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Effect of Constitute Materials Proportions on Rheological and Mechanical Properties of Self-Compacting Concrete

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Abstract

Self-compacting concrete shows superior advantages more than normal vibrated concrete. Self-compacting concrete is strongly an imperative alternate of normal vibrated concrete. Till now there is no standard design method for self-compacting concrete. Assessment of self-compacting concrete is based on investigation of its rheological and mechanical properties. Concrete is set self-compacting concrete when fillingability, passingability and segregation of the concrete are existed in the rheological state. Twelve self-compacting concrete mixes are proportioned considering three different values for each constituent material. The twelve self-compacting concrete mixes are tested in rheological state to evaluate the mix fillingability, passingability and segregation resistance. The twelve self-compacting concrete mixes are tested in compression test to assess its mechanical properties. Tests results of the self-compacting concrete mixes in rheological and mechanical states are investigated and analyzed. Both rheological and mechanical properties of self-compacting concrete are highly influenced by the change in quantity of each constitute material.

Keywords: *Self-Compacting, Concrete, Fillingability, Passingability, Segregation.*

1. Introduction

The development of self-compacting concrete has recently been one of the most important developments in the building industry. The important of using self-compacting concrete concept is to decrease the risk due to the human factor to enable the economic efficiency and able to flow and to fill the pros/voids in concrete without vibration (Deepika et al., 2017, Faseyemi, 2015 and Srishaila, 2015). Self-compacting concrete has good resistance to segregation and bleeding because of its cohesive properties (Gedric, 2017). Researches have set some guidelines for mixtures proportioning of self-compacting concrete, which include reducing the volume ratio of aggregate to cementations materials; increasing the paste volume; carefully controlling the maximum coarse aggregate particles size and total volume; and using various viscosity enhancing admixtures and superplasticizer (Aggarwal et al., 2008 and Pamnani et al., 2013).

There is no standard method for self-compacting concrete design and many academic institutions, ready-mixed, precast and contracting companies have developed their own mix proportions method (Deepika et al., 2017 and Srishaila, 2015). On the other hand, it is apparent that workability depends on a number of interacting factors such as water content, aggregate type and grading, aggregate to cement ratio, kind and dosage of superplasticizer, and the fineness of cement (Farediwala et al., 2012).

The following clauses demonstrate the variation of quantity for the constitute materials of self-compacting concrete. Boukendakdji et al. (2016) used water cement ratio equals 0.45, sand equals 50% of total aggregate and superplasticizer equals 0.8 to 2.4% of cement content. Kamran and Miahra (2014) used water cement ratio equals 0.45, coarse aggregate equals 48% of total aggregate, fly ash equals 15, 25 and 35% of cement content, and superplasticizer equals 1% of cement content. Dumne (2014) used water cement ratio equals 0.55,

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coarse aggregate equals 68% of total aggregate, fly ash equals 11% of cement content and superplasticizer ranging from 0.9 to 1.22% of cement content.

Mahajan and Singh (2013) used 0.41 water cement ratio, 37% coarse aggregate of total aggregate, 43% fly ash of cement content and 1% superplasticizer of cement content. Farediwals and Jamnu (2012) used 0.4 and 0.5 water cement ratios, 50 and 56% coarse aggregate of total aggregate, 17.5% fly ash of cement content, and superlasticizer ranging from 1.5 to 2.3% of cement content. Khaleel et al. (2011) used water cement ratio ranging from 0.37 to 0.43, 50% coarse aggregate of total aggregate, 10% filler of cement content and superplasticizer ranging from 0.8 to 1.85% of cement content.

From the above mentioned researches there are numerous variations in proportions of constitute materials of self-compacting concrete. However, water ratio is ranging from 0.37 to 0.55, coarse aggregate is ranging from 37 to 68% of total aggregate, fly ash is ranging from 10 to 43% of cement content and superplasticizer is ranging from 0.8 to 2.4% of cement content. A concrete is classified a self-compacting concrete, if the basic workability requirements fillingability, passingability and segregation resistance are fulfilled simultaneously (Khaleel et al., 2011 and TSSCC, 2012). Self-compacting concrete filling ability, passing ability and segregation resistance are evaluated by performing slump flow, J-ring and V-funnel tests, respectively (TSSCC, 2012 and EFNARC, 2002).

The aim of this research is investigation the effect of proportions for the constitute materials of self-compacting concrete on both rheological and mechanical properties.

2. Materials and Methods

A local produced Portland cement with grade and specific gravity of CEM I 42.5 and 3.15, respectively was used in casting of self-compacting concrete mixes. The used cement is produced meeting both E.S.S. 4756-1/2013 and BS EN 197-1/2011. Natural siliceous sand with specific gravity and fineness modulus of 2.65 and 2.54, respectively was used in casting of self-compacting concrete mixes. The used sand was sieved using 5 mm standard sieve to clarify the sand from yellow and black loam, grains with greater sizes, and stranger materials.

Natural lime stone crushed dolomite with specific gravity and fineness modulus of 2.55 and 6.74, respectively was used in casting of self-compacting concrete mixes. The used crushed dolomite was sieved using standard sieves of 5 and 20 mm. However, 5 mm standard sieve was used to remove smaller grain size and fine aggregate, and 20 mm standard sieve was used to remove the greater grain size and maintain the used crushed dolomite nominal maximum size equals 20 mm according to the instructions mentioned in references (TSSCC, 2012, EFNARC, 2002 and EGSCC, 2005).

The fly ash used in casting self-compacting concrete mixes is a concrete additive of a new generation in fine powder form. The used fly ash spherical particles reduce the water requirements and create a lubricating effect that causes concrete to flow and pump better. Self-compacting concrete with that type of fly ash is more cohesive and is less prone to segregation. The used fly ash specific gravity is 2.2 (Fly Ash, 2008).

A high-range water-reducer HRWR superplasticizer with density of 1.05 kg/liter was used in casting of self-compacting concrete mixes. The used HRWR superplasticizer is a third generation high performance concrete admixture for homogenous concrete which complied with both ASTM-C-494 Type G and F, and BS EN 934 part 2:2001 requirements (ViscoCrete, 2010). Clean drinkable water was used in casting and curing of self-compacting concrete mixes.

The twelve self-compacting concrete mixes are proportioned according to the instruction and guidelines of the Technical Specifications for Self-Compacting Concrete, 2012 however, the guidelines are:

1. Water powder ratio (W/P) is ranging from 0.8 to 1.1 by volume.
2. Water content is equal or less than 200 liter/m^3.
3. Powder content is ranging from 400 to 600 kg/m^3.
4. Cement content is equal or more than 350 kg/m^3.
5. Sand content is ranging from 40 to 50% of total aggregate.
6. Nominal maximum size of coarse aggregate equals or less than 20 mm.

Based on the previous guidelines and instructions water cement ratios W/C are 0.35, 0.40 and 0.45, and sand S contents are 40, 45 and 50% of the total aggregate. According to the manufacturer instructions fly ash FA contents are 25, 30 and 35% of cement content (Fly Ash 2008), and superplasticizer SP contents are 1, 1.5 and 2% of cement content (ViscoCrete, 2010). The twelve self-compacting concrete mixes were classified into four groups as demonstrated in Table 1. According to the three different contents of the sand, there were three types of mixed aggregates. Sieve analysis test results for sand, crushed dolomite CD, 40% sand mixed aggregate, 45% sand mixed aggregate and 50% sand mixed aggregate are shown in Fig. 1.

Table 1: Self-Compacting Concrete Mixes Proportions

G	Mix	Self-Compacting Concrete Mix Proportions (kg/m^3)					
		C	S	CD	W	FA	SP
A	MWC0.35	350	825	1009	122.5	105	5.51
	MWC0.4	350	825	1009	140	105	5.51
	MWC0.45	350	825	1009	157.5	105	5.51
B	MS 40	350	721	1081	140	105	5.51
	MS 45	350	812	993	140	105	5.51
	MS 50	350	904	904	140	105	5.51
C	MFA 25	350	822	1004	140	87.5	5.51
	MFA 30	350	822	1004	140	105	5.51
	MFA 35	350	822	1004	140	122.5	5.51
D	MSP 1	350	815	994	140	105	3.67
	MSP 1.5	350	815	994	140	105	5.51
	MSP 2	350	815	994	140	105	7.35

Table 1 Cont.: Self-Compacting Concrete Mixes Proportions

G	Mix	Self-Compacting Concrete Mix Proportions					
		W/C	S (%)	FA (%)	SP (%)	P (kg/m^3)	W/P
A	MWC0.35	0.35	45	30	1.5	455	0.80
	MWC0.4	0.40	45	30	1.5	455	0.88
	MWC0.45	0.45	45	30	1.5	455	0.99
B	MS 40	0.40	40	30	1.5	455	0.88
	MS 45	0.40	45	30	1.5	455	0.88
	MS 50	0.40	50	30	1.5	455	0.88
C	MFA 25	0.40	45	25	1.5	437.5	0.92
	MFA 30	0.40	45	30	1.5	455	0.88
	MFA 35	0.40	45	35	1.5	472.5	0.93
D	MSP 1	0.40	45	30	1	455	0.88
	MSP 1.5	0.40	45	30	1.5	455	0.88
	MSP 2	0.40	45	30	2	455	0.88

Slump flow, J-ring and V-funnel tests set-up are shown in Figs. 2, 3 and 4, respectively. Fig. 5 shows J-ring test set-up for Mix MWC0.35. Table 2 summarizes measured items for each test, its corresponding property and its acceptance limits. For each self-compacting concrete mix, six cubes were cast and cured. However, three cubes were tested up to failure in compression test at age of 7-day as well as the other three cubes were tested at age of 28-day.

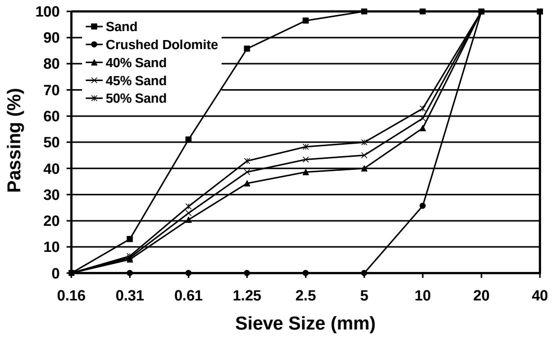

Fig. 1: Sieve analysis test results for aggregates

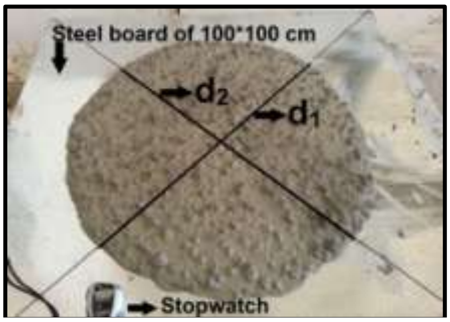

Fig. 2: Slump flow test of a SCC mix

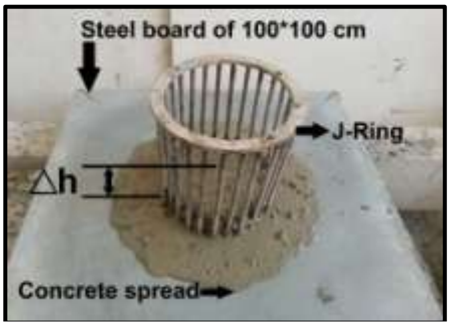

Fig. 3: J-Ring test of a SCC mix

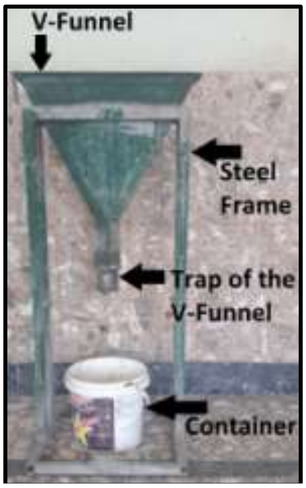

Fig. 4: V-Funnel test set-up

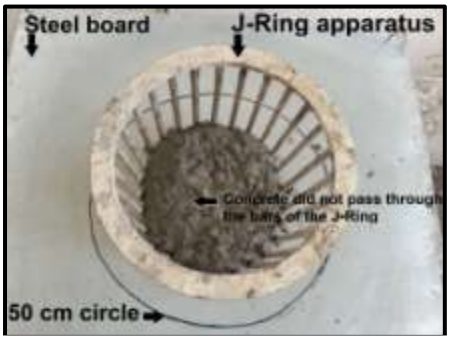

Fig. 5: J-Ring test set-up of SCC mix MWC0.35

Table 2: Rheological Tests for SCC (TSSCC, 2012)

Test	Measured Items	Unit	Acceptance Limits		Property
Slump flow test	d_a	mm	600	800	Filling ability
	t_{50cm}	sec	2	5	Filling ability
J-Ring test	Δh	mm	0	20	Passing ability
	t_{50cm}	sec	-	-	Passing ability
	d_a	mm	-	-	Passing ability
V-Funnel test	t_0	sec	6	12	Filling ability
	$t_{5minutes}$	sec	t_0 + 0	t_0 + 3	Segregation resistance

Where:

1. d_f: The average of diameters of concrete measured in two perpendicular directions,
2. t_{50cm}: The time of concrete reaches a spread circle of 50 cm in diameter,
3. Δh: The difference in height between the concrete just inside and outside the J-ring bars,
4. t_0: The time between opening the trap door and when the light is seen from the above through the V-funnel, and
5. $t_{5minutes}$: The time after a period of 5 minutes between opening of the trap door and when the light is seen from above through the V-funnel.

3. Results

Slump flow test results are illustrated in Figs. 6 and 7. J-ring test results are shown in Figs. 8, 9 and 10. Zero values of J-ring test 50-cm flow time t_{50cm} of self-compacting concrete mixes MWC0.35, MFA25 and MFA35 indicated that concrete did not reach the 50 cm in diameter circle. V-funnel test results are illustrated in Figs. 11 and 12. Zero values of V-funnel 5-minutes flow time $t_{5minutes}$ of self-compacting concrete mix MWC0.35 indicated that concrete did not drop from the funnel. 7-day and 28-day compressive strengths results for self-compacting concrete mixes shown in Fig. 13.

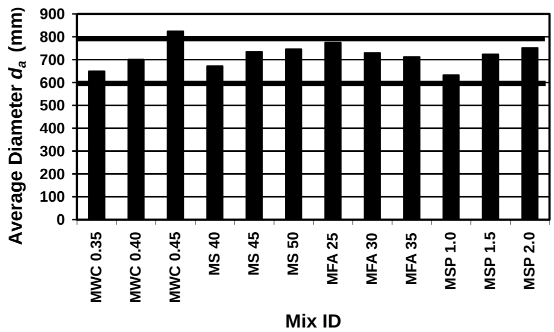

Fig. 6: Average diameter d_a of slump flow test for SCC mixes

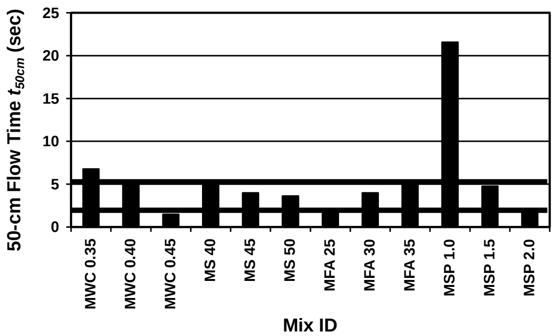

Fig. 7: 50-cm flow time t_{50cm} of slump flow test results for SCC mixes

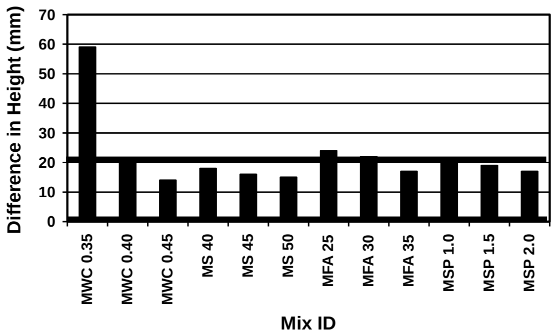

Fig. 8: Difference in height Δh of J-ring test results for SCC mixes

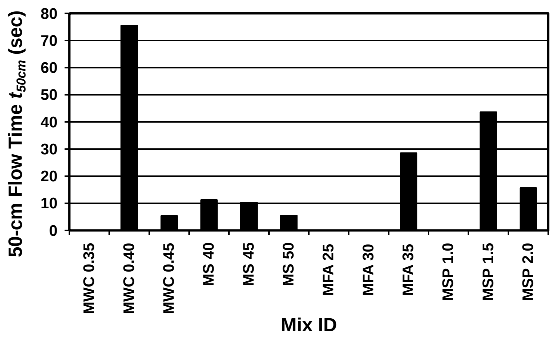

Fig. 9: 50-cm flow time t_{50cm} of J-ring test results for SCC mixes

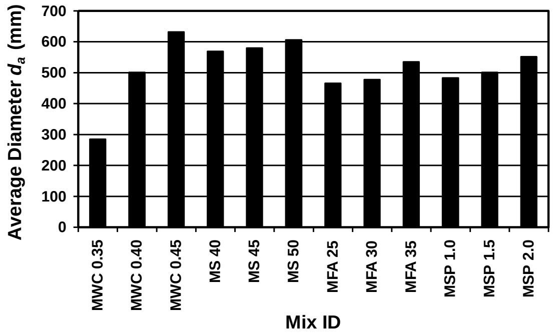

Fig. 10: Average diameter d_a of J-ring test results for SCC mixes

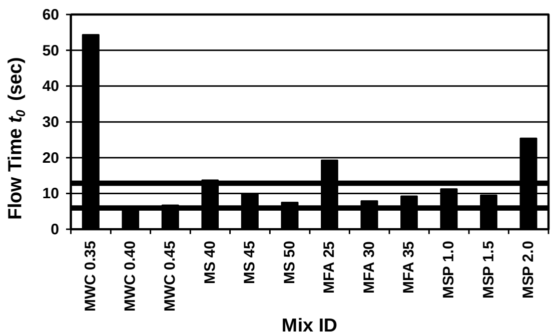

Fig. 11: Flow time t_0 of V-funnel test results for SCC mixes

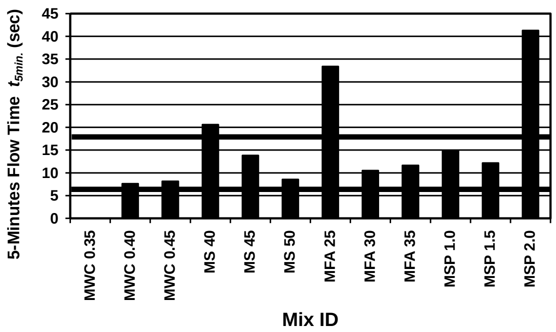

Fig. 12: 5-Minutes flow time $t_{5minutes}$ of V-funnel test results for SCC mixes

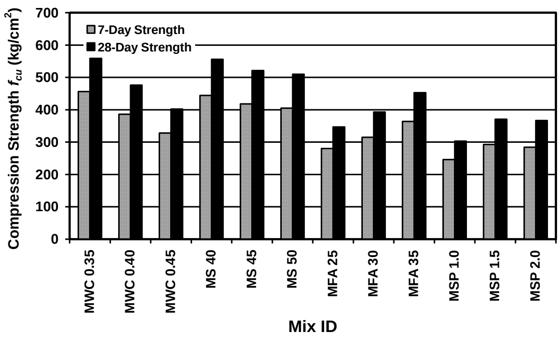

Fig. 13: 7-Day and 28-day concrete compressive strengths results of SCC mixes

4. Discussion

Using water cement ratios 0.4 and 0.45 increased slump flow test average diameter d_a of SCC mixes by about 8 and 27% but reduced slump test flow time t_{50cm} by about 23 and 78%, respectively more than 0.35. Using aggregate with 45 and 50% of sand increased slump flow test average diameter d_a of SCC mixes by about 9 and 11% but reduced slump flow test flow time t_{50cm} by about 25 and 32 %, respectively more than 40% sand.

Using 25 and 30% fly ash of cement content increased slump flow test average diameter d_a of SCC mixes by about 9 and 3% but reduced slump flow test flow time t_{50cm} by about 65 and 21%, respectively more than 35% fly ash. Using 1.5 and 2% superplasticizer of cement content increased slump flow test average diameter d_a of SCC mixes by about 14 and 19% but reduced slump flow test flow time t_{50cm} by about 78 and 90%, respectively more than 1% super plasticizer.

Using water cement ratios 0.4 and 0.45 reduced J-ring test difference in concrete height Δh of SCC mixes by about 66 and 76% as well as reduced J-ring test flow time t_{50cm} by about 50 and 96%, respectively with respect to 0.35. Using water cement ratios 0.4 and 0.45 increased J-ring test average diameter d_a of SCC mixes by about 76 and 122%, respectively more than 0.35. Using aggregate with 45 and 50% sand reduced J-ring test difference in concrete height Δh of SCC mixes by about 11 and 17% as well as reduced J-ring test flow time t_{50cm} by about 9 and 51%, respectively with respect to 40% sand. Using aggregate with 45 and 50% sand increased J-ring test average diameter d_a of SCC mixes by about 2 and 7%, respectively more than 40% sand.

Using 30 and 35% fly ash of cement content reduced J-ring test difference in concrete height Δh of SCC mixes by about 9 and 30% as well as reduced J-ring test flow time t_{50cm} by about 0 and 113%, respectively with respect to 25% fly ash. Using 30 and 35% fly ash of cement content increased J-ring test average diameter d_a of SCC mixes by about 3 and 15%, respectively more than 25% fly ash. Using 1.5 and 2% superplasticizer of cement content reduced J-ring test difference in concrete height Δh of SCC mixes by about 10 and 20% as well as reduced J-ring flow time t_{50cm} by about 100 and 164%, respectively with respect to 1% superplasticizer. Using 1.5 and 2% superplasticizer of cement content increased J-ring average diameter d_a of SCC mixes by about 4 and 15%, respectively more than 1% superplasticizer.

Using water cement ratios 0.4 and 0.45 reduced V-funnel flow time t_0 of SCC mixes by about 91 and 88% as well as reduced V-funnel 5 minutes flow time $t_{5minutes}$ by about 107 and 100%, respectively with respect to 0.35. Using aggregate with 45 and 50% sand reduced V-funnel flow time t_0 of SCC mixes by about 28 and 46% as well as reduced V-funnel 5 minutes flow time $t_{5minutes}$ by about 33 and 59%, respectively with respect to 40% sand.

Using 30 and 35% fly ash of cement content reduced V-funnel flow time t_0 of SCC mixes by about 59 and 52% as well as reduced V-funnel 5 minutes flow time $t_{5minutes}$ by about 68 and 65%, respectively with respect to 25% fly ash. Using 1 and 1.5% superplasticizer of cement content V-funnel flow time t_0 of SCC mixes by about 56 and 63% as well as reduced V-funnel 5 minutes flow time $t_{5minutes}$ by about 64 and 71%, respectively with respect to 2% superplasticizer.

Using water cement ratios 0.35 and 0.4 increased self-compacting concrete 7-day compression strengths by about 39 and 18% as well as increased 28-day compression strengths by about 40 and 19%, respectively with respect to 0.45. Using aggregate with 40 and 45% sand increased self-compacting concrete 7-day compression strengths by about 10 and 4% as well as increased 28-day compression strengths by about 9 and 2%, respectively with 50% sand.

Using 30 and 35% fly ash of cement content increased self-compacting concrete 7-day compression strengths by about 13 and 30% as well as increased 28-day compression strengths by about 14 and 32%, respectively with respect to 25% fly ash. Using 1.5 and 2% superplasticizer of cement content increased self-compacting concrete 7-day compression strengths by about 19 and 15% as well as increased 28-day compression strengths by about 23 and 22%, respectively with respect to 1% superplasticizer.

5. Conclusions

Increasing water cement ratio from 0.35 to 0.45 increased fillingability, passingability but reduced both early and late compression strengths of self-compacting concrete. However, increasing water cement ratio up to 0.4 increased segregation resistance of self-compacting concrete. Increasing sand from 40 to 50% of total aggregate increased fillingability, passingability and segregation resistance but reduced both early and late compression strengths of self-compacting concrete. Increasing fly ash from 25 to 35% of cement content increased passingability, segregation resistance, and early and late compression strengths of self-compacting concrete. However, increasing fly ash up to 30% of cement content increased fillingability of self-compacting concrete. Increasing superplasticizer from 1 to 2% of cement content increased fillingability, passingability, and early and late compression strengths of self-compacting concrete. However, increasing superplasticizer more than 1.5% of cement content increased segregation resistance of self-compacting concrete. Both fillingability and passingability of self-compacting concrete are significantly increased by increasing water cement ratio, but fillingability is significantly reduced by increasing superplasticizer content. Both early and late compression strengths of self-compacting concrete are significantly increased by increasing fly ash content but are significantly reduced by increasing water cement ratio.

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