Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.4, No.4, pages: 16-25

Investigating the Effect of Iron Ore Powder on Fresh and Hardened Properties of Self-Compacting Concrete

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(Date of received: 25/06/2022, Date of accepted: 26/11/2022)

ABSTRACT

One of the issues that strongly affect the properties of self-compacting concrete is the role of fillers. The effect of the type and performance of fillers on the properties of concrete in a fresh and hardened state is important. In this research, the effect of using iron ore powder as filler on the rheological and mechanical properties of self-compacting concrete has been investigated. To evaluate the rheological properties of self-compacting concrete, slump flow and T50 tests were performed on samples with different percentages of iron ore powder (0 to 80%). The mechanical properties of the samples were also measured by performing concrete compressive strength tests at the ages of 3, 7, 28, and 90 days. The results of the tests performed on the samples show that increasing the amount of iron ore powder, increases the unit weight of the self-compacting concrete and decreases the slump flow by up to 30%. In addition, the results of the compressive strength test show that, in general, with the increase in the amount of iron ore powder, the compressive strength of the samples has decreased between 2-23%. Based on the results of this research, an optimal amount for iron ore powder replacement cannot be reported.

Keywords:

Iron ore powder, Heavy concrete, Concrete fresh properties, Concrete hardened properties.

1. Introduction

Based on the definition, if the specific weight of concrete is above 2600 kg/m3, it is called heavy concrete. This concrete is used in places where there are x-rays and gamma rays or neutron radiation involved [1]. Heavy concrete can be used to build offshore infrastructure. Also, the use of heavy concrete in underwater structures is beneficial due to its high density. Golipour et al. (2016), showed the high importance of heavy concrete in the construction for protective panels of nuclear power plant reactors, medical centers, accelerator research centers, and military centers [2]. Ilmenite, limonite, hematite, magnetite, and barite are the common minerals used in heavy concrete manufacturing technology [2]. Self-compacting Concrete (SCC) is proposed as an strong option to solve the major problems of conventional concretes [3,4]. Usually, more powder or adhesive materials are used in SCC concrete in comparison with the normal concrete [5]. To provide the stability of fresh concrete prevent the danger of bleeding and settlement of larger particles, a larger amount of powder materials is needed [6]. The paste of adhesive materials acts as a lubricant for coarse aggregates and causes the aggregates to flow without blocking[7,8]. However, this concrete mixture has a high compressive strength. In general, the amount of powder in SCC is about 100±200 kg/m3 or even higher. Saidi et al. (2020) used the iron ore powder as reactive filler in concrete [9]. Zhao et al. (2021), evaluated iron ore tailings on workability, mechanical properties, and durability of concrete in china. They reported low pozzolanic activity of this material and diversity in the characteristics [10]. Zhao et al. (2014) reported less than an 11% decrease in ultra-high-performance concrete compressive strength using less than 40% iron ore tailings [11]. Han et al. (2020) investigated the mechanical properties, microstructure and permeability of high-volume iron tailing powder concrete and high-volume fly ash concrete. They reported low compressive strength, low tensile strength, coarse pore structure, loose microstructure, and high chloride permeability for this type of concrete [12]. In this research, we show the possibility of making heavy self-compacting concrete using iron ore powder. To this end, the effect of using iron ore powder as filler on the rheological and mechanical properties of self-compacting concrete has been investigated. To evaluate the rheological properties of self-compacting concrete, slump flow and T50 tests were performed on samples with different percentages of iron ore powder (0 to 80%). The compressive strength was also measured by the ages of 3, 7, 28, and 90 days.

2. Materials and methods

In areas where concrete is simultaneously exposed to chlorine and sulfate ions, it is recommended to use cement type II (modified Portland cement). The coastal areas along the Persian Gulf are an example of these areas. Based on the manufacture data, the chemical composition and physical properties of cement are presented in Table 1.

Table 1. Chemical and physical properties of cement type II.

Chemical properties (%)							Physical properties		
CaO	SiO_2	C_3A	Al_2O_3	Fe_2O_3	MgO	SO_3	Initial setting (min)	28-day standard mortar 5*5 cubic sample strength (MPa)	Specific surface)cm^2/gr(
63	20.5	7.5	6	5.5	4	3	60	355	2900

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Based on ASTM C109-90, the compressive strength of Portland cement and standard sand (DIN) mortar at 28 days is shown in table 1 [13]. To determine the fineness of cement we measure the specific surface area of fine materials using Blaine air permeability apparatus [14]. The result is shown in table 1. Initial setting time is defined as a specified time required for cement paste to change from liquid state to plastic state [15]. The initial setting time based on ASTM is shown in Table 1. Drinking water is suitable for making concrete. the pH of water is about 7.59. As stated earlier, the main goal of this research is to investigate the effect of using iron ore powder on the rheological and mechanical properties of self-compacting concrete. The iron ore powder used in this research was prepared by Gohar Zamin Iron Ore Company, Sirjan and Kerman. Table 2 shows the specifications of the iron ore powder based on the company data. Also, the grain size distribution of iron ore powder can be seen in Figure 1.

Table 2. Specifications of iron ore powder.

Chemical properties (%)					Physical properties			
Fe	FeO	P	S	SiO_2	Natural moisture (%)	Water absorption (%)	Apparent specific weight (gr/cm3)	Grain-specific weight (gr/cm3)
66.5	25.5	0.05	0.12	2.5	5.66	12.95	3.06	4/07

Fe: iron, FeO: iron oxide, P: phosphorus, S: sulfur, SiO2: silicon dioxide

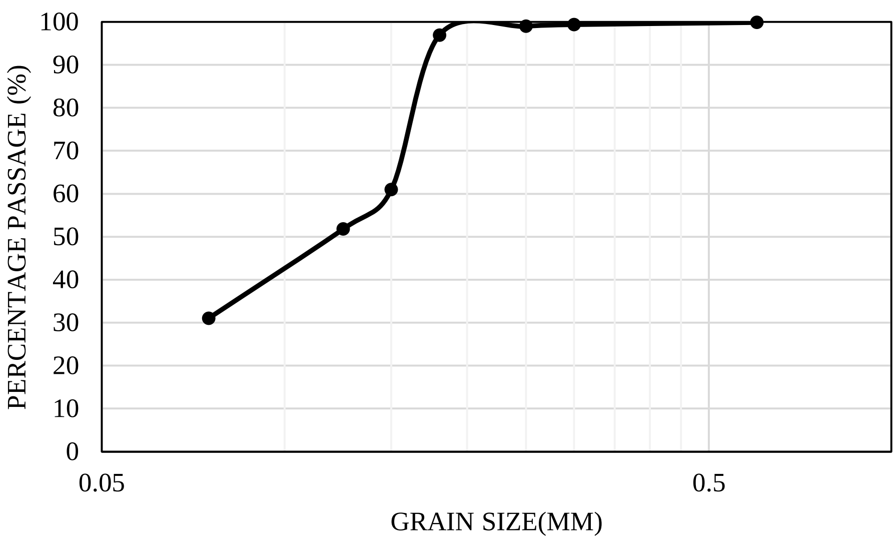

Figure 1. grain size distribution of iron ore powder

Silica powder is one of the necessary materials for providing proper viscosity in self-compacting concrete. Fillers such as silica powder passed through the sieve #120 can fill the voids between the cement particles, thus reducing the porosity and increasing the density of concrete. This category of fillers, due to having a very high specific surface area, increases the intergranular friction and causes an increase in the viscosity of concrete, so, in making SCC, the use of superplasticizers in order to increase the fluidity of concrete is unavoidable. Silica powder's apparent specific weight (bulk) is 2.48 gr/cm3, and its grain-specific weight (real) is 3.03 (gr/cm3). Figure 2 highlights the difference between concrete samples containing silica (white) and iron ore (black) powders.

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Figure 2. Difference between samples made with silica powder and iron ore powder after the jack test.

In this research, fine aggregates (sand) in the sizes of 0 to 4.75 mm (S) and coarse aggregates (gravel) in two size categories of 4.75 to 9.5 mm (G1) and 9.5 to 19 mm (G2) are used. The natural aggregates are obtained from mines around Behbahan city. The properties of aggregates are shown in Table 3. The apparent specific weights of S, G1 and G2 are 1.9, 1.63, and 1.55 gr/cm3, respectively. The grain-specific weights of S, G1, and G2 are 2.45, 2.59, and 2.59 gr/cm3, respectively. Figure 3 shows the grading curves of aggregates.

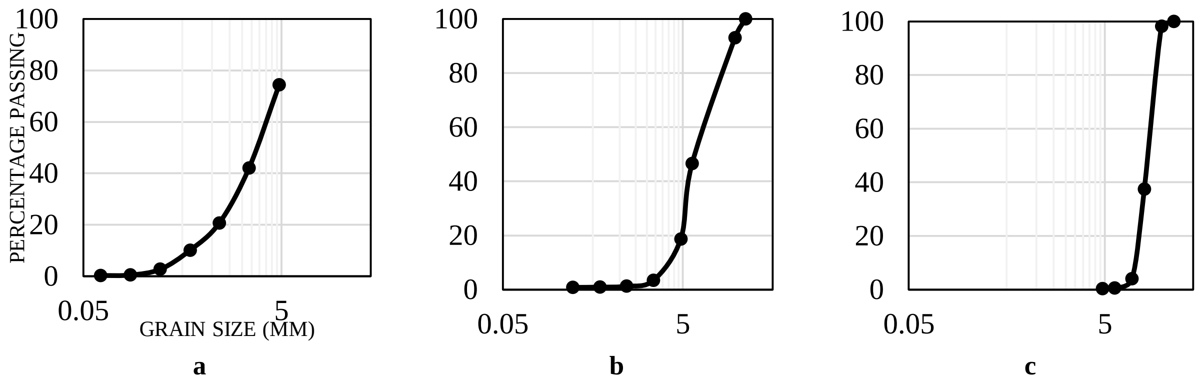

Figure 3. Grading curves of aggregates, a. sand, b. G1 and c. G2

Polycarboxylates-based super plasticizer PC5000 (HR) with a specific weight of 1100 kg/m3 and a concentration of 20% under the European standard EN-934-2 is used. The mix designs of concrete as described in Table 3 are considered for tests. A normal concrete (NC) sample, a self-compacting concrete sample without iron ore powder, and other designs from 10 to 80% iron ore powder can be seen in the Table 3.

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Table 3. Concrete mix designs

mix	C (kg)	W (kg)	w/c	S (kg)	G1(kg)	G2(kg)	SiP (kg)	Iop (kg)	SP (kg)	VMA(kg)	IOP/C (%)
NC	433	180	0.416	1192	358	152	0	0	0	0.0	0
SCC-IO-0	430	168	0.39	1182	355	150	132	0	6	6.7	0
SCC-IO-10	430	194	0.39	1368	411	174	118	57	7	7.8	10
SCC-IO-20	430	192	0.39	1352	405	172	107	115	7	7.7	20
SCC-IO-30	430	189	0.39	1336	401	170	96	172	7	7.6	30
SCC-IO-40	430	187	0.39	1320	396	168	86	229	7	7.5	40
SCC-IO-50	430	185	0.39	1305	391	166	78	287	7	7.4	50
SCC-IO-60	430	183	0.39	1290	387	164	70	344	7	7.3	60
SCC-IO-70	430	181	0.39	1276	383	162	63	401	7	7.2	70
SCC-IO-80	430	183	0.39	1289	387	164	57	459	7	7.3	80

NC: normal concrete; C: Cement; W: water S: sand; G: gravel; SiP: silica Powder; Iop: iron ore powder; SP: superplasticizer;

3. Results and discussion

A tilting cylindrical mixer is used to mix concrete. To make concrete, first, coarse aggregates and some fine-grained materials are added to the mixer. Then some water is added to the materials to moisten their surface. The mixing of granular materials is done in the mixer for 2 minutes and then the remaining cement and fine grains are added to the mixer at the same time the remaining water with the superplasticizer dissolved in it is added to the mixture and the concrete is mixed for 3 minutes. After mixing, the slump flow and T50 tests are performed. In Figure 4, the values of slump flow are displayed. It can be seen that with the increase in the iron ore powder, the slump flow of the samples has decreased, which is due to the heavier concrete with the increase in the amount of iron ore powder. The minimum acceptable diameter of slump flow for self-compacting concrete is 60 cm. all mixes pass this limit.

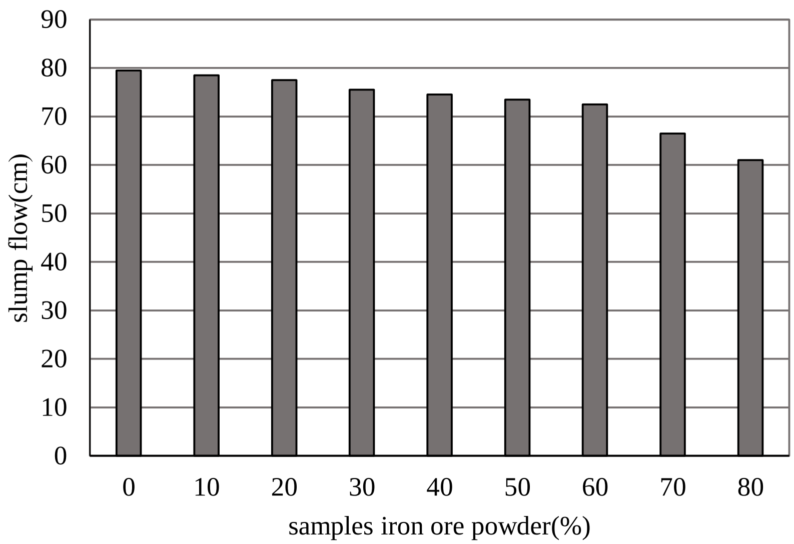

Figure4. Slump flow test results for SCC mixes.

Figure 5, shows the T50 test results for SCC mixes. EFNARC [16] considers the time to reach a diameter of 50 cm (T50) between 3 and 7 seconds for common engineering applications. According to this standard, samples containing 70% and 80% iron ore powder are not suitable for common engineering applications.

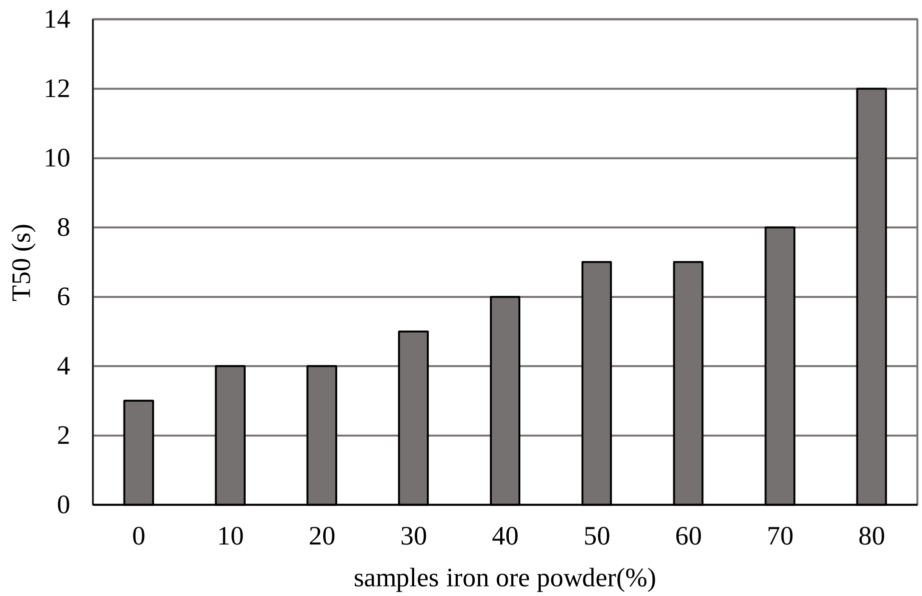

Figure 5. T50 test results for SCC mixes.

In all tests, the temperature of fresh concrete is between 27 and 29 degrees Celsius. To investigate the compressive strength of concrete, cubic samples of 15 x 15 were used. Figure 6 shows a sample. After 24 hours, the concrete samples are moved to the curing pond. Before each test, the samples are dried in the air (Figure 7). The unit weights of the 28-day air-dried samples are given in Table 4. Based on Table 4, it can be seen that the volumetric replacement of silica powder with iron ore powder has increased the unit weight.

Figure 6. Cubic concrete samples.

Table 4. Unit weights of the 28-day air-dried concrete samples

mix	Iron ore powder ratio (volumetric %)	Unit weight(kg/m3)
NC	0	2235
SCC-IO-0	0	2317
SCC-IO-10	10	2483
SCC-IO-20	20	2506
SCC-IO-30	30	2677
SCC-IO-40	40	2699
SCC-IO-50	50	2783
SCC-IO-60	60	2849
SCC-IO-70	70	2935
SCC-IO-80	80	3008

Figure 7. Air-dried concrete samples.

Figure 8. The cubic concrete sample under the compressive jack.

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The results of the compressive strength test (Figure 8) in different ages are given in table 5. Also, the amount of difference in strength at each age and each amount of iron ore powder with the SCC without iron ore powder are given in table 5. It can be seen that the addition of iron ore powder decreased the strength in all ages.

Table 5. Compressive strength test results.

mix	Compressive strength (MPa)				Difference with SCC-IO-0 (%)			
	3	7	28	90	3	7	28	90
NC	20.91	22.95	28.64	28.87	-	-	-	-
SCC-IO-0	22.34	27.97	36.97	38.73	0	0	0	0
SCC-IO-10	21.22	26.76	36.45	37.12	-5.01	-4.33	-1.41	-4.16
SCC-IO-20	21.66	26.1	36.03	38.08	-3.04	-6.69	-2.54	-1.68
SCC-IO-30	20.05	25.67	35.99	36.21	-10.25	-8.22	-2.65	-6.51
SCC-IO-40	21.68	24.29	33.36	35.67	-2.95	-13.16	-9.76	-7.90
SCC-IO-50	20.19	24.55	32.26	33.56	-9.62	-12.23	-12.74	-13.35
SCC-IO-60	20.07	22.59	30.45	34.46	-10.16	-19.23	-17.64	-11.03
SCC-IO-70	19.19	22.02	30.94	32.29	-14.10	-21.27	-16.31	-16.63
SCC-IO-80	18.93	21.28	30.93	31.59	-15.26	-23.92	-16.34	-18.44

For more clarity and to find the effect of iron ore powder on the hardened properties of SCC, the effect of adding iron ore powder on strength at different ages and unit weights is given in Figure 9. For display purposes, the specific weight values are divided by 10. In this figure, the effect of iron ore powder on strength and unit weight can be clearly seen. Based on this figure, by moving to the right or left side of the curve, as needed, SCC with desired properties can be produced.

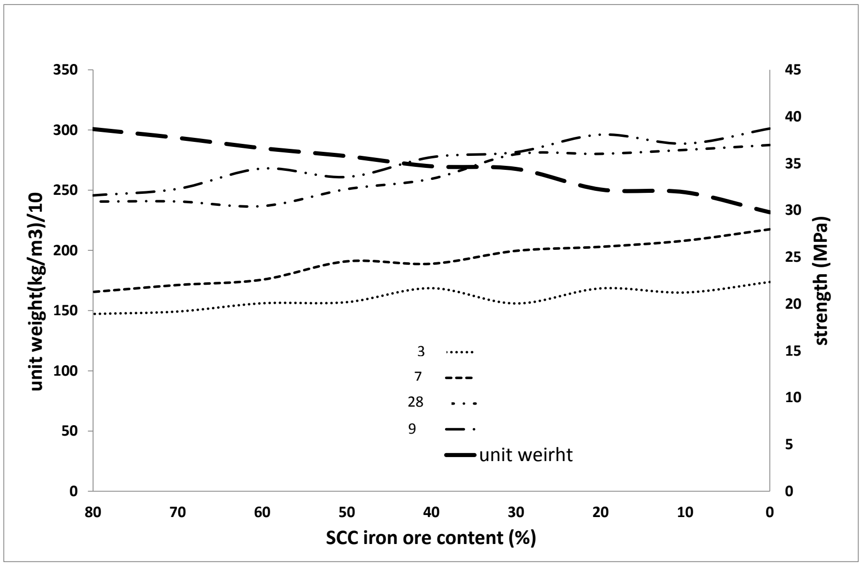

Figure 9. SCC strength at different ages and unit weights (at age 28 day).

4. Conclusions

In this paper, the effect of adding iron ore powder on the fresh and hardened properties of self-compacting concrete was tested. For this purpose, silica powder was replaced with iron ore powder in different amounts. The results of the tests performed on the samples showed that with the increase in the amount of iron ore powder, the unit weight of the self-compacting concrete increases, therefor its slump flow decreases. In addition, the results of the compressive strength test on the samples show that, in general, with the increase in the amount of iron ore powder, the compressive strengths decrease, which indicates the effect of iron ore powder on the mechanical properties of concrete. Increasing the amount of iron ore powder and replacing silica powder with iron ore powder in self-compacting concrete increases the weight of concrete because the unit weight of iron ore powder is higher than that of silica powder. According to the fresh test results and recommendations of ICAR Institute [17] and EFNARC Institute [16], the amount of iron ore powder up to 60% is suitable and the samples with 70% and 80% iron ore powder do not satisfy SCC limits. In general, a linear trend has been observed in reducing the compressive strengths and increasing the unit weights of samples containing iron ore powder. So it can be concluded that, in general, the long-term resistance of samples containing iron ore powder has decreased compared to samples without iron ore powder.

5. Acknowledgment

The tests of the present paper are performed in the special concrete center (SCC) of the Behbahan Khatam Alanbia University of Technology University. By this way, we would like to express our gratitude to the center and the university.

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