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Performance of self-compacting concrete cast in hot weather conditions

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Introduction

A special kind of concrete known as self-compacting concrete (SCC) can compact itself with no need for external vibration. It is distinguished by its capacity to flow, cover deeply recessed narrow members and create uniformly integrated concrete members free of bleeding or segregation traces. This performance cannot be accomplished by using regular concrete in the usual manner. Studies were conducted to ascertain and assess the properties of SCC. These studies served as the foundation for the development of SCC standards (ETS Committee, 2009).

Professor Hajime Okumura first suggested the idea of SCC in 1986, but the prototype was first created by Professor Ozawa at the University of Tokyo in Japan in 1988 (Ozawa, Mackawa & Kunishima, 1989; Okamura & Ozawa, 1995). The same elements that make up traditionally vibrated concrete – cement, aggregates, and water – as well as different quantities of chemical and mineral admixtures – make up SCC's ingredients. High-range water reducers (super-

plasticizers) and viscosity-enhancing compounds are the most frequently used chemical admixtures because they alter the rheological characteristics of concrete. Mineral admixtures are used in the manufacturing of SCC because they not only offer financial advantages, but also lower water heat. Additionally, some mineral admixtures are known to enhance the workability and long-term performance of concrete (EFNARC, 2002; Ahmed, Seleem, Badawy & Elakhras, 2016), as well as enhance its rheological characteristics and decrease the thermally induced cracking (Bilodeau & Malhotra, 2000; Dinakar, Babu & Santhanam, 2008). Silica fume (SF), fly ash (FA) and limestone powder (LP) were used the most in SCC (Bouzoubaâ & Lachemi, 2001; Türkmen, 2003; Nehdi, Pardhan & Koshowski, 2004; Felekoğlu, Tosun, Baradan, Altun & Uyulgan, 2006; Esping, 2008; Khatib, 2008; Leemann, Loser & Münch, 2010).

Silica fume, and fly ash and some other materials were also used to produce sustainable concrete. Najaf, Abbasi and Zahrai (2022) investigated the impact of using micro silica, waste glass powder and polypropylene fibers together in order to obtain sustainable lightweight concrete, which has high compressive strength, flexural strength, ductility and impact resistance. The use of micro silica as partially replacing cement and waste glass powder replacing some aggregates had its beneficial environmental impact. It was found that the best percentages of 10% micro silica, 25% glass powder and 1.5 wt.% of fibers improved significantly its compressive strength and flexural strength of light weight concrete and also increased its impact resistance. It was mentioned that using micro silica as partially replacing cement by 10 wt.% could reduce the amount of CO₂ produced by 5 t while constructing a 5-story building and that had its valuable effect on the environment. Lightweight aggregates (Mueller, Metcherine & Haist, 2001) and recycled concrete aggregates (Corinaldesi & Moriconi, 2003; Tu, Jann & Hwang, 2005) were also utilized in SCC. Increased viscosity may be necessary to lower the possibility of segregation because lightweight aggregate has a tendency to float (Shi & Yang, 2005). The water absorption of aggregate made from recycled concrete may greatly affect the filling ability as a result of fast losing of consistency.

The impact of aggregate types (gravel, dolomite and basalt) and the impact of sand to aggregate ratio on SCC characteristics was researched by Seleem, Badawy and Shehabeldin (2006). Survey outcomes showed that the optimum recommended values of sand to aggregate ratio were found to be 47.5% for gravel SCC and 50% for basalt SCC. At sand to aggregate ratio of 47.5%, the best flow behavior was recorded for dolomite SCC while basalt SCC recorded the worst behavior.

Khalil (2008) studied the impact of delay time on the rheological and strength characteristics of the SCC mix; the amount of time from the conclusion of the mixing process until the beginning of concrete placement, or even its end, and the function of using a retarding admixture with the SCC mix. It was discovered that as the delay time grew, the rheological characteristics of the SCC blend gradually decreased to the point where some of the SCC limits were not met at a delay time of 30 min. Even with a 30 min time delay, the inclusion of 0.5% retarding admixture could bring the mixture's rheological characteristics within the SCC limits (Khalil, 2008).

Saafan and Bait Al-Shab (2020) investigated the behavior of SCC under simulated hot weather conditions as Climate has been an issue to consider during the last years and the ambient temperature is more critical for SCC than conventional concrete and SCC basic requirement is related to its consistency and ability to flow during placement. The studied parameters involved the ambient temperature, materials temperature and using a retarder. Tests performed included the measurement of the rheological properties, compressive strength and early shrinkage. Temperature of the thermally insulated chamber, mixing water and the solid materials ranged between 50°C and the ambient temperature of 25°C in different combinations. The rheological properties were adversely affected by temperature and an enhancement in performance was obtained by cooling of the concrete materials and using a retarder. Using a retarder resulted in an adverse effect on the compressive strength results between 7 and 90 days under simulated hot weather conditions. The effect of time delay of 20 min before casting was also considered.

Aim and research significance

The production of SCC in the laboratory and the investigation of the effect of various parameters on its behavior showed high sensitivity for this type of concrete to temperature; an increase in the ambient temperature of few degrees was sufficient for SCC to lose its required rheological characteristics and did not satisfy its rheological limits, which were necessary for its use. In addition, the work in situ on a large scale is different from working in a controlled environment such as the laboratory. Therefore, the aim of this work is to develop a suitable SCC design mix based on experience to be used in situ under hot weather conditions of about 35°C and to study the characteristics of this mix as well as the impact of various ingredients of the SCC mix on its rheological and hardened properties under such conditions. Intended variables are the cement content, ratio of coarse to fine aggregate, water to cement ratio, chemical admixture content and mineral admixture content such as fly ash or silica fume.

The experimental work

Cement from the Suez Corporation in Egypt, Category I ordinary portland cement (C42.5), was used. Natural siliceous sand as a fine aggregate and pulverized limestone as a coarse aggregate with 14 mm maximum particle size was used. The specific gravity and water absorption for sand and limestone aggregates were 2.63%, 0.65%, and 2.61%, 0.8%, respectively. With a water-cementitious materials ratio of 0.45, clean tap water was used. The chemical admixture used was a high-ranged super plasticizers from Basf company called Master Glenium RMC 315. Besides, SF and FA were used in SCC mixes to determine how well the mineral admixtures performed. Silica fume and fly ash used in this study were from Sika Company in Obour city, Egypt and FA was categorized as Class C in accordance with the ASTM C 618 standard (ASTM International [ASTM], 2023).

According to the Egyptian Technical Standards for SCC (ETS Committee, 2009), the SCC mixtures were prepared. The amounts of ingredients needed for one cubic meter of concrete are listed in Table 1. One mix served as the control, while the other eleven mixes with mineral admixtures were made in various configurations. Table 1 provides the ratios of different combinations. The chemical admixture, viscosity enhancing admixture (VEA), was used with a ratio of 2% of the cement content. Silica fume was added at 2 proportions (5%, 10%) as a substitute for some of the cement content. The fly ash was added by 2 proportions (25%, 35%) as a substitute for some of the cement content.

TABLE 1. Amounts of materials needed for 1 m³ of self-compacting concrete (SCC) mixes

Mix code	Cement content [kg·m ⁻³]	Mineral admixture			Coarse to fine aggregate ratio (C : F _{agg.})	Dolomite content [kg·m ⁻³]	Sand content [kg·m ⁻³]	Water to cement ratio (w/c)	Water content [kg·m ⁻³]	Chemical admixture	
		%	silica fume (SF)	fly ash (FA)						%	kg·m ⁻³
M1	450.0		–	–	1 : 0.8	951.0	761.0	0.45	202.0	2	9.0
M2	500.0		–	–	1 : 0.8	885.0	708.0	0.45	225.0	2	10.0
M3	405.0	10	45.0	–	1 : 0.8	951.0	761.0	0.45	202.0	3	13.5
M4	450.0	10	50.0	–	1 : 0.8	885.0	708.0	0.45	225.0	3	15.0
M5	450.0		–	–	1 : 0.8	917.0	734.0	0.5	225.0	2	9.0
M6	450.0		–	–	1 : 1	856.0	856.0	0.45	202.0	2	9.0
M7	450.0		–	–	0.8 : 1	761.0	951.0	0.45	202.0	2	9.0
M8	450.0		–	–	1 : 0.8	951.0	761.0	0.45	202.0	3	13.5
M9	405.0	10	45.0	–	1 : 0.8	951.0	761.0	0.45	202.0	2	9.0
M10	427.5	5	22.5	–	1 : 0.8	951.0	761.0	0.45	202.0	2	9.0
M11	337.5	25	–	112.5	1 : 0.8	951.0	761.0	0.45	202.0	2	9.0
M12	292.5	35	–	157.5	1 : 0.8	951.0	761.0	0.45	202.0	2	9.0

Source: own work.

The behavior of each mix in its fresh condition was assessed directly after the end of mixing using the slump flow, V-funnel and L-box experiments. After that the concrete batch was poured in oiled molds of different test examples created for testing the mechanical characteristics for each mix. The standard cubic test specimens with measurements of $150 \times 150 \times 150$ mm and cylindrical specimens of 150×300 mm for the compressive and splitting tension tests were used. Pouring of concrete was carried out in one layer to the top edge of the mold without any compaction or vibration. The excess concrete was scrapped off and the top surface was finished using a trowel. The molds were kept horizontal during and after placing concrete until hardening as shown in Figure 1. After about 24 h the specimens were taken out of the molds and submerged in 25°C pure water until testing.



FIGURE 1. The cubic (a) and cylindrical (b) specimens in the molds

Source: own work.

Results and discussion

Table 2 includes the results of the fresh properties of each SCC combination. Slump-flow, V-funnel, and L-box experiments results are given in Table 2 (Fig. 2). The diameter of the bulk of concrete after it had been released from a standard slump cone was measured in 2 perpendicular directions. This diameter is known as the slump flow. Slump flow measurements of all SCC mixes were acceptable, falling between 600 and 800 mm, which was a sign of good deformability. The flowability (filling ability) of concrete having a nominal maximum size of 20 mm aggregate

was assessed using the V-funnel test. It was performed on the mixtures to evaluate their flow rates through small openings without obstacles. In order to estimate the flowability of SCC mixtures in confined spaces, the flow time test was found. The range of 6 to 12 s is considered an appropriate flow period for SCC. The L-box test is a popular technique for assessing how well new concrete passes through crowded steel rebars. The blockage ratio ($BR = H_2/H_1$) should be between 0.8 and 1.0. It is employed to assess the passage skill.

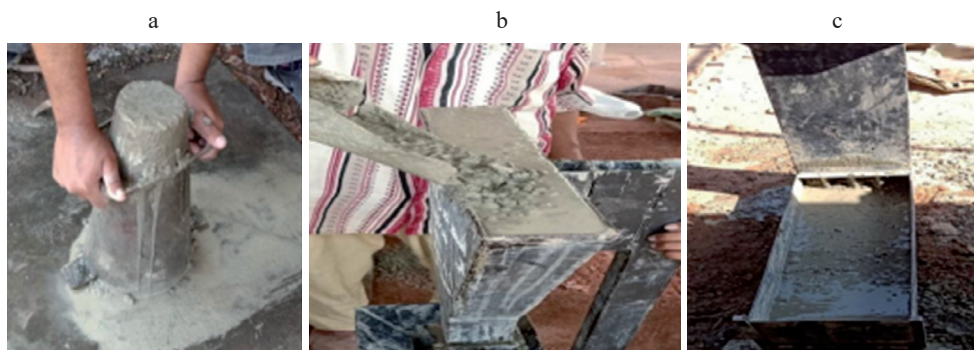


FIGURE 2. Self-compacting concrete (SCC) mix under the slump-flow diameter (a), V-funnel (b) and L-box tests (c)

Source: own work.

TABLE 2. Rheological and hardened characteristics of SCC mixtures

Mix code	Slump flow test [mm]	V-funnel test [s]	L-box test (ratio)	7-day compressive strength [MPa]	28-day compressive strength [MPa]	56-day compressive strength [MPa]	28-day tensile strength [MPa]
M1	610	7.5	0.81	29.5	39.5	42.0	3.8
M2	570	8.4	0.75	33.0	41.5	45.5	3.9
M3	700	6.5	0.90	32.0	42.5	49.3	4.1
M4	650	6.8	0.85	36.0	45.2	53.7	4.5
M5	680	6.5	0.87	20.4	29.6	33.1	2.7
M6	650	6.5	0.84	19.8	29.4	31.0	2.7
M7	580	10.0	0.73	18.4	26.2	28.1	2.5
M8	720	6.3	0.94	25.3	36.4	39.2	3.4
M9	550	14.0	0.67	36.0	47.3	54.8	4.6
M10	650	6.8	0.84	32.2	43.0	51.3	4.1
M11	670	6.4	0.86	31.0	41.8	53.3	4.1
M12	620	8.0	0.80	34.2	45.1	56.8	4.8

Source: own work.

Table 2 also shows the compressive strength results of the hardened characteristics for all of the mixtures that were tested test at 7 days, 28 days and 56 days and the indirect tension test at 28 days (Fig. 3). Each result was a mean value for 3 tested specimens.

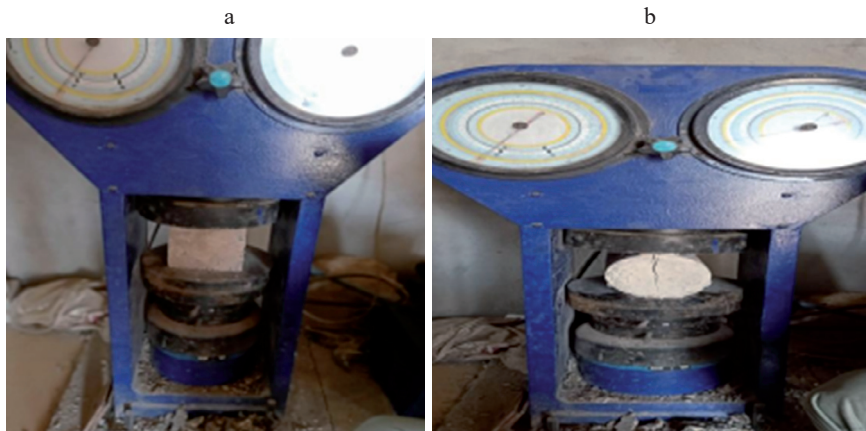


FIGURE 3. Compressive (a) and splitting tensile strength (b) tests of self-compacting concrete (SCC) mix specimens

Source: own work.

Cement content impact on properties of self-compacting concrete

Increasing the cement content from 450 to 500 $\text{kg}\cdot\text{m}^{-3}$ resulted in a decline in the SCC mix rheological characteristics as shown in Table 2 and Figure 4. A reduction in the slump flow from 610 to 570 mm was obtained. The addition of 10% SF to the SCC mix led to the same trend. There was an increase in the compressive strength of SCC mixes as a consequence of the rise in the cement content from 450 to 500 $\text{kg}\cdot\text{m}^{-3}$ at 7 days, 28 days, and 56 days as shown in Figure 5. An increase from 39.5 to 41.5 MPa was obtained at 28 days. The same trend was obtained in the splitting tension test after 28 days. The addition of 10% SF to SCC mix led to the same trend. The results here agree with the effect of cement content on the fresh and hardened properties of SCC at normal conditions at an ambient temperature of 25°C. The increase of its content led to a decrease in the rheological properties due to its consumption of a larger amount of the mixing water in surrounding its particles. However, the increase in the cement content resulted in an increase in the compressive and splitting tensile strengths with the formation of more calcium silicate hydrate (CSH) compounds responsible for the strength.

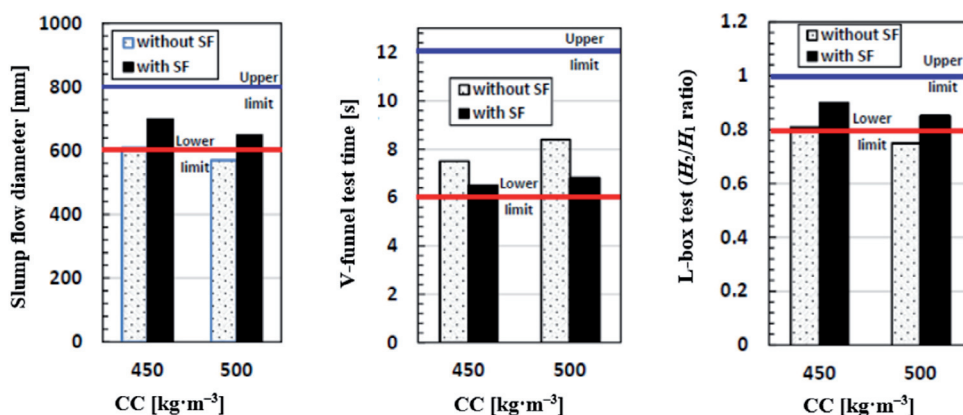


FIGURE 4. Rheological properties for self-compacting concrete (SCC) mixes of various cement contents (cement content – CC, silica fume – SF)

Source: own work.

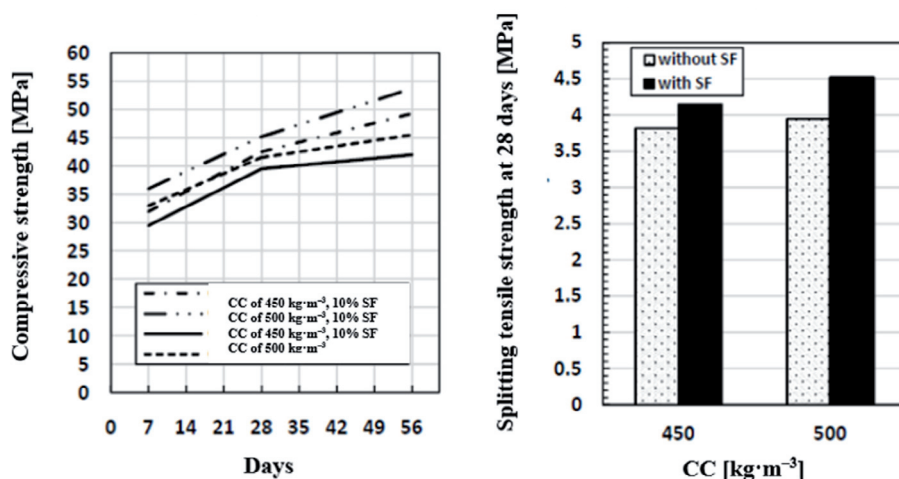


FIGURE 5. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various test results (cement content – CC, silica fume – SF)

Source: own work.

Water to cement ratio impact on self-compacting concrete properties

The rheological characteristics of the SCC mix increased as a consequence of the rise in water to cement ratio (w/c) from 0.45 to 0.5 kg·m⁻³ as given in Table 2 and Figure 6. The slump flow increased from 610 to 680 mm. As the water to cement ratio increased from 0.45 to 0.5, the compressive strength of SCC mixtures decreased

at all ages of 7, 28 and 56 days (Fig. 7). A decrease from 39.5 to 29.6 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength at 28 days. This agrees with the role of water in SSC at normal conditions at an ambient temperature of 25°C. The increase in the amount of water increased the rheology of SCC, but it adversely affected the strength of the concrete mix due to the pores resulting from the evaporation of excess water used for rheology.

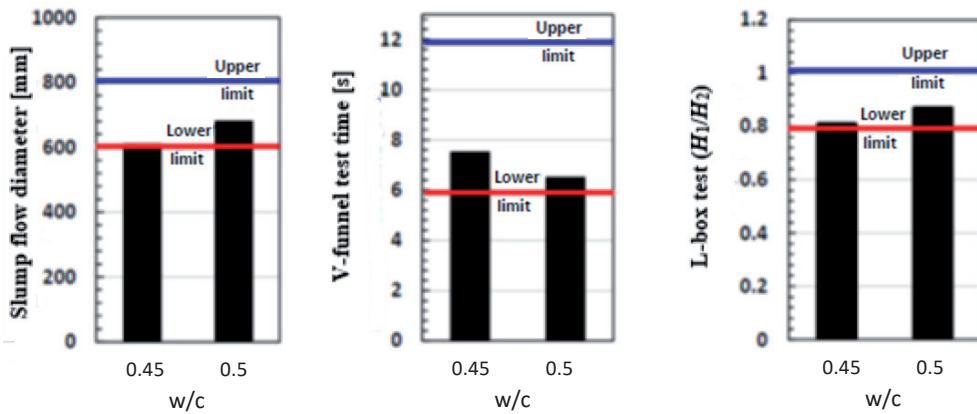


FIGURE 6. Rheological properties for self-compacting concrete (SCC) mixes of various water to cement ratios (w/c)
Source: own work.

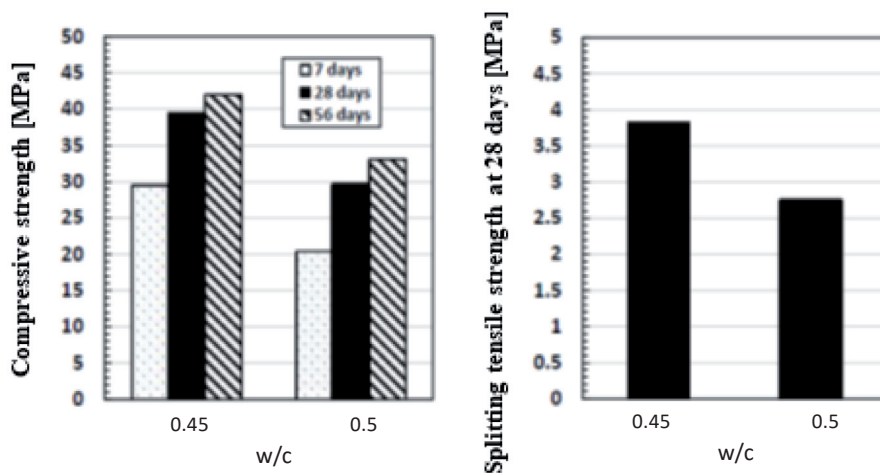


FIGURE 7. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various water to cement ratios (w/c)
Source: own work.

Coarse to fine aggregate ratio impact on self-compacting concrete properties

The change in the coarse to fine aggregate ratio from 1 : 0.8 (or 1.25 : 1) to 0.8 : 1 resulted in a reduction in the SCC mix rheological characteristics. A reduction in the slump flow from 610 to 580 mm was obtained. However, the ratio of coarse to fine aggregate of 1:1 gave the best rheological properties with a 650 mm slump flow as given in Table 2 and Figure 8. The change of coarse to fine aggregate ratio from 1 : 0.8 (or 1.25 : 1) to 0.8 : 1 through the ratio of 1 : 1 resulted in a decrease in the SCC compressive strength at all ages of 7, 28, and 56 days (Fig. 9). A reduction from 39.5 to 26.2 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength at 28 days. This also agrees with the effect of coarse to fine aggregate ratio on the properties of SCC at normal conditions at an ambient temperature of 25°C. It is known that the paste volume fraction is greater in both viscosity modifying admixture and powder-type SCC than in ordinary concrete at the expense of the volume of aggregate, and particularly at the expense of coarse aggregate. This means that the coarse to fine aggregate ratio of SCC is smaller than that of ordinary concrete in order to satisfy the SCC rheological properties; SCC rheological properties are based on low yield stress, moderate viscosity and retention of the kinetic energy of the flowable mix by reducing the volume fraction of coarse aggregate. These measures are required to satisfy the fluidity, resistance and prevention of interparticle collision, and segregation resistance (Bonen & Shah, 2004).

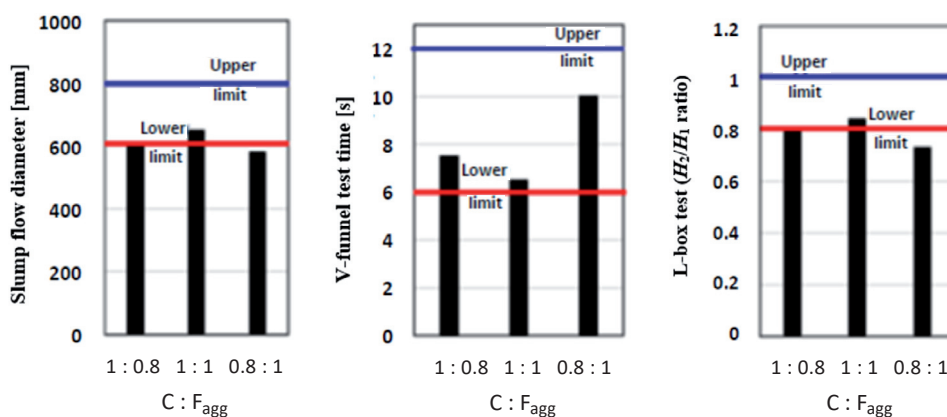


FIGURE 8. Rheological properties for self-compacting concrete (SCC) mixes of different coarse to fine aggregate ratios ($C : F_{agg}$.)

Source: own work.

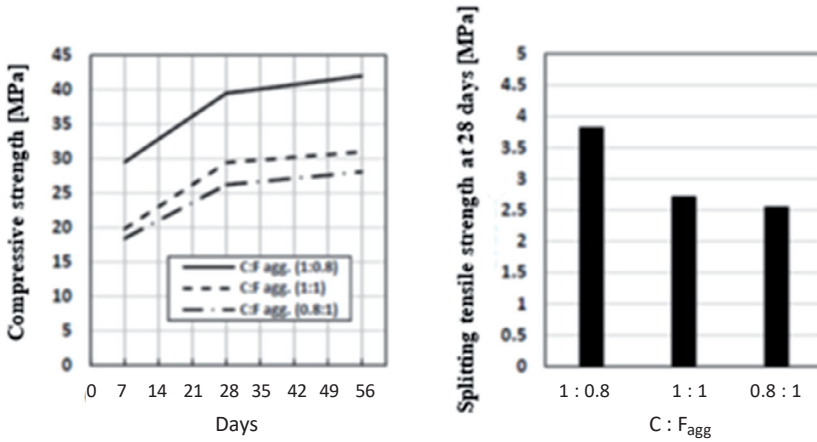


FIGURE 9. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various coarse to fine aggregate ratios (C : F_{agg}.)

Source: own work.

Chemical admixtures impact on self-compacting concrete properties

The increase in the percentage of the high range super plasticizer (SP) added from 2 to 3% by weight of cement led to a rise in the rheological properties of the SCC mixes as shown in Table 2 and Figure 10. The slump flow increased from 610 to 720 mm. The addition of 10% SF to SCC mix led to the same result. The increase in the percentage of the high range super plasticizer from 2 to 3% resulted in

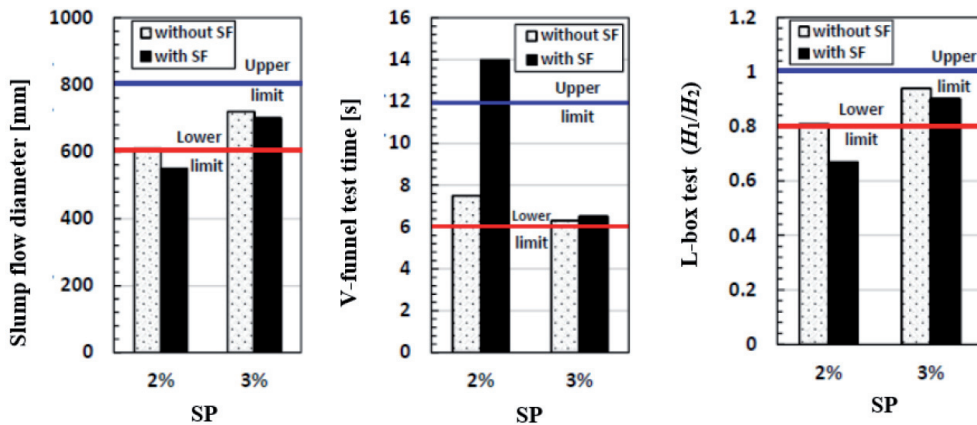


FIGURE 10. Rheological properties for self-compacting concrete (SCC) mixes of different percentages of superplasticizer (SP), (silica fume – SF)

Source: own work.

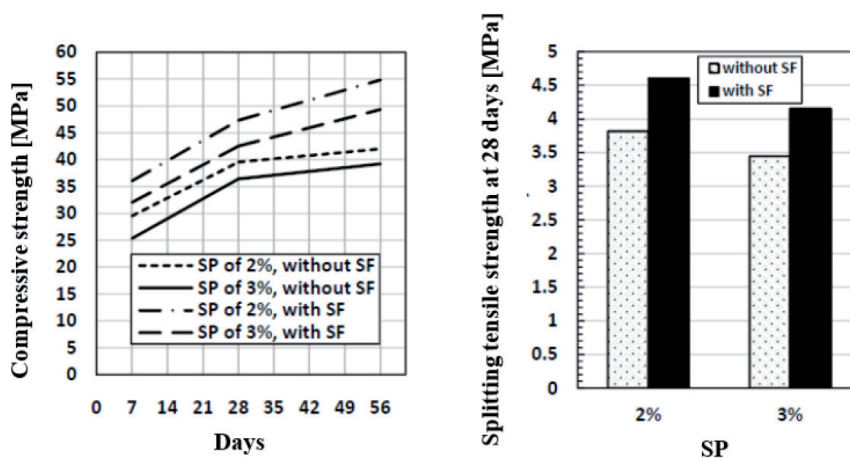


FIGURE 11. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various percentages of superplasticizer (SP), (silica fume – SF)

Source: own work.

a reduction in the SCC mixes compressive strength at all ages of 7 days, 28 days, and 56 days (Fig. 11). A decrease from 39.5 to 36.4 MPa was obtained at 28 days (7.8% less). The same trend was obtained for the splitting tensile strength after 28 days. The addition of 10% SF to SCC mix led to the same results. This agrees with the role of the high range super plasticizer in SCC at normal conditions at an ambient temperature of 25°C.

Mineral admixtures impact on self-compacting concrete properties

Silica fume impact on self-compacting concrete properties

The rheological characteristics of the SCC mix increased as a result of the addition of 5% silica fume partially replacing a similar amount of cement as shown in Table 2 and Figure 12. The slump flow increased from 610 to 650 mm. The rheological characteristics of the SCC mix decreased and no longer satisfied the rheological limits of the SCC mix as a result of the addition of 10% silica fume partially replacing similar amount of cement. A reduction in the slump flow from 650 to 550 mm was obtained. The compressive strength of the SCC mixes increased at all ages of 7, 28, and 56 days when silica fume was increased from 0% to 5% partially replacing similar amount of cement (Fig. 13). An increase from 39.5 to 43 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength after 28 days. The compressive strength of the SCC mixes increased

at the same ages when silica fume was increased from 5 to 10% partially replacing similar amount of cement. An increase from 43 to 47.3 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength at 28 days. This effect of SF agrees with its effect on SCC at normal conditions at an ambient temperature of 25°C.

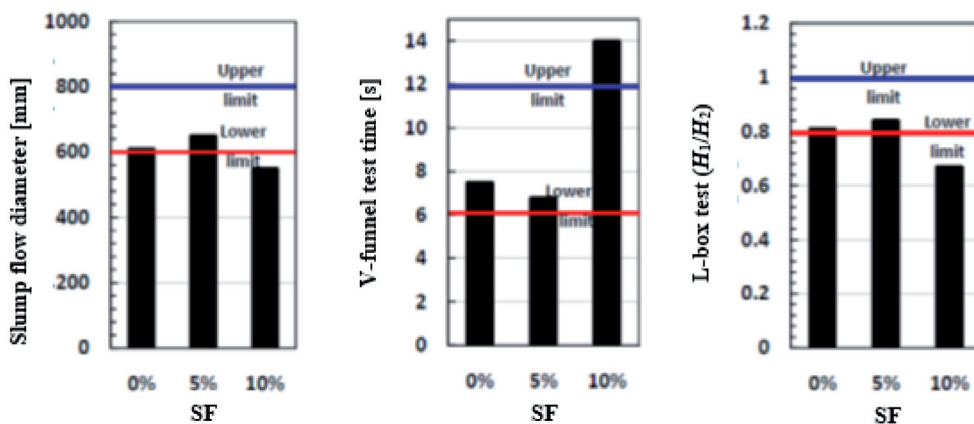


FIGURE 12. Rheological properties for self-compacting concrete (SCC) mixes for various percentages of silica fume (SF)

Source: own work.

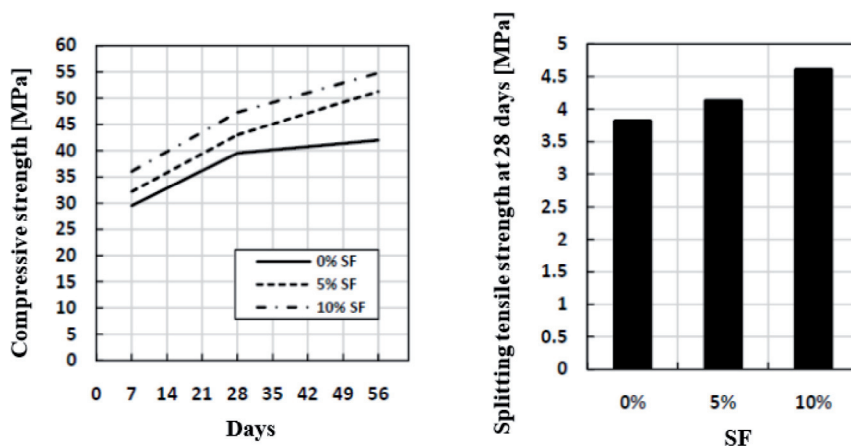


FIGURE 13. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various percentages of silica fume (SF), (silica fume – SF)

Source: own work.

Fly ash impact on self-compacting concrete properties

The rheological properties of the SCC mix increased as a consequence of the addition of fly ash, which was increased from 0% to 25% as a partial substitute of the weight of cement as shown in Table 2 and Figure 14. The slump flow increased from 610 to 670 mm. The rheological properties of the SCC mix decreased, but still satisfied the rheological limits of the SCC mix as a consequence of the rise in fly ash from 25 to 35% partially replacing a similar amount of cement. A reduction in the slump flow from 670 to 620 mm was obtained.

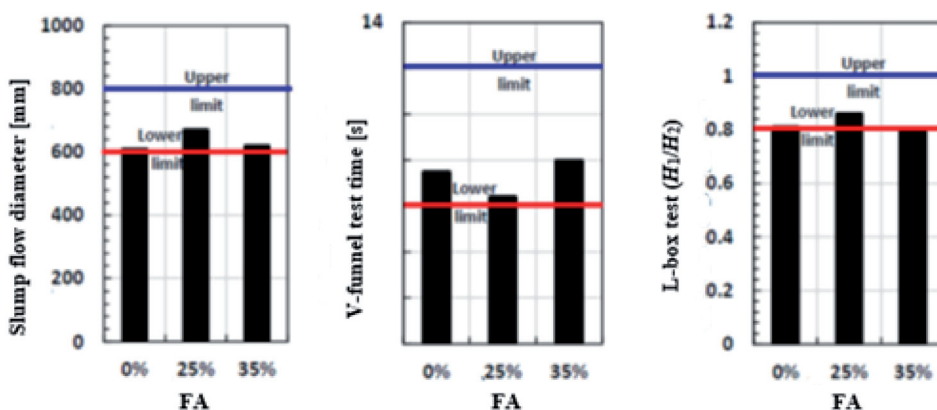


FIGURE 14. Rheological properties for self-compacting concrete (SCC) mixes for various percentages of fly ash (FA)

Source: own work.

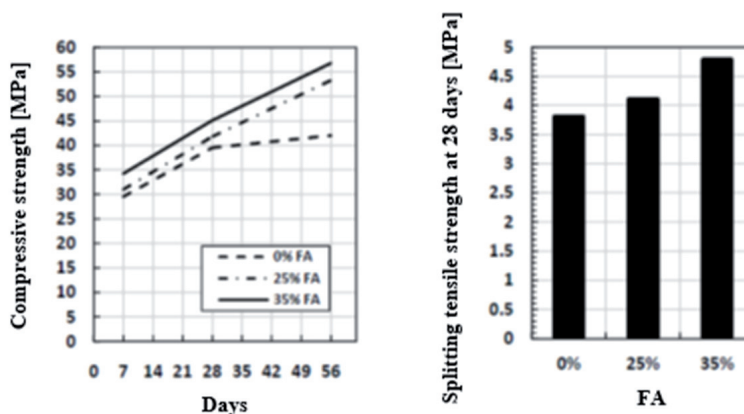


FIGURE 15. Compression and splitting tension test results of self-compacting concrete (SCC) mixes for various percentages of fly ash (FA)

Source: own work.

The increase in fly ash from 0 to 25% as a partial replacement of the weight of cement resulted in an increase in the compressive strength of the SCC mixes at all ages of 7 days, 28 days and 56 days as shown in Figure 15. An increase from 39.5 to 41.8 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength at 28 days. The compressive strength of the SCC mixes increased at the same ages as a result of the addition of fly ash, which was increased from 25 to 35% partially replacing a similar amount of cement. An increase from 41.8 to 45.1 MPa was obtained at 28 days. The same trend was obtained for the splitting tensile strength at 28 days. This effect of FA agrees with its effect on SCC at normal conditions at an ambient temperature of 25°C.

Comparison of fly ash and silica fume's impacts of on self-compacting concrete mixes

The SCC mix with 5% SF gave comparable rheological results to the SCC mix with 25% FA as shown in Table 2 and Figure 16. Both satisfied the rheological SCC limits. The SCC mix with 5% SF showed the marginally increased compressive strength in the SCC mix when compared with that of 25% FA at 7 and 28 days while the latter provided a little bit more compressive strength than the former at 56 days.

The optimum SCC mix constituents from this study which satisfied the SCC rheological limits and produced 52 MPa compressive strength at 56 days was achieved with cementitious content of 450 kg·m⁻³ and a 0.45 water cementitious ratio, 1 : 0.8

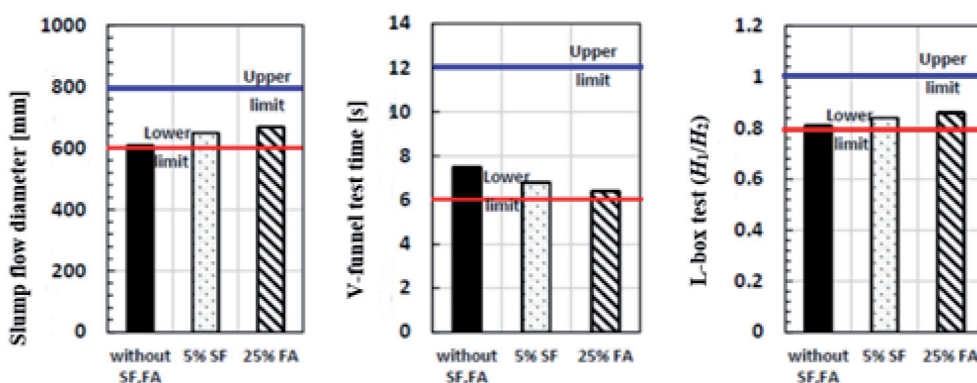


FIGURE 16. Rheological properties for self-compacting concrete (SCC) mixes with different pozzolanic materials (silica fume – SF, ash fly – FA)

Source: own work.

coarse to fine aggregate ratio, 2% high range chemical admixture, either 5% SF or 25% FA mineral admixture as partially replacing similar weight of cement.

However, higher values of compressive and splitting tensile strengths could be obtained with 10% SF or 35% FA contents as a substitute for similar amounts of cement, but without satisfying the lower limits of the rheological characteristics of SCC mixes in case of the former mix with 10% SF or satisfying at about the lower limits in case of the latter mix with 35% FA.

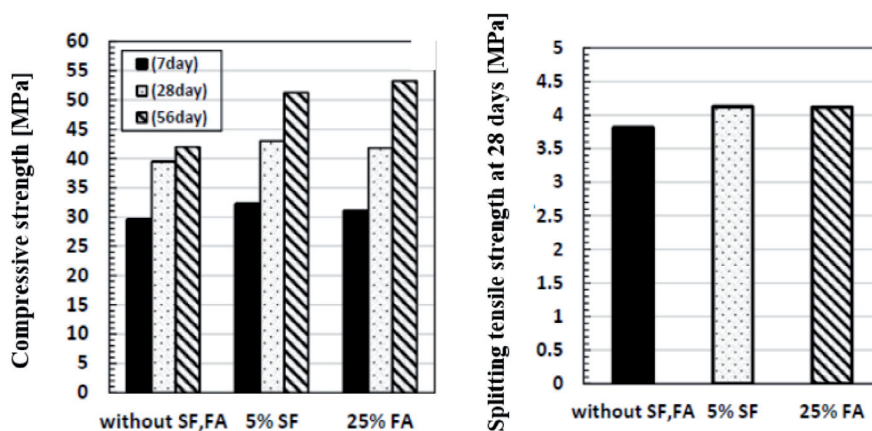


FIGURE 17. Compression and splitting tension test results of self-compacting concrete (SCC) mixes with different pozzolanic materials (silica fume – SF, ash fly – FA)

Source: own work.

Conclusions

It is worth mentioning that this study focused on the production of SCC mix in situ in hot weather conditions at a temperature of about 35°C. It can be concluded within the limits of this study that a properly proportioned SCC mix can perform well under such conditions. The impact of SCC mix ingredients on the rheological and hardened properties of the mix under such conditions was similar to their impact under normal conditions at 25°C and as follows:

- 1) It was found that the SCC mix rheological properties increased with decreasing the cement content, increasing w/c ratio, decreasing C : F_{agg.} ratio to a certain extent, increasing the high range superplasticizer, increasing FA content and increasing SF but up to 5% after which a decrease in the rheological properties occurred.

- 2) Compressive and splitting tensile strengths of the SCC mixes increased as the cement content of the SCC mixes rose, the w/c ratio decreased and, the C : F_{agg.} ratio increased, the high range super plasticizer decreased and the SF or FA increased as a substitute for a similar amount of cement.
- 3) Optimum values were obtained for these ingredients, which satisfied the SCC rheological characteristics of the mix and gave a compressive strength of about 42 MPa at 28 days and about 52 MPa at 56 days.
- 4) These optimum constituent values were 450 kg·m⁻³ of cement, 0.45 water cementitious ratio, and a coarse to fine material ratio of 1 : 0.8, a high range superplasticizer of 2%, and a mineral admixture of either 5% SF or 25% FA as a substitute for a similar amount cement.
- 5) Higher strengths were obtained using 10% SF or 35% FA while satisfying the rheological characteristics of the SCC mixes only in the case of using 35% FA.

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Summary

Performance of self-compacting concrete cast in hot weather conditions. This work focused on how self-compacting concrete (SCC) performs in situ in hot weather conditions at an ambient temperature of about 35°C. Tests for the rheological properties and compressive and splitting tensile strength aspects were carried out. The results of SCC mix ingredients on the rheological and hardened features of SCC mix were studied. Variations in the amount of portland cement content (CC), water to cement ratio (w/c), coarse to fine aggregate ratio (C : F), chemical admixture ratio, and pozzolanic admixture ratio were considered. Optimum values were obtained for these ingredients, which satisfied the SCC rheological characteristics and gave a 28-day compressive strength of 42 MPa, and 52 MPa after 28 days and 56 days, respectively. These optimum constituent values were 450 kg·m⁻³ of cement, 0.45 water cementitious ratio, and a coarse to fine material ratio of 1 : 0.8, a high range superplasticizer of 2%, and a mineral admixture of either 5% silica fume or 25% fly ash as a substitute for a similar amount cement.