

Splitting tensile strength of self-consolidating concrete and its size effect

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ABSTRACT

This paper presents the result of experimental study on splitting tensile strength of self-consolidating concrete (SCC). Brazilian splitting tests on a series of SCC cylindrical specimens of different diameters, $D = 70, 100, 150, 195$ and 300 mm, and of different heights, $H = 75, 100, 150, 200$ and 300 mm, were conducted. All the specimens were cast from the same batch of concrete with an average cubic compressive strength, $f_{cu} = 61.4$ MPa. The maximum aggregate size was 15 mm. The plywood bearing strips with the width to the cylindrical diameter ratios, $t/D = 6.7\%$ and 16.7% , were used in the tests. The influence of diameter and height of the specimens as well as width of the bearing strips on the splitting tensile strength were investigated. Cracking initiation and propagation were also monitored during the tests by using strain gages and camera.

Test result shows that the splitting tensile strength of concrete was not only affected by the diameter but also the height of these specimens. For cylinders with same t/D ratio and height, the splitting tensile strength decreases as the diameter increases, whereas for the cylinders with same diameter, the splitting tensile strength may decrease as the height increases.

1. INTRODUCTION

Self-compacting concrete (SCC) was originated from Japan in the late 1980's, and has been recently one of the most promising developments in the building industry (Daczko 2012). It is a new type of concrete that can flow through and fill the gaps of reinforcement and corner of its mold by its own weight without any need for vibration and compaction during the pouring process (Kim 1998).

Compared to the conventional concrete (CC), SCC contains larger quantities of

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mineral fillers such as finely crushed limestone or fly ash, as well as higher quantities of high-range water-reducing admixtures, and the maximum size of the coarse aggregate is smaller (Abidelah 2009, Türkel 2010 and Persson 2001). These modifications in the composition of the mixture may affect the mechanical properties of the concrete in its hardened state. In recent years, extensive studies have been conducted on the mechanical behavior of SCC, such as compressive strength, tensile strength, modulus of elasticity, bond behavior, etc (Almeida 2010, Anagnostopoulos 2009, Aslani 2013 and Domone 2007). However, very little attention has been paid on the study of size effect of the SCC tensile and compressive strength, which are considered as intrinsic properties of quasi-brittle material.

In this paper, SCC cylinder specimens with different sizes varying in diameters as well as heights were prepared and the effect of specimen size on tensile strength of SCC was studied experimentally.

2. EXPERIMENTAL PROGRAM

2.1 Test specimens

To investigate the influence of specimen size on the splitting tensile strength, SCC cylinders varying in both diameters and heights were used. The diameters of specimens, D , were 70, 100, 150, 195 and 300 mm, respectively, and the heights, H , were 75, 100, 150, 200 and 300 mm, respectively. Plywood load bearing strips, free of imperfections, with thickness of 3 mm and height slightly higher than the height of specimen were employed. To eliminate the influence of strip width, t , on the test results of specimens with different sizes, constant relative strip width, $t/D = 6.7\%$, was used. Besides, relative strip width, $t/D = 16.7\%$ was also used for comparison. Detailed information for specimens is given in Table 1.

Self-compacting concrete used to cast the cylinder specimens was supplied by a local concrete ready-mix supplier. All the specimens were cast from the same batch of concrete. The concrete mixture is given in Table 2. The maximum aggregate size is 15 mm in the concrete mix. Before casting, the fresh properties of SCC was tested by Slump-flow test, V-funnel test, L-box test and Sieve segregation resistance test in accordance with the European Guidelines for Self Compacting Concrete (EFNARC 2005). Test results are listed in Table 3.

Polyvinyl chloride thick wall tubes as shown in Fig. 1 were used as molds for preparation of cylindrical specimens. The specimens were prepared by directly pouring concrete into molds without compaction. Immediately after casting, the cylinders were covered with plastic and remained untouched for 24 hours after which they were demolded and stored in a controlled atmosphere room with a constant humidity of 90% and a temperature of 20 ± 3 °C until testing.

All the specimens were tested at an age greater than 90 days to ensure that the strength increase due to ongoing hydration was negligible. Before testing, the ends of cylinders were grounded and strips were glued to the specimen in the correct position.

Cubic compressive strength of concrete was tested at the age of splitting test, and the average compressive strength of six cubic specimens were 61.4 MPa, with

standard deviation $S_d = 5.00$, and coefficient of variation $C_v = 8.13\%$.

2.2 Testing and instruments

The SCC splitting tensile strength tests were conducted in a 3000 kN universal testing machine. The load was applied at the rate of 1.0 MPa/min. Parts of specimens were attached with strain gauges, as shown in Fig. 2, to monitor crack initiation and propagation.

Tab. 1 Geometry of specimens and test results

Specimen	Geometry of specimen		Relative width of strips, t/D (%)	Experimental splitting tensile strength, f_{st} (MPa)		
	Diameter (mm)	Height (mm)		mean	standard deviation, S_d	coefficient of variation, C_v (%)
PS1	70	75	6.7%	4.50	0.22	4.82
PS2	70	150	6.7%	3.55	0.25	6.99
PS3	70	200	6.7%	3.86	0.33	8.49
PS4	70	300	6.7%	2.84	0.22	7.86
PS5	100	75	6.7%	4.83	0.15	3.01
PS6	100	100	6.7%	4.80	0.37	7.69
PS7	100	150	6.7%	4.04	0.31	7.67
PS8	100	300	6.7%	3.26	0.21	6.46
PS9	150	75	6.7%	4.16	0.15	3.58
PS10	150	100	6.7%	3.81	0.25	6.55
PS11	150	150	6.7%	3.21	0.22	6.83
PS12	150	200	6.7%	2.77	0.05	1.93
PS13	150	300	6.7%	2.98	0.05	1.71
PS14	195	100	6.7%	4.36	0.11	2.61
PS15	300	75	6.7%	4.35	0.20	4.58
PS16	300	100	6.7%	3.57	0.26	7.40
PS17	300	150	6.7%	2.87	0.25	8.63
PS18	300	300	6.7%	2.71	0.19	7.08
PL1	150	300	16.7%	4.01	0.10	2.46
PL2	300	150	16.7%	3.53	0.13	3.59
PL3	300	300	16.7%	3.00	0.07	2.28

Note: P represents splitting tensile test, S represents smaller relative strip width ($t/D = 6.7\%$), L represents larger relative strip width ($t/D = 16.7\%$), 1-18 represent different sizes of specimens.

Tab. 2 Mixture proportion of self-compacting concrete

Cement (kg/m ³)	Sand (kg/m ³)	Gravel (kg/m ³)	Water (kg/m ³)	Flyash (kg/m ³)	Admixture (kg/m ³)
440	660	980	170	80	18

Tab. 3 Fresh property tests and test results

Fresh property test	Test results
Slump-flow test	SF=640 mm, T ₅₀₀ = 3.0s
V-funnel test	t _V = 7.7s
L-box test	PA = 0.81
Sieve segregation resistance test	SR = 3%



Fig. 1 Molds for specimens



Fig. 2 Specimen with strain gauges

3. TEST RESULTS AND DISCUSSION

3.1 Failure modes

All the specimens exhibited the expected splitting failure and failed in three different modes. The common features of the failure modes are that the central splitting crack initiates in the diametric tensile zone and develops towards the bearing strips, and the maximum load is governed by the growth of the central crack.

The modes of failure observed in the test as follows:

(1) Ideal splitting failure. As shown in Fig. 3(a), the central splitting crack initiated at the diametrical tensile zone and developed towards the strips. Failure of the specimen was associated with the growth of the central crack.

(2) Central crack with local crushing. As shown in Fig. 3(b), after the maximum

load reached associated with the growth of the central crack, local crushing occurred under the strips.

(3) Central crack with secondary cracks. As shown in Fig. 3(c), after the initiation of central crack, secondary cracks occur at some distance from the load platen, and develop towards the strips.

Among the tested specimens, 73.3% exhibited central fracture associated with secondary cracks on the strip sides, and 22.8% showed ideal splitting failure. Only 3.8% of specimens showed the central fracture associated with local crushing of concrete. Investigation of failure of specimens shows that the failure mode seems to be related with specimen size and relative width of the strip. Most of the specimens showing ideal splitting failure are those with smaller diameters, i.e., $D = 70, 100,$ and 150 mm, while most of specimens with larger diameters, i.e., $D = 195$ mm and 300 mm, showed central fracture associated with secondary cracks.

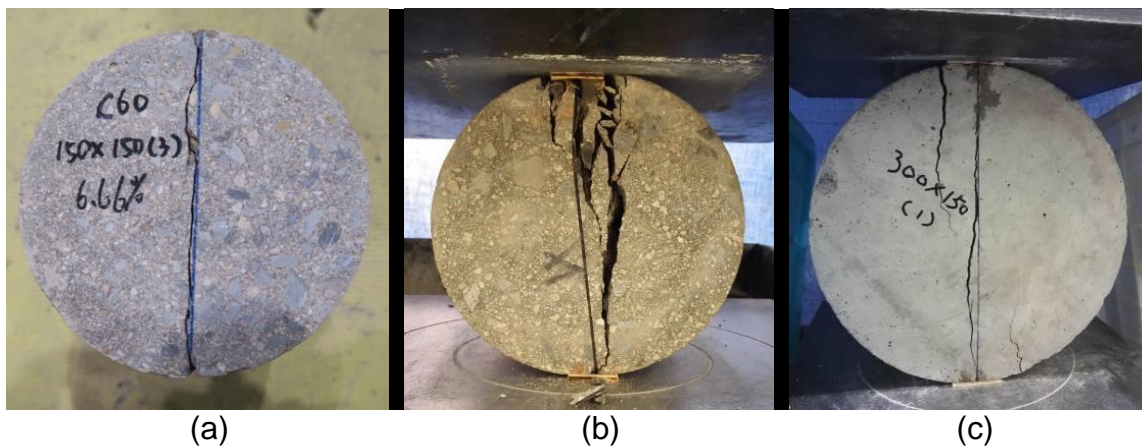


Fig. 3 Failure modes of specimens

3.2 Splitting tensile strength of SCC

The experimental splitting tensile strength of the specimen, f_{st} , can be calculated by the following expression (ASTM 2004):

$$f_{st} = \frac{2P}{\pi DH} \quad (1)$$

where P = maximum load applied diametrically on the specimen, D = diameter of the specimen and H = height of the specimen. The averaged splitting tensile strength of four to five SCC specimens with same size along with corresponding standard deviation and coefficient of variation are listed in table 1.

3.3 Influence of specimen diameter

Fig. 4 and 5 present the experimental results of specimens with $t/D = 6.7\%$ and 16.7% , respectively. Splitting tensile strength for specimens of the same height are

