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Compressive, shear and torsional strength of beams made of self-compacting concrete

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Abstract. The aim of this study is to provide experimental data regarding the compressive, shear and torsional strength of self-compacting concrete (SCC) used in rectangular beams, and then comparing the results with the equations presented by the CSA A23.3-04 and ACI 318-11. In fact, the gathered information in this field is quite useful for calibrating the computer models of other researchers. The other goal of this study was to investigate the effects of silica fume and superplasticizer dosages on the mechanical properties of SCC. In this research, SCC is made based on 16 different type mixing layout. Also two normal concrete (NC) or vibrating concrete are constructed to compare the results of SCC and NC. This work concentrated on concrete mixes having water/binder ratios of 0.45 and 0.35, which contained constant total binder contents of 400 kg/m^3 and 500 kg/m^3, respectively. The percentages of silica fume that replaced cement were 0% and 10%. The superplasticizer dosages utilized in the mixtures were 0.4%, 0.8%, 1.2% and 1.6% of the weight of cement. Beam dimensions used in this test were 30×30×120 cm^3.The results of this research indicated that shear and torsional strength of SCC beams to be used in computer models can be calculated utilizing the equations presented in CSA A23.3-04 and ACI 318-11.

Keywords: self-compacting concrete; rectangular beam; shear strength; torsional strength

1. Introduction

Self-compacting concrete (SCC) is a kind of concrete that is able to flow under its own weight. Moreover, SCC is cohesive enough to fill spaces of any dimension and shape without bleeding or segregation. This characteristic makes SCC mostly helpful wherever placing is not easy, such as in heavily reinforced concrete members or in complex formwork. This technology is based on increasing the amount of fine materials, such as silica fume or limestone fillers, without altering the water content compared to ordinary concrete. SCC should have a low yield value to guarantee high flowability. High range water reducers based on polycarboxylate ethers are typically used to plasticize the SCC mixtures (Mazloom and Yoosefi 2011). SCC is very sensitive to fluctuation in water content; therefore, stabilizers like polysaccharides are used too. Because SCC is characterized by particular fresh concrete properties, many new tests are developed to compute

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flowability, blocking tendency, self-leveling and viscosity of the mix. The strength and durability of well-designed SCC are similar to normal concrete. It is not easy to keep SCC in the desired steadiness over a long period of time; nevertheless, construction time is shorter, and the construction of SCC is environmentally more pleasant (no noise, no vibration). Additionally, SCC produces a good surface layer. These advantages make SCC especially valuable for use in precasting factories, but SCC is also used in cast-in-place manufacturing (Okamura and Ouchi 1999, Nawy 2008). Also SCC has a variety of applications in retrofitting the structural elements in the case of jacketing (Constantin and Constantin 2012, Constantin *et al.* 2014).

It is worth noting that Felekoglu *et al.* (2007) studied the effect of water to cement ratio on the properties of SCC. Moreover, Jianxiong *et al.* (1999) investigated the influence of superfine sand and pozzolanic additives on SCC.

The divisions of gravity loads create shear and bending forces in almost all the resisting components. Because of the massive nature of reinforced concrete elements, rotating forces including torsion are also conveyed along the load path. Concrete is strong in compressive strength, but is very weak in tension and consequently in torsion and shear. Since the tension strength of concrete is low, it is essential to cautiously think about the tension stress resulting from diagonal tension. In the casing of shear, the failure could happen due to diagonal tension or shear compression failure, and in both conditions, the failure is much more brittle than the flexural failure. Also a concrete beam under torsion stresses fails in diagonal tension on each face to shape cracks running in a spiral about the beam. The torsion stresses may be changed by the shear forces on each face. This action on each face in a beam is like vertical shear (Day 2006, Macginley and Choo 2003).

CSA A23.3-04 and ACI 318-11 are proposed and calibrated with data for vibrated concrete, and originally SCC is not considered there. The objective of this study is to provide experimental data regarding the shear and torsional strength of SCC rectangular beams. These results are used for estimating the exactness of the existing equations, presented by the CSA A23.3-04 and ACI 318-11, for predicting the shear and torsional strength of SCC. Persson (2001), Felekoglu (2003), and Suksawang *et al*. (2006) have investigated some mechanical properties of SCC too.

2. Materials and mix proportions

The cement used in this investigation was ordinary Portland cement (OPC), and its physical properties and chemical compositions are given in Tables 1 and 2 respectively. Quartzite crushed gravel and Natural River sand with a nominal maximum size of 14 mm were utilized as the aggregates. The control mixes were cast using OPC, while the other mixes were prepared by replacing 10% of the cement with silica fume on mass-for-mass basis. It should be mentioned that using the mass-for-mass basis above changes the volume of the mixtures. Because the maximum density changes of fresh concrete mixtures was lower than 3%, the volume changes were not considered in the mix designs. The water/binder ratios were 0.35 and 0.45 respectively. The same mix proportions were used for the concrete mixes with the dosages of 0.4%, 0.8%, 1.2% and 1.6% of a kind of polycarboxylate based superplasticizer. The solid contend of the liquid superplasticizer was 40% and its water content was adjusted the water dosage of the mixtures. It is worth nothing that Su and Miao (2003) have introduced a method for the mix design of flowing concrete. To produce laboratory samples, 16 self-compacting concrete (SCC) and 2 normal concrete (NC) mixtures are made. The details of the mix proportions of the present research are given in Table 3.

As a result of using different dosages of the superplasticizer, the fresh and hardened properties of the mixes were quite different (Mazloom *et al*. 2004). Workability tests performed in this research were ordinary slump, slump flow and J-ring. The results of these tests and the production method of specimens can be observed in the previous published paper of the first author (Mazloom and Yoosefi 2013).

3. Test procedure

For each mix, the following specimens were made: three 150 × 300 (diameter× length) mm cylinders for compressive strength; three 300 × 300 × 1200 (with × height × length) mm rectangular beams for shear strength; three 300 × 300 × 1200 (with × height × length) mm rectangular beams for torsional strength. After being de-moulded at the age of one day, all the specimens were cured in water at 20±2 ^{o}C. Then, one hour before the test, they were removed from the water pool.

The 28-day compressive strengths of cylindrical specimens were determined according to ASTM-C39. For shear and torsional strengths, the instrumentation used are shown in Figs. 1 and 2 respectively. Chalioris (2008) expresses the test set-up and stability of Fig. 2 and its support condition in torsion. The loading rates of the two tests were the same and they can be observed with data logger instrument in Fig. 5.

Table 1 Physical properties of cement consumption

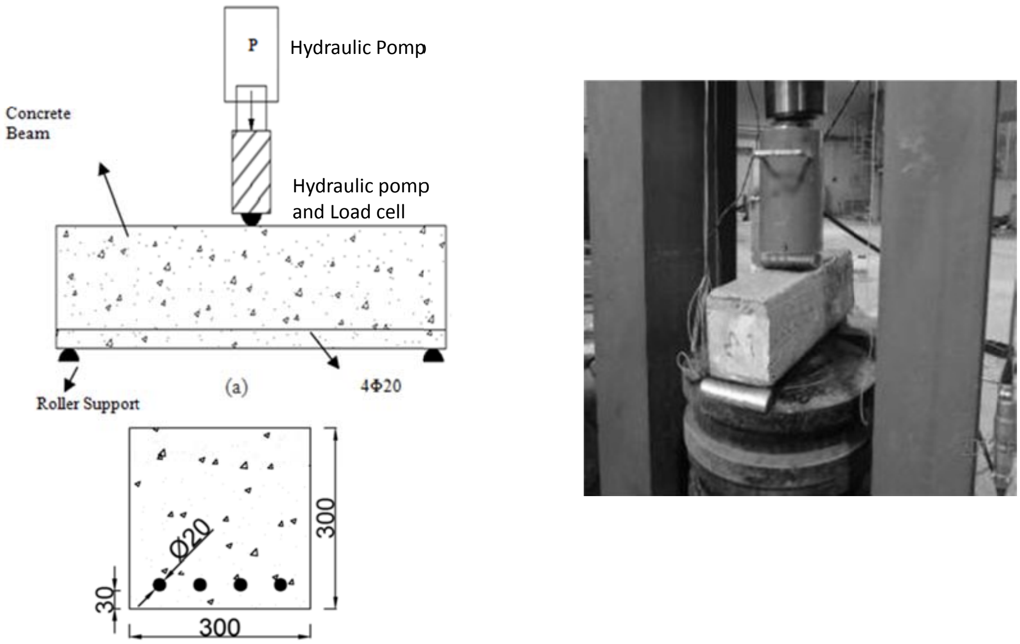
Physical property	quantity
Blain tininess (m^2/kg)	330
Initial setting (min)	120
Final setting (min)	240
Three-day strength(MPa)	17
Seven-day strength(MPa)	27
Twenty-eight-day strength(MPa)	40

Table 2 Chemical properties of cement consumption

Chemical composition	Percentage in cement consumption	Chemical composition	Percentage in cement consumption
CaO	63.95	K_2O_3	0.54
SiO_2	21.46	Na_2O	0.26
Al_2O_3	5.55	C_3S	50.96
Fe_2O_3	3.46	C_2S	23.10
MgO	1.86	C_3A	8.85
SO_3	1.42	C_4AF	10.53

Table 3 Mix design

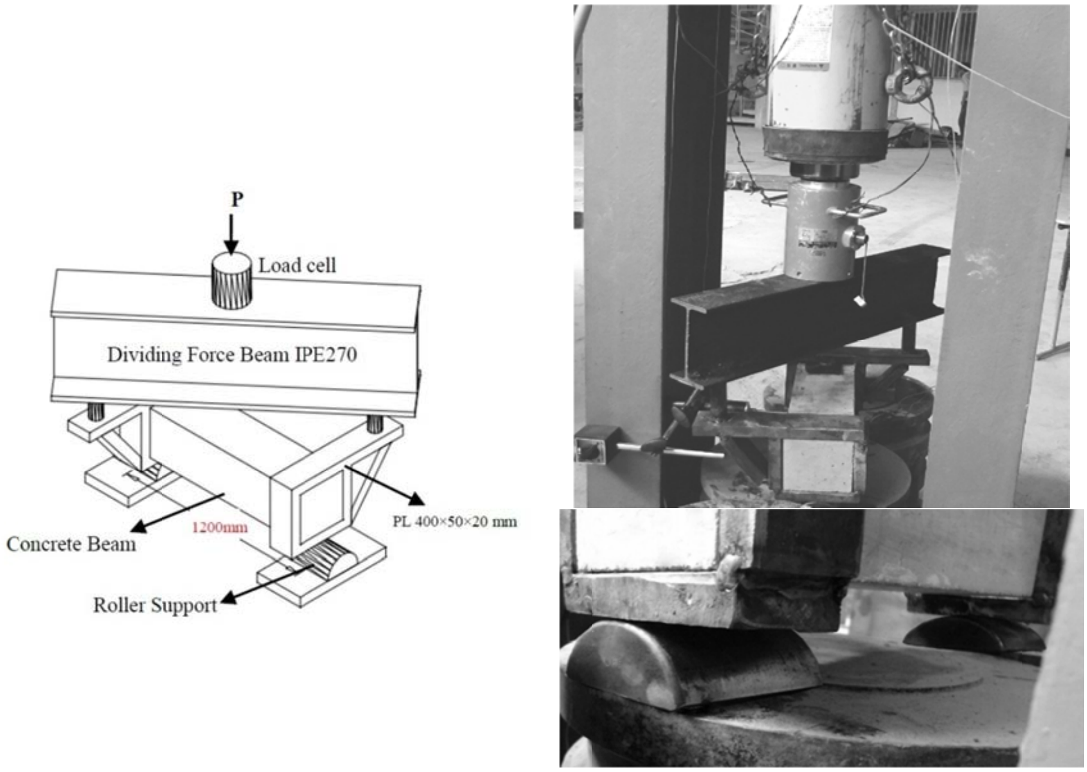
Mix components	Concrete mixes					
	W/C=0.35			W/C=0.45		
	OPC	SF10	NC	OPC	SF10	NC
	Without silica fume	With 10% silica fume	Without additive	Without silica fume	With 10% silica fume	Without additive
Water $(\frac{kg}{m^3})$	175		175	180		180
Cement $(\frac{kg}{m^3})$	500	450	500	400	360	400
Silica fume $(\frac{kg}{m^3})$	---	50	---	---	40	---
Limestone powder $(\frac{kg}{m^3})$	155		155	150		150
Gravel$(\frac{kg}{m^3})$	867		867	833		833
Sand$(\frac{kg}{m^3})$	668		668	722		722
Super plasticizer (% of cement weight)	0.4%, 0.8%, 1.2%, 1.6%		-	0.4%, 0.8%, 1.2%, 1.6%		-



(a) Technical properties of concrete shear strength test machine and section

(b) Devices made by the authors for testing the shear strength of concrete

Fig. 1 Shear test device



(a) Technical properties of concrete torsional strength test machine

(b) Devices made by the authors for testing the torsional strength of concrete and supports

Fig. 2 Torsion test device

In fact, the average increase rate of tension stress in the bottom fiber of shear tests was 0.1MPa/s. Since the aim of this research was to obtain the shear and torsional capacities of SCC beams, stirrups were not used; moreover, the longitudinal reinforcement of 4Φ20 with the yield strength of 400 MPa was utilized in shear specimens to avoid the bending collapse of them. The concrete cover of 30 mm was used for this reinforcement.

4. Results and discussion

The results of compressive, shear and torsional strengths of SCC are presented in this part of the paper.

4.1 Compressive strength

The compressive strength is the most significant property of concrete. The compressive strength of concrete is its characteristic normally considered in structural design; moreover, for some purposes like shear and torsional strength, and the resistance to cracking, the tensile strength is required. There is presently no standard method for obtaining the direct tensile strength of concrete. According to the nature of strength of concrete, it would be anticipated that the compressive and tensile strengths are strictly related. Due to the convenience of performing compressive strength tests, experimental relationships have been developed so that other strength properties like shear and torsional strengths may be estimated from the results of compressive strength tests (Mehta and Monteiro 2006, Kamara *et al.* 2008).

For cylindrical samples, the 28-day compressive strengths are shown in Table 4 and Figs. 3 and 4. It can be seen that silica fume can contribute to the compressive strength development of concrete significantly. This is because of the filler effect and the excellent pozzolanic properties of the material, which translate into a stronger transition zone at the paste aggregate interface. The advantage of this pozzolanic reaction is double; increased compressive strength and chemical resistance.

Superplasticizing admixtures play an important role in ensuring optimum strength development of SCC. In water to binder ratio of 0.35, the optimum dosage of superplasticizer was 1.2%, and in water to binder ratio of 0.45, the optimum dosage of superplasticizer was 0.8%. It can be said that for improved workability of the mixes by excessive use of superplasticizer, the compressive strength of the SCC reduced. This may be because of wider stretch of the air bobbles in the mixes as a consequence of upper dosages of the superplasticizer.

4.2 Shear strength

Exterior transverse load is resisted by internal shear to preserve section balance. Since concrete is weak in tension, the principal tensile stress in a beam cannot surpass the tensile strength of the concrete. The principal stress is composed of two components: flexural stress and shear stress. The beam web should be reinforced to prevent diagonal shear cracks from opening. The resistance of the plain concrete in the web carries a part of the shear stress, and the equilibrium has to be borne by the diagonal tension reinforcement (Cladera and Mari 2005).

Table 4 Compressive and shear strength test results

Mix Design (w/c=0.35)	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Compressive strength of cylindrical samples (MPa)	Shear strength of beam samples (kN)	Mix Design (w/c=0.45)	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Compressive strength of cylindrical samples (MPa)	Shear strength of beam samples (kN)
SCC1	Without Silica fume	0.4	44	84	SCC9	Without silica fume	0.4	26.6	68.4
SCC3		0.8	38.3	86.6	SCC11		0.8	44.7	89.2
SCC5		1.2	51.9	94.4	SCC13		1.2	43.7	78.8
SCC7		1.6	46.5	80	SCC15		1.6	37.7	62.7
SCC2	With 10% silica fume	0.4	40.9	88.2	SCC10	With 10% silica fume	0.4	33.9	71
SCC4		0.8	39.2	89.2	SCC12		0.8	50.7	93.4
SCC6		1.2	65.7	98.6	SCC14		1.2	46.2	80.4
SCC8		1.6	41.1	75.2	SCC16		1.6	45.2	67.1
NC1	Without additive		30.6	72.6	NC2	Without additive		29.1	69.4

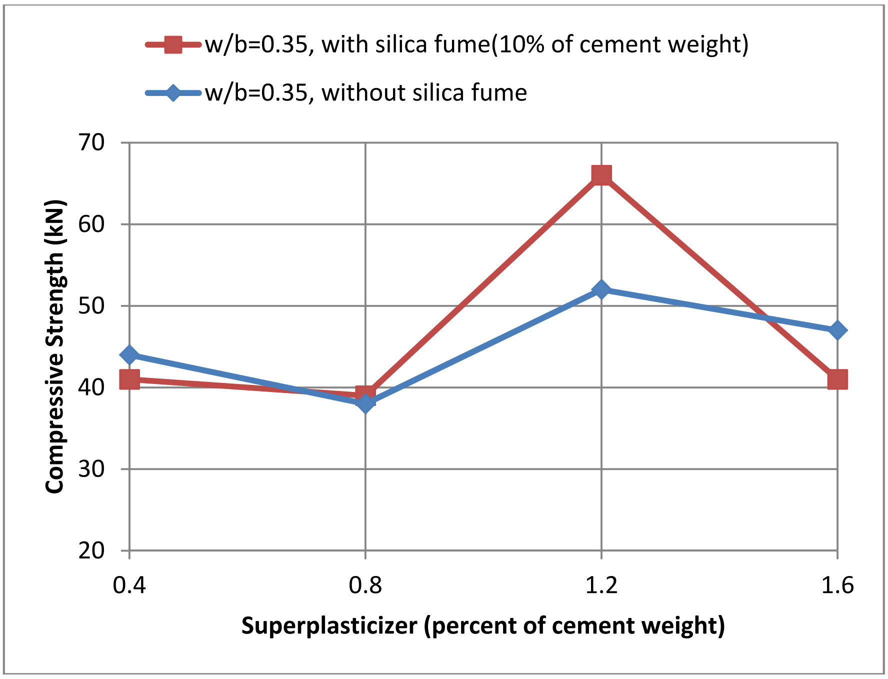


Fig. 3 Compressive strength of SCC for w/b=0.35

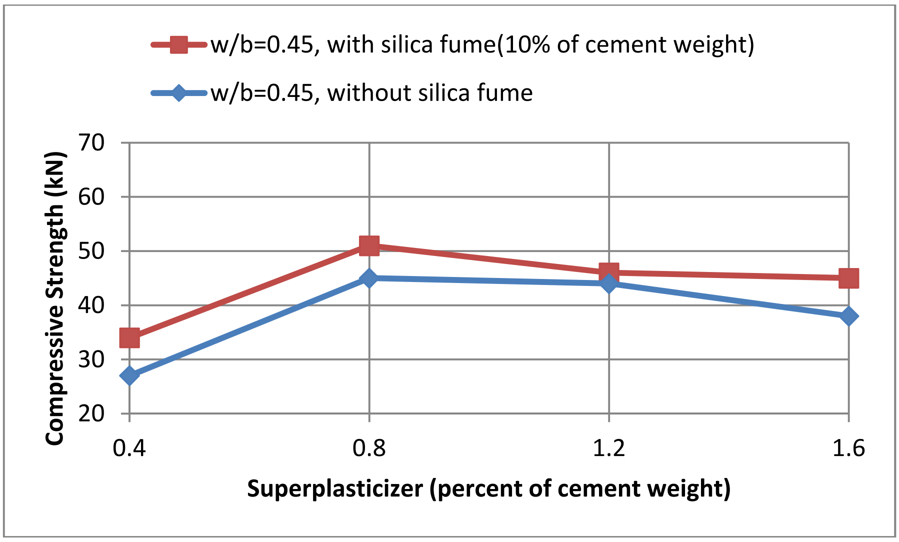


Fig. 4 Compressive strength of SCC for w/b=0.45

Shear forces accompany a change in bending moment in beams and give rise to diagonal tension in the concrete and bond stresses between the reinforcement and the concrete. Shear in a reinforced concrete beam without shear reinforcement causes cracks on inclined planes by the support as shown in Fig. 1. The following actions form the mechanism shear resistant in concrete beams: Shear stresses in the compression zone with a parabolic distribution; aggregate interlock along the cracks; dowel action in the bars where the concrete between the cracks transmits shear forces to the bars (Cladera and Mari 2004).

The existing codes state that shear failure in beams without shear reinforcement usually happen at about 30° to the horizontal. If the angle is steeper due to the load causing shear or since the section where the shear is to be checked is near the support, the shear capability is improved. This improvement is because the concrete in diagonal compression resists shear (Schiessl and Zilch 2001, Choulli 2005).

For beam samples, the 28-day shear strengths are shown in Table 4 and Figs. 6 and 7.In the failure mechanisms of the beams it was observed that the crack essentially traveled from the load point to a location near the support, and then a sudden brittle failure occurred. The slope of the diagonal cracks ranged from 14° to 40° from the horizontal line. The first diagonal crack took place at about 80% of the ultimate shear load. According to the test results, it can be said that the mechanisms of shear resistance were essentially the same in all beam specimens.SCC and NC beams had almost the same crack patterns. However, SCC beams exhibited smaller crack widths than NC beams. It may be due to the fact that, the smoother surface of cracks in SCC allows for a relative displacement between the crack tips with smaller crack opening to NC.

In all beam specimens the formation of the first shear crack in beams with SCC took place earlier than in beams made with normal concrete, as the tensile strength of the normal concrete was higher than the tensile strength of the SCC. It can be seen that the increase of compressive strength in self-compacting concrete improves the shear strength with a lower rate. This finding is in agreement with the findings of Hegger *et al*. (2005).

According to Table 4 and Figs. 6-7, the optimum dosage of superplasticizer for shear strength like compressive strength, is 1.2% for w/b=0.35 and 0.8% for w/b=0.45.

CSA A23.3-04(2004) and ACI 318-11(2011) give the following equations for calculating the shear strength provided by the concrete for beams without web reinforcement subject to shear and flexure

$$V_{c,CSA} = \varphi_c 0.2\sqrt{f_c} b_w d \qquad \text{(CSA A23.3-04)} \qquad (1)$$

$$V_{c,ACI} = \text{Ø}\frac{1}{6}\sqrt{f_c} b_w d, \qquad \text{(ACI 318-11)} \qquad (2)$$

b_w : Beam width, mm
d: Farthest distance to the center of the reinforcement bar tensile longitudinal compressive, mm
fc: Compressive strength of standard cylindrical sample, MPa (N/mm^2)
φ_c: Safety factor for concrete offer by CSA A23.3-04(0.65)
Ø: Safety factor for concrete under shear and torsion offer by ACI 318-11 (0.75)

The methods above are for estimating the shear strength of normal concrete, and they are not suggested for SCC. In this part of the paper, the application of Eqs. (1) and (2) in SCC are checked. Table 5 summarizes the calculations for evaluating the shear strength of SCC from its compressive strength. It can be seen that in all circumstances, the equations provide conservative predictions of the ultimate shear load when compared to the experimental results. In other words, to insert the shear strength of SCC in computer models, the equations presented by the CSA A23.3-04 (2004) and ACI 318-11(2011) can be used, and the safety factor of ACI equation is about 4% higher than that of CSA. By comparison between safety factors obtained from Self-compacting

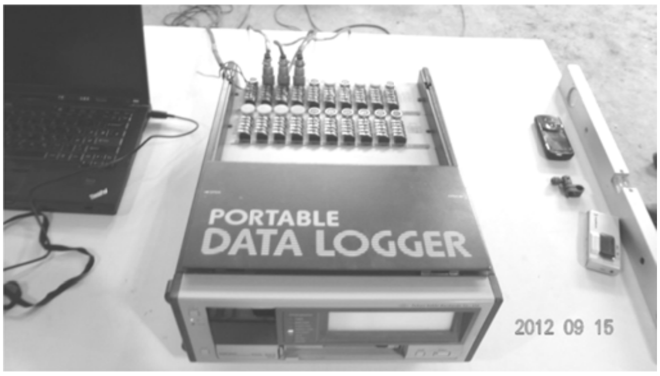


Fig. 5 The data logger used for measurement

concrete and normal concrete, it was concluded that the safety factor of normal concrete was from 2 to 12 percent higher than SCC. Moreover, Table5 shows that increasing the water/binder ratio from 0.35 to 0.45 decreased the safety factor for predicting the shear strength of SCC using the CSA A23.3-04 and ACI 318-11 equations about 10% in average. It means the exactness of the existing models is sensitive to water/binder ratio.

4.3 Torsional strength

A moment acting about the longitudinal axis of a member is called a torsional moment, T. Torsion on structural elements may be categorized into two kinds of statically determinate, and statically indeterminate. In rectangular sections, the shearing stresses vary in level from zero at the centroid to a maximum at midpoints of the long sides. If the member is not sufficiently reinforced for torsion, a sudden brittle failure can happen. When the principal tensile strength goes beyond the maximum tensile strength of concrete, cracking will occur spiraling around the outside surface of the beam as shown in Fig. 2. One or more inclined cracks expand when the maximum principal tensile stress reaches the tensile strength of the concrete. The start of cracking causes failure of an unreinforced member (Chalioris 2007, Aky and Al-Mahaidi 2006).

For beam samples, the 28-day torsional strengths are shown in Table 6 and Figs. 8 and 9. In failure mechanisms of the beams the diagonal cracks on each face running in a spiral around the beams were observed and then sudden brittle failures occurred. In fact, the failure mechanisms were the results of shear forces on each face. The action on each face was similar to the vertical shear of beams.

According to the test results, SCC and NC beams had almost the same crack patterns. In all the beam specimens, the formation of the first crack in SCC beams took place three to five seconds earlier than normal concrete beams. In fact, the tensile strength of the normal concrete was higher than the tensile strength of the SCC. According to Table 6 and Figs. 8 and 9, by increasing the compressive strength of Self-compacting concrete the torsional strength increases in a lower rate. The reason for this could be because NC beams presented a more important interlocking effect, which produced a more rigid behavior after the first crack. This interlocking effect decreases as the load and the crack width increases. Moreover, it can be said for torsional strength like compressive and shear strength, the optimum dosage of superplasticizer was 1.2% for W/b=0.35 and 0.8% for W/b=0.45.

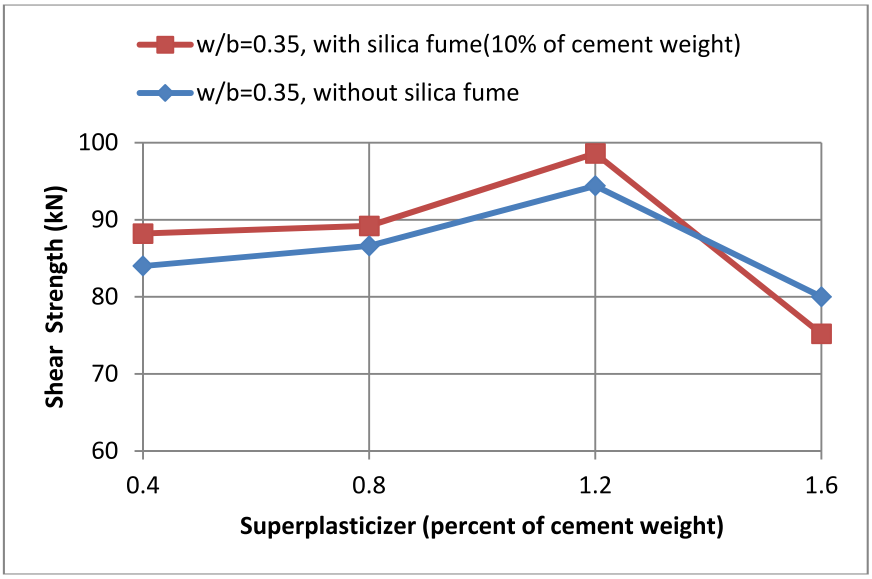


Fig. 6 Shear strength of SCC for w/b=0.35

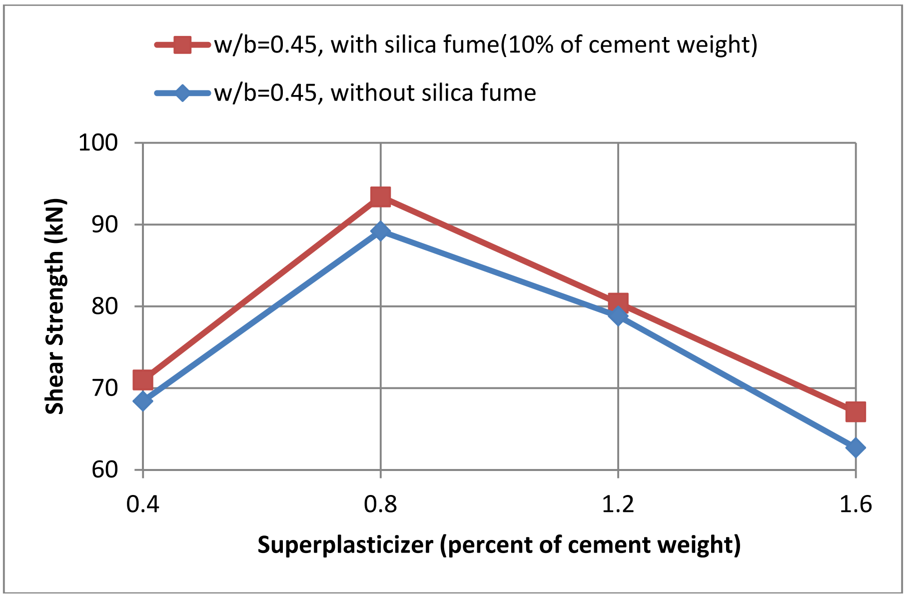


Fig. 7 Shear strength of SCC for w/b=0.45

Torsional cracking is assumed to occur when the principal tensile stress reaches the tensile strength of the concrete in biaxial tension-compression. CSA A23.3-04(2004) and ACI 318-11(2011) gives the following equations for calculating the torsional strength provided by the concrete for beams without reinforcement subject to only torsion

$$T_{cr,CSA} = \varphi_c 0.4\sqrt{f_c}(\frac{A_c^2}{P_c}) \qquad \text{(CSA A23.3-04)} \qquad (3)$$

$$T_{cr,ACI} = \emptyset \frac{1}{3}\sqrt{f_c}(\frac{A_c^2}{P_c}) \qquad \text{(ACI 318-11)} \qquad (4)$$

T_{cr}: N. mm
A_c : Beam cross section area, mm²
P_c: Beam external perimeter mm
f_c: Compressive strength of standard cylindrical sample, MP_a (N/mm2)
φ_c: Safety factor for concrete offer by CSA A23.3-04 (0.65)
Ø: Safety factor for concrete under shear and torsion offer by ACI 318-11 (0.75)

The methods above are for estimating the torsional strength of normal concrete, and they are not suggested for SCC. In this part of the paper, the application of Eqs. (3) and (4) in SCC are checked. Table 7 summarizes the calculations for evaluating the torsional strength of SCC from its compressive strength. It can be seen that in all circumstances, the equations provide conservative predictions of the ultimate torsional load when compared to the experimental results. In other words, to insert the torsional strength of SCC in computer models, the equations presented by the CSA A23.3-04 (2004) and ACI 318-11(2011) can be used, and the safety factor of ACI equation is about 4% higher than that of CSA. By comparison between safety factors obtained from Self-compacting concrete and normal concrete, it was concluded that SCC and normal concrete had almost the same safety factors in torsion.

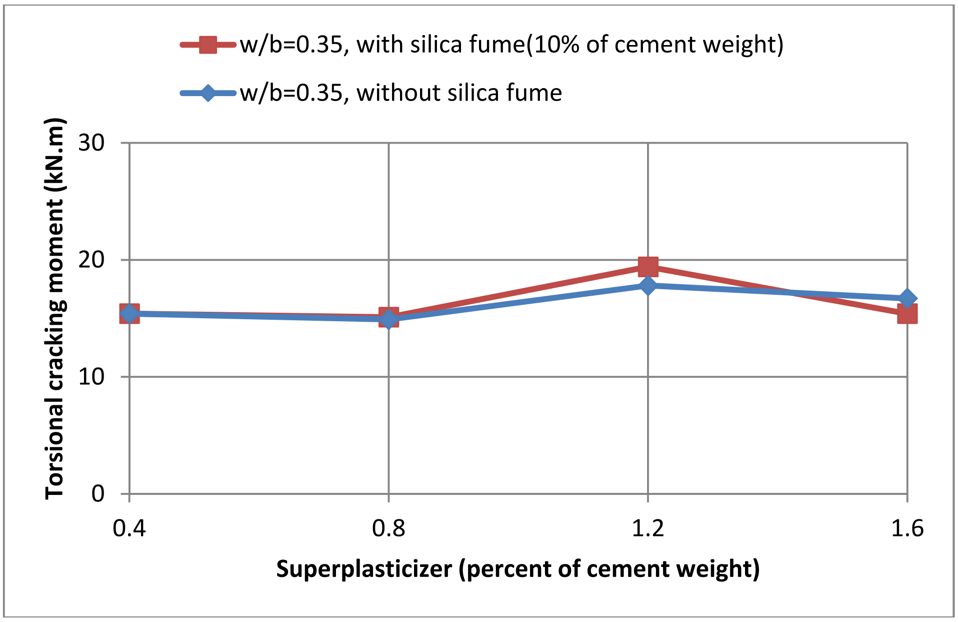


Fig. 8 Torsional strength of SCC for w/b=0.35

Table 5 Prediction of shear strength using CSA A23.3-04 and ACI 318-11

Mix Design (w/c=0.35)	W/C	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Obtained V_c From test(kN)	$V_{c,CSA} = \varphi_c 0.2\sqrt{f_c} b_w d$ (kN)	$V_{c,ACI} = \emptyset \frac{1}{6}\sqrt{f_c} b_w d$ (kN)	CSA Safety factor= $\frac{\text{test}}{\text{regulation}}$	ACI Safety factor= $\frac{\text{test}}{\text{regulation}}$
SCC1	0.35	Without silica fume	0.4	84	67.3	64.6	1.27	1.32
SCC3			0.8	86.6	62.8	60.3		
SCC5			1.2	94.4	73	70.1		
SCC7			1.6	80	69.1	66.3		
SCC2		With 10% silica fume	0.4	88.2	64.8	62.2	1.28	1.33
SCC4			0.8	89.2	63.5	61		
SCC6			1.2	98.6	82.2	78.9		
SCC8			1.6	75.2	65	62.4		
NC(0.35)		Without additive		72.6	56.1	53.9	1.29	1.35
SCC9	0.45	Without Silica fume	0.4	68.4	52.3	50.2	1.20	1.25
SCC11			0.8	89.2	67.8	65.1		
SCC13			1.2	78.8	67	64.3		
SCC15			1.6	62.7	62.3	59.8		
SCC10		With 10% silica fume	0.4	71	59	56.6	1.16	1.20
SCC12			0.8	93.4	72.2	69.3		
SCC14			1.2	80.4	68.9	66.1		
SCC16			1.6	67.1	68.2	65.5		
NC(0.45)		Without additive		69.4	54.7	52.2	1.27	1.32

5. Conclusions

Based on the analysis of the test results, presented herein, the following conclusions can be drawn:

• Silica fume could contribute to the compressive strength development of concrete at the w/b of 0.45. This improvement was from7 to 27 percent. This may be because of the filler effect and the excellent pozzolanic properties of the material, which translate into a stronger transition zone at the paste aggregate interface. However, Silica fume did not improve the compressive strength at the w/b of 0.35, with the exception of a superplasticizer dosage of 1.2%. This may be because of the negative effect of water absorption of silica fume at low w/b ratios.

Table 6 Torsional strength test results

Mix Design (w/c=0.35)	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Torsion cracking moment of beam samples (kN.m)	Mix Design (w/c=0.45)	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Torsion cracking moment of beam samples (kN.m)
SCC1	Without Silica fume	0.4	15.4	SCC9	Without silica fume	0.4	11.3
SCC3		0.8	14.9	SCC11		0.8	17.6
SCC5		1.2	17.8	SCC13		1.2	15.9
SCC7		1.6	16.7	SCC15		1.6	14.3
SCC2	With 10% silica fume	0.4	15.4	SCC10	With 10% silica fume	0.4	13.2
SCC4		0.8	15.1	SCC12		0.8	17
SCC6		1.2	19.4	SCC14		1.2	16.5
SCC8		1.6	15.4	SCC16		1.6	15.7
NC(0.35)	Without additive		13.5	NC(0.45)	Without additive		13

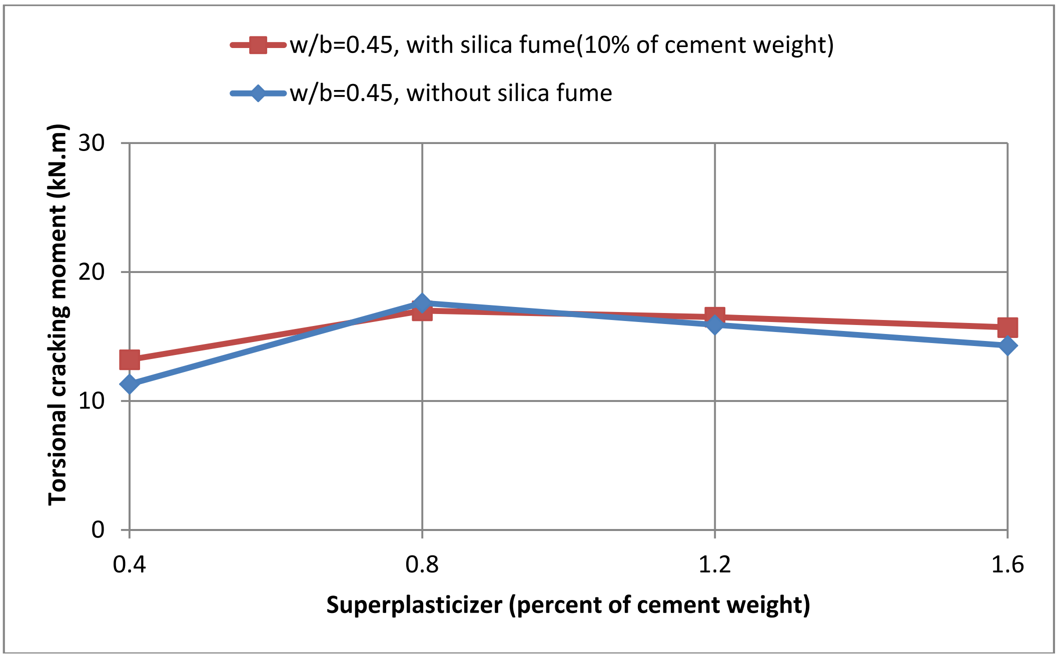


Fig. 9 Torsional strength of SCC for w/b=0.45

Table 7 Prediction of torsional strength using CSA A23.3-04 and ACI 318-11

Mix Design (w/c=0.35)	W/C	Silica fume (% of cement Weight)	Super plasticizer (% of cement Weight)	Torsion cracking moment of beam samples (KN.m)	$T_{cr,CSA} = \varphi_c 0.4\sqrt{f_c}(\frac{A_c^2}{P_c})$ (kN.m)	$T_{cr,ACI} = \emptyset\frac{1}{3}\sqrt{f_c}(\frac{A_c^2}{P_c})$ (kN.m)	CSA Average factor= $\frac{\text{test}}{\text{regulation}}$	ACI Average factor= $\frac{\text{test}}{\text{regulation}}$
SCC1	0.35	Without silica fume	0.4	15.4	11.6	11.1	1.37	1.43
SCC3			0.8	14.9	10.9	10.5		
SCC5			1.2	17.8	12.6	12.1		
SCC7			1.6	16.7	12	11.5		
SCC2		With 10% silica fume	0.4	15.4	11.2	10.8	1.36	1.42
SCC4			0.8	15.1	11	10.6		
SCC6			1.2	19.4	14.2	13.6		
SCC8			1.6	15.4	11.3	10.8		
NC(0.35)		Without additive		13.5	9.7	9.3	1.39	1.45
SCC9	0.45	Without silica fume	0.4	11.3	9.1	8.7	1.35	1.41
SCC11			0.8	17.6	11.7	11.2		
SCC13			1.2	15.9	11.6	11.1		
SCC15			1.6	14.3	10.8	10.4		
SCC10		With 10% silica fume	0.4	13.2	10.2	9.8	1.33	1.39
SCC12			0.8	17	12.5	12		
SCC14			1.2	16.5	11.9	11.4		
SCC16			1.6	15.7	11.8	11.3		
NC(0.45)		Without additive		13	9.5	9.1	1.37	1.43

• In water to binder ratio of 0.35 and 0.45, the optimum dosage of superplasticizer was 1.2%, and 0.8% respectively. In other words, the optimum superplasticizer dosage was lower at a higher w/b ratio. It can be said that for improved workability of the mixes by excessive use of superplasticizer, the compressive strength of the SCC reduced. This may be because of wider stretch of the air bobbles in the mixes as a consequence of upper dosages of the superplasticizer. According to the figs. 4-7 and fig. 9 the highest compressive, shear and torsional strengths belong to 0.8% superplasticizer dosage.

• To insert the shear and torsional strength of SCC in computer models, the equations presented by the CSA A23.3-04 and ACI 318-11 can be used, and the safety factor of ACI equation is about 4% higher than that of CSA. By comparison between safety factors obtained from Self-compacting concrete and normal concrete, it was concluded that both of them had almost the same safety factors in torsion. But in shear, the safety factor of normal concrete was from 2 to 12 percent higher than SCC.

• Increasing the water/binder ratio from 0.35 to 0.45 decreased the safety factor for predicting the shear strength of SCC using the CSA A23.3-04 and ACI 318-11 equations about 10% in average. In other words, the exactness of the existing models is sensitive to water/binder ratio.

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