash (FA). Trials were conducted to assess the proportions of QDP, SF + QDP or FA required for producing SCC meeting the flow criteria. SCC specimens were prepared and tested for compressive strength, pulse velocity, split tensile strength and flexural strength. The results indicated that the mechanical properties of SCC incorporating QDP (8–10%) were equal to or better than those of SCC prepared with either SF plus QDP or FA alone. The use of QDP alone results in a significant cost saving in regions where SF and FA have to be imported from other countries.

1. Introduction

SCC is a concrete that is able to consolidate itself without the need for vibration. It fills all recesses, spaces and voids, even in highly congested reinforced concrete members. It is expected to flow freely without any segregation of its constituents to form nearly a level surface. SCC can be designed to fulfill the requirements of specifications regarding density, strength and durability, particularly the filling ability, passing ability and segregation resistance [1].

SCC consists basically of the same constituents as a normally vibrated concrete. However, there is a clear difference in the concrete composition. It requires a higher proportion of ultra fine materials and the incorporation of chemical admixtures, particularly an effective high range water reducer. Ordinary and commonly used filler materials may include: fly ash, quarry dust powder, blast furnace slag, silica fume, and/or quartzite powder [1–4].

The use of SCC is steadily increasing with increasing number of applications as it offers many advantages to the construction industry, such as the elimination of consolidation work that results in reducing the efforts and cost of placement, shortening of the construction time, and therefore, improving the productivity. The use of SCC also leads to a reduction in the noise during casting, better working conditions, and the possibility of increasing the placing times in inner city areas. The benefits of using SCC also include: improving homogeneity of concrete production and the excellent surface quality without blowholes or other surface defects [5].

SCC is generally produced by utilizing fine materials, such as silica fume or fly ash. A combination of these materials is also used. Recently, an ultra fine fly ash has been used as filler. However, these materials are not available locally in many regions of the world. Under such situations, it is desirable to utilize the locally available materials to decrease the cost of the SCC.

In the reported study, SCC mixes were developed utilizing quarry dust powder (QDP). Trials were conducted with varying proportions of QDP and the mixes meeting the flow criteria were selected for evaluation of mechanical properties.

2. Experimental program

2.1. Cement and fillers

ASTM C 150 Type I Portland cement was utilized in all the concrete mixtures. QDP, silica fume (SF) and fly ash (FA) were used as fillers. Table 1 shows the chemical composition of Type I Portland cement, silica fume, fly ash, and limestone quarry dust powder.

2.2. Aggregates

Crushed limestone was used as coarse aggregate while dune sand was used as fine aggregate. The specific gravity and absorption of the coarse and fine aggregates are summarized in Table 2. The grading of coarse aggregates (shown in Table 3) corresponded to ASTM C 33 limits. Potable water was used for mixing the concrete constituents.

* Tel.: +966 3 860 4966; fax: +966 3 860 3785.
E-mail address: hdehwah@kfupm.edu.sa

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Table 1
Chemical composition of Type I Portland cement, silica fume, fly ash, and quarry dust powder.

Constituent	Weight (%)			
	Type I cement	Silica fume	Fly ash	Quarry dust powder
SiO_2	19.92	90.68	64.13	11.79
Al_2O_3	6.54	0.66	30.01	2.17
Fe_2O_3	2.09	0.23		0.68
CaO	64.7	0.15	–	45.7
MgO	1.84	0.20	2.94	1.80
SO_3	2.61	0.13	1.91	
K_2O	0.56	–	–	0.84
Na_2O	0.28	0.14	0.95	1.72
L.O.I	0.73	5.23	1.10	35.10
C_3S	55.9	–	–	–
C_2S	19	–	–	–
C_3A	7.5	–	–	–
C_4AF	9.8	–	–	–

Table 2
Absorption and specific gravity of coarse and fine aggregates.

Aggregate	Absorption (%)	Bulk specific gravity
Coarse (limestone)	1.1	2.60
Fine (dune sand)	0.6	2.56

Table 3
Grading of coarse aggregates.

Sieve opening (mm)	Passing (%)	ASTM C 33 (no. 67) grading limit
19	100	90–100
9.5	30	20–55
4.75	10	0–10
2.36	0	0–5

2.3. Plasticizer and stabilizer

Suitable dosages of a commercial plasticizer and a stabilizer were used to obtain the desired flow properties. The plasticizer used is a high performance concrete superplasticizer based on modified polycarboxylic ether that greatly improves cement dispersion and provides flowable concrete with greatly reduced water demand. It is compatible with all Portland cements that meet recognized international standards. Its relative density is 1.1@ 20 °C and pH is 6.6. The stabilizer used consists of a mixture of water-soluble copolymers which is adsorbed onto the surface of the cement granules, thereby changing the viscosity of the water and influencing the rheological properties of the mix.

2.4. Mix design

Fifteen trial mixtures were prepared with different proportions of fillers, namely QDP, SF + QDP and FA. These mixtures were designed according to the rational mix-design method [6], and the proportioning of materials was carried out on weight basis. The flow characteristics of the trial mixtures were evaluated by conducting the Slump flow test, V-flow test, U-box flow test and L-box flow test. Out of these 15 mixtures, only five mixes meeting the generally accepted flow criteria were selected and included in this study for further evaluation. The selected mixtures, their designation and constituents are shown below:

Mix #1 (M1): 8% QDP and w/cm ratio of 0.40.
Mix #2 (M2): 8% QDP and w/cm ratio of 0.38.
Mix #3 (M3): 10% QDP and w/cm ratio of 0.4.
Mix #4 (M4): 8% QDP plus 5% SF and w/cm ratio of 0.40.
Mix #5 (M5): 30% FA and w/cm ratio of 0.40.

The mixtures were prepared with a cementitious materials content of 400 kg/m^3 and effective water to cementitious materials ratio (w/cm) in the range 0.38–0.40. The coarse aggregate to total aggregate ratio was kept fixed at 0.5 and the fine to total aggregate ratio was in the range 0.40–0.42 and the quantity of QDP was varied in the range of 8–10% of the total aggregates. SF was used as 5% replacement of Type I Portland cement while FA was used as 30% replacement of Type I Portland cement. The stabilizer was kept fixed at 0.5 and the dosage of stabilizer was varied to obtain the desired flow properties. The concrete ingredients were mixed in a revolving drum mixer for approximately 5–7 min to obtain uniform consistency and flowable characteristics. The weights of constituents in each mixture are shown in Table 4.

2.5. Specimen preparation and testing

Three specimens representing same constituent were used for each test throughout this study and the average values were reported.

Cube specimens, 100 × 100 × 100 mm, were prepared for evaluating the compressive strength. The compressive strength was determined according to ASTM C 39 after 7, 14, 28, and 90 days of water curing. The compressive load was applied at a rate of 2.2 N/s using a servo-hydraulic compression machine.

Cylindrical concrete specimens, 75 mm in diameter and 150 mm high, were prepared to evaluate the split tensile strength. They were tested for split tensile strength according to ASTM C 496 after 28 days of water curing.

Cylindrical concrete specimens, 75 mm in diameter and 150 mm high, were utilized to determine the pulse velocity according to ASTM C 597 after 7, 14, 28, and 90 days of water curing.

The flexural strength was determined according to ASTM C 293 using a mid point loading method utilizing 100 mm × 100 mm × 500 mm prismatic concrete specimens.

3. Results

3.1. Compressive strength

The compressive strength of all SCC specimens is plotted in Fig. 1. The compressive strength increased linearly with age up to about 28 days. Thereafter, the increase in strength was not that significant. The maximum compressive strength was noted in M2 (8% QDP, w/cm = 0.38) specimens. The compressive strength of M3 (10% QDP, w/cm = 0.40) specimens was more than that of M4 (8% QDP plus 5% SF and w/cm = 0.40) specimens, while the compressive strength of M1 (8% QDP, w/cm = 0.40) specimens was less than that of M4 specimens. However, the difference in strength between these two specimens was not that significant. The minimum compressive strength was noted in M5 (30% FA, w/cm = 0.40) specimens. The compressive strength of specimens prepared with only QDP was more than that of SCC specimens incorporating SF plus QDP or FA alone.

After 28 days of curing, the compressive strength of M1, M2, M3, M4, and M5 specimens was 62.7, 70.1, 65, 64.4, and 52.1 MPa, respectively. After 90 days of curing, these values were 64.8, 79.0, 70.7, 68.5, and 56.1 MPa, respectively. The maximum compressive strength was noted in the M2 (8% QDP, w/cm = 0.38) specimens while the minimum compressive strength was noted in M5 (30% FA, w/cm = 0.4) specimens.

The compressive strength of all the SCC specimens increased significantly. The mixes incorporating QDP alone performed better

Table 4
Weights of constituents of the mixes.

Mix designation	Effective w/cm ratio	Weights of constituents (kg/m^3)						Admixture, l/100 kg cement	
		Cement	Quarry dust powder	Silica fume	Fly ash	Coarse aggregate	Fine aggregate	Plasticizer	Stabilizer
M1	0.40	400	139.2	0	0	870.2	731.0	1.0	0.50
M2	0.38	400	140.8	0	0	880.0	739.2	1.4	0.50
M3	0.40	400	171.2	0	0	842.3	684.8	1.2	0.50
M4	0.40	380	140.3	20	0	876.9	736.6	1.8	0.50
M5	0.40	280	0	0	120	974.9	974.9	1.1	0.50