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Case study

Effect of construction joints on the splitting tensile strength of concrete

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ABSTRACT

The purpose of this study is to experimentally correlate the compressive strength (f'_c) of concrete to the splitting tensile strength (T) for plain concrete in the existence of a construction joint, and formulate an empirical equation relating T to f'_c. Both the American Concrete Institute code (ACI 318-08 (ACI Committee 318, 2008)) and the American Society for Testing and Materials (ASTM (ASTM Standard C496, 2002; ASTM Standard C192/C192M, 2002; ASTM Standard C39/C39M, 2005; ASTM Standard C617, 2002)) provide the testing methods and standards, as well as the applicable theoretical and experimental formulas for the correlation between T to f'_c for concrete specimens, which are monolithic, indicating that the specimens lack any construction joints. Providing a useful reduction factor in the splitting tensile strength of concrete due the existence of a construction joint is essential. It is a well known fact that construction joints are used in every concrete structure, which indicates that engineers would definitely benefit from an equation that could relate the splitting tensile strength of concrete in function of its compressive strength.

The results suggest that the reduction in the splitting tensile strength in the presence of a construction joint is not as much as most engineers tend to believe. Due to that belief, most engineers tend to overdesign for steel reinforcement at those joints to compensate for this reduction. The objective of the study is to better the understanding of the effects of a construction joint on the splitting tensile strength. Thus provide an empirical equation to assist engineers in their design calculations, therefore reducing the amount of steel reinforcement at the construction joints. Thus also leading to cost saving on projects.

1. Introduction

There are two traditional tests methods to measure the tensile strength of concrete, the splitting tensile strength of concrete cylinders and the flexural strength of beams. The splitting known as the Brazilian or the indirect tension test is a popular method of characterizing the tensile strength of concrete. This is mainly due to the fact that the cylinder is a commonly and routinely fabricated specimen. Moreover, the testing procedure is quite simple, and has been specified in several recommendations and standards (e.g., ASTM C496 (ASTM Standard C496, 2002) and RILEM CPC6 (RILEM, 1994)).

The splitting tensile strength test (Fig. 1) consists of applying a diametric compressive load along the entire length until failure occurs. This loading induces tensile stresses on the plane containing the applied load and compressive stresses in the

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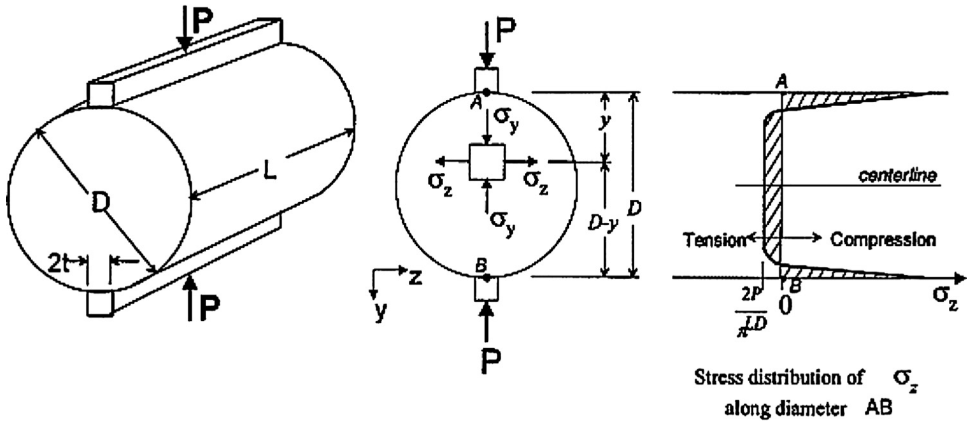

Fig. 1. Concrete cylinder splitting tensile strength test (ASTM Standard C496, 2002).

area around the applied load. To avoid local compressive strength, plywood strips are used between the specimen and the plate. Tensile failure occurs instead of compressive failure since the areas under the load application are in a triaxial compression state, therefore allowing them to resist higher compressive stresses than what would have been indicated by a uniaxial compressive strength (ASTM Standard C496, 2002). Both tensile strength and compressive strength of concrete are important factors that affect the cylinder's ability to resist failure.

The ASTM designation C496 describes the test method for splitting tensile strength of concrete, and details the procedure for obtaining the results by breaking cylinders measuring 300 mm by 150 mm. These mentioned standards require the cylinder to be monolithic. It should be noted that the strength obtained from the splitting test depends on the diameter of the specimen (Bazant et al., 1991; Tang et al., 1992). However, the use of a standard diameter, such as 150 mm, circumvents this problem, as in compression tests. The resulting strength is not necessarily a material property but nevertheless, a reliable value that can be used for comparison and design.

The ACI code (ACI Committee 318, 2008) under section (8.6.1) provides the relationship between the splitting tensile strength of concrete (T) and the compressive strength of concrete (f'_c) with equation as follows:

$$T = \frac{\sqrt{f'_c}}{1.8} \tag{1}$$

where

T = splitting tensile strength in MPa.

f'_c = compressive strength of concrete in MPa.

It is often not possible to complete a job at one go, for example because of the size or complexity of the structure or because of limited materials or manpower. When work resumes it will be necessary to place fresh concrete on or against the previous pour that will have already hardened. The resultant contact surface is known as a construction joint or day work joint (ACI, 1995). The purpose of this study is to experimentally derive an empirical relationship that correlates the compressive strength of concrete to the splitting tensile strength for a cylinder that contains a construction joint. Such an

Fig. 2. Aluminum plate inserted at mold centerline to create CJ.

Table 1
Concrete mix design and corresponding f'_c.

Mix	CA (%)	FA (%)	Cement (%)	Water (%)	W/C ratio	f'_c (MPa)[a]
Mix A	50.49	23.99	16.08	9.44	50.49	36.62
Mix B	50.87	24.17	16.20	8.77	50.87	39.26
Mix C	50.23	23.86	16.00	9.91	50.23	34.15
Mix D	50.14	23.82	15.97	10.06	50.14	30.91
Mix E	50.06	23.78	15.95	10.21	50.06	30.22
Mix F	50.30	23.90	16.02	9.77	50.30	28.22
Mix G	49.98	23.75	15.92	10.35	49.98	25.88

[a] Average value of the testing of three cylinders.

equation can be useful for structural engineers to realistically estimate the tensile strength for a construction location that contains a construction joint, resulting in the reduction in the amount of steel to be placed at those joints, thus leading to some cost savings on projects.

2. Overview of the experimental study

Seven different mix designs were developed for this experimental study. Each mix design consisted of nine cylinders. Six of those cylinders were monolithic, in which three of them were to be tested for their compressive strength and the other three for their splitting tensile strength. The remaining three contained a construction joint (CJ) vertically placed at the center the mold (Fig. 2), and they were also to be tested for their splitting tensile strength. A total of sixty three test cylinders were poured for this project, of which twenty one contained a construction joint and the other forty two were monolithic. The mixes were identified as follows: Mix A, Mix B, Mix C, Mix D, Mix E, Mix F and Mix G (Table 1). ASTM standards (ASTM Standard C496, 2002; ASTM Standard C192/C192M, 2002; ASTM Standard C39/C39M, 2005; ASTM Standard C617, 2002) were used for concrete mixing and pouring, cylinder curing and capping, testing for cylinder compressive strength, and testing for splitting tensile strength of concrete.

On the first day three monolithic and half of the three non-monolithic test cylinders were poured based on the following steps:

- Cylinder molds were cleaned inside out, while applying oil to the inside faces of the molds (ASTM C192, sect. 4).
- Aluminum sheets were placed in the exact center of the cylinder molds to form construction joints. Wooden planks were placed behind the joints so that they are kept straight up in the middle and at 7.5 cm from both ends of the mold.

Fig. 3. Pouring the non-monolithic cylinders.

Fig. 4. Roughening the construction joint face.

- Concrete mix designs were prepared. The concrete quantity (volume) required for 5 cylinders was 0.0265 m^3, which included 10% waste. Generally the coarse aggregates and the fine aggregates filled up 2 buckets each, while cement and water filled up 1 bucket each (ASTM C192, sect. 6). The buckets were always weighed on the scale before filling them up with the material in order to get rid of their weight and get only the required weights of the aggregates. The buckets were filled using the scoops with the required aggregates and then weighed on the electronic scale.
- Mixing concrete (ASTM C192, sect. 7 (ASTM Standard C192/C192M, 2002)): Prior to starting the rotation of the power-driven concrete mixer, half of the coarse aggregates are added into the mixer. Then, the fine aggregates are added, followed by the cement, followed by the other half of coarse aggregates. Finally, water was added while turning on the mixer. The batch was mixed for 3 min, followed by a 3 min rest and then turned back on for an additional 2 min. Once the mixing is over, the sliding door was opened while it was running and the concrete was poured into a clean and wet wheelbarrow. The remaining concrete that was stuck in the mixer was removed using a scoop.
- Pouring the test cylinders (ASTM C192, sect. 7 (ASTM Standard C192/C192M, 2002)): Concrete was placed in the cylindrical molds in three layers, each occupying one-third of the volume. Each layer was stroked 25 times using the 16 mm tamping rod. The bottom layer was consolidated throughout its entire depth with distributed strokes across the cross section of the mold. For the upper layers, the rod was allowed to penetrate the underlying layer for about 25 mm while rodding. After each layer was poured, the mallet was used to tap the outside of the mold lightly 10–15 times. Finally after the cylinder was full, the top surface was smoothened out using the trowel.
- Curing (ASTM C192, sect. 8 (ASTM Standard C192/C192M, 2002)): After finishing, plastic sheets were placed on top of the molds in order to prevent excessive loss of water due to evaporation.

Fig. 5. UTM testing of cylinder.

On the second day, again three monolithic test cylinders are poured using the previous procedures. Whereas the other three halves of the non-monolithic cylinders were poured after performing the following procedures (Figs. 3 and 4):

- The construction joints were removed from the cylinder molds.
- The three monolithic cylinders poured on the first day were labeled. For example for Mix A: A 1–1, A 1–2, A 1–3. Labeled as well was the date on which they were poured.
- The smooth surface on the face of the concrete due to the placement of a construction joint was roughened using a sharp-edged steel rod.
- After roughening the joint surface in random fashion with a chisel, the inside of the molds were cleaned again. Along with the preparation of three other molds for the pouring of another three monolithic cylinders.

On the third day, the molds were removed based on the following procedures:

- Bolts of the cylinder molds were unscrewed using a wrench, and the molds were removed (ASTM C617, sect. 8.2 (ASTM Standard C617, 2002)).

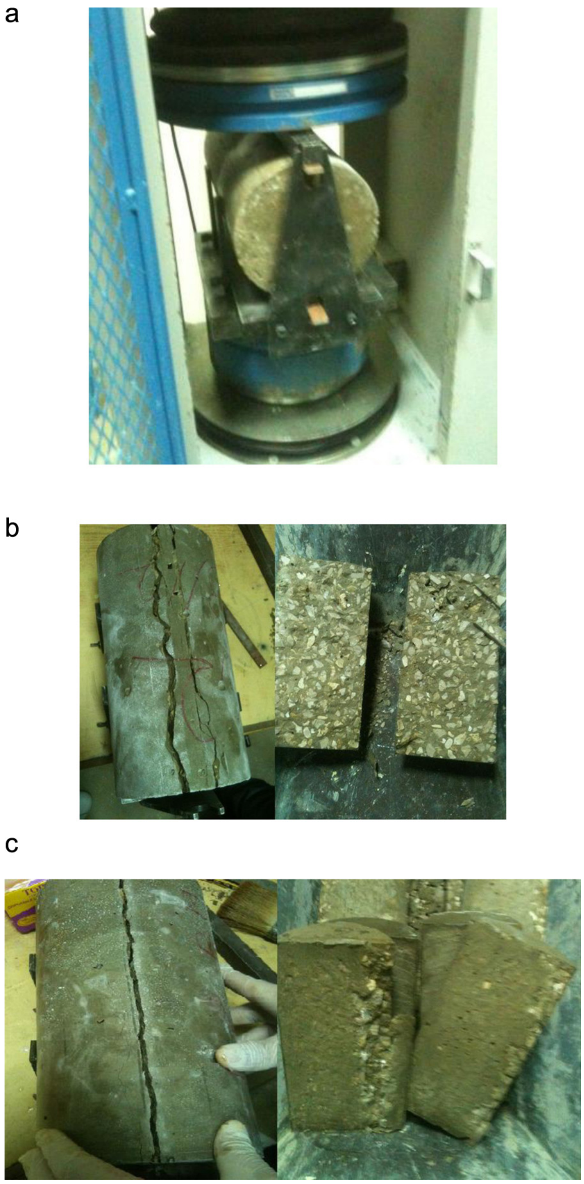

Fig. 6. (a) Splitting tensile strength device, (b) failure of monolithic cylinder, (c) failure of a non-monolithic (CJ) cylinder.

- The rest of the cylinders were labeled. The monolithic cylinders poured on the second day were labeled as follows, Mix B for example: B 2–1, B 2–2, B 2–3. As for the ones containing construction joints the following labeling was used, Mix F for example: FJ 1, FJ 2, FJ 3. As well as the date on which they were poured on.
- All cylinders were stored in water tanks saturated with calcium hydroxide for curing. A minimum of 28 days of curing was allowed before testing.

3. Experimental results

After 28 days of pouring and curing the concrete, the three monolithic cylinders of a particular mix were capped according to ASTM C617 (ASTM Standard C617, 2002) and placed inside the compression machine according to ASTM (Fig. 5). The maximum load at failure was recorded for the three cylinders. Then the type of failure was observed. Finally the compressive strength was calculated by dividing the maximum failure load by the cross-sectional area:

$$f'_c = \frac{P}{A} \quad (2)$$

where

f'_c = compressive strength of concrete in MPa.

P = failure load applied in N.

A = cross-sectional area of cylinder in mm^2.

The average compressive strength of the three cylinders was calculated for each mix design.

The remainder six cylinders from each mix design were utilized in the splitting tensile strength according to ASTM C496. For the three monolithic cylinders, each one was placed in the splitting tensile strength apparatus which consists of two plywood strips, one on top and one on bottom as well as a metal bar on top of the second plywood. As for the three non-monolithic cylinders, the specimen is placed in a way that the construction joint is vertical and in the center perpendicular to the plywood strips. Then each cylinder is placed into the compression machine. At failure, the maximum load was recorded. Lastly, the splitting tensile strength of each cylinder (monolithic and non-monolithic) for each mix design was calculated using the following equation:

$$T = \frac{P}{\pi l d} \quad (4)$$

where

T = splitting tensile strength of concrete in MPa.

P = failure load in N.

l = length of cylinder in mm.

d = diameter in mm.

Table 2
Compressive strength test cylinders.

Cylinder ID	Weight in air (g)	Weight in water (g)	Height (mm)	Diameter (mm)	Area (mm^2)	Max load (kN)
A 1–1	12886.3	7389.3	300.4	151.0	17907.86	664.4
A 1–2	13017.3	7503.3	300.4	151.0	17907.86	658.0
A 2–1	12920.1	7409.1	300.5	152.0	18145.84	653.2
B 1–1	12488.1	7184.8	300.4	152.0	18145.84	691.2
B 1–2	13072.3	7538.4	300.5	152.0	18145.84	729.5
B 2–1	13043.1	7526.0	300.5	152.0	18145.84	716.5
C 1–1	12930.7	7446.4	300.3	151.0	17907.86	588.0
C 1–2	12917.4	7450.1	300.4	151.0	17907.86	633.6
C 2–1	12994.1	7499.0	300.4	152.5	18256.16	624.6
D 1–1	12922.1	7442.1	300.4	152.0	18145.84	564.0
D 1–2	12960.1	7454.0	300.5	151.0	17907.86	428.0
D 2–2	12951.9	7448.9	300.2	151.0	17907.86	550.4
E 1–1	12415.7	7120.7	300.1	151.0	17907.86	541.1
E 1–2	12405.4	7140.0	300.4	150.0	17671.45	580.9
E 2–2	12388.4	7104.2	300.4	151.0	17907.86	491.9
F 1–1	12430.4	7168.7	300.5	151.0	17907.86	499.8
F 1–2	12857.9	7413.0	300.4	151.0	17907.86	512.4
F 2–2	12459.3	7457.7	300.4	151.0	17907.86	503.5
G 1–1	12387.2	7102.3	300.4	150.0	17671.45	462.0
G 1–2	12370.2	7221.2	300.5	152.0	18145.84	478.4
G 2–2	12390.4	7090.3	300.5	152.0	18145.84	456.6

Note: Values for the ID crossed out is rejected due to experimental errors.

The average tensile strength for the monolithic cylinders is calculated for each mix design, as well as the average tensile strength for the non-monolithic cylinders (Fig. 6).

Table 2 summarizes the data collected for the cylinders in each mix design in order to get the compressive strength of concrete.

Table 3 summarizes the data collected for the cylinders of each mix design in order to get the splitting tensile strength of concrete.

Table 3
Cylinder data for splitting tensile strength.

Cylinder ID	Cylinder type	T (MPa)	$T_{Average}$ (MPa)
A 1–3	Monolithic	3.87	3.87
A 2–2		3.94	
A 2–3		3.81	
AJ 1	CJ	1.65	1.85
AJ 2		1.49	
AJ 3		2.42	
B 1–3	Monolithic	4.25	4.36
B 2–2		4.31	
B 2–3		4.53	
BJ 1	CJ	2.10	2.52
BJ 2		2.55	
BJ 3		2.91	
C 1–3	Monolithic	3.20	3.54
C 2–2		3.83	
C 2–3		3.58	
C J1	CJ	1.95	1.60
C J2		1.18	
CJ3		1.67	
D 1–3	Monolithic	3.91	3.54
D 2–2		3.26	
D 2–3		3.44	
DJ1	CJ	1.05	1.33
DJ2		0.63	
DJ3		1.62	
E 1–3	Monolithic	3.18	3.39
E 2–2		3.40	
E 2–3		3.58	
EJ1	CJ	0.79	1.50
EJ2		1.50	
EJ3		1.50	
F 1–3	Monolithic	2.84	2.91
F 2–2		2.95	
F 2–3		2.94	
FJ1	CJ	1.16	1.28
FJ2		1.35	
FJ3		1.33	
G 1–3	Monolithic	2.67	2.65
G 2–2		2.57	
G 2–3		2.72	
GJ1	CJ	1.01	1.03
GJ2		0.78	
GJ3		1.04	

Note: Values crossed out are rejected due to experimental errors.

Table 4
Average calculated and experimental splitting tensile strength.

Mix ID	f'_c Average (MPa)	$T_{monolithic}$ Calculated (MPa)	$T_{monolithic}$ Experimental (MPa)	% Variation vs. experimental	$T_{ConstructionJoint}$ (MPa)	% Variation CJ vs. monolithic
A	36.62	3.36	3.87	−13.18	1.85	−52.20
B	39.26	3.48	4.36	−20.18	2.52	−42.20
C	34.15	3.25	3.54	−8.19	1.60	−54.80
D	30.91	3.09	3.54	−12.71	1.33	−62.43
E	30.22	3.05	3.39	−10.03	1.50	−55.75
F	28.22	2.95	2.91	1.37	1.28	−56.01
G	25.88	2.83	2.65	6.79	1.03	−61.13

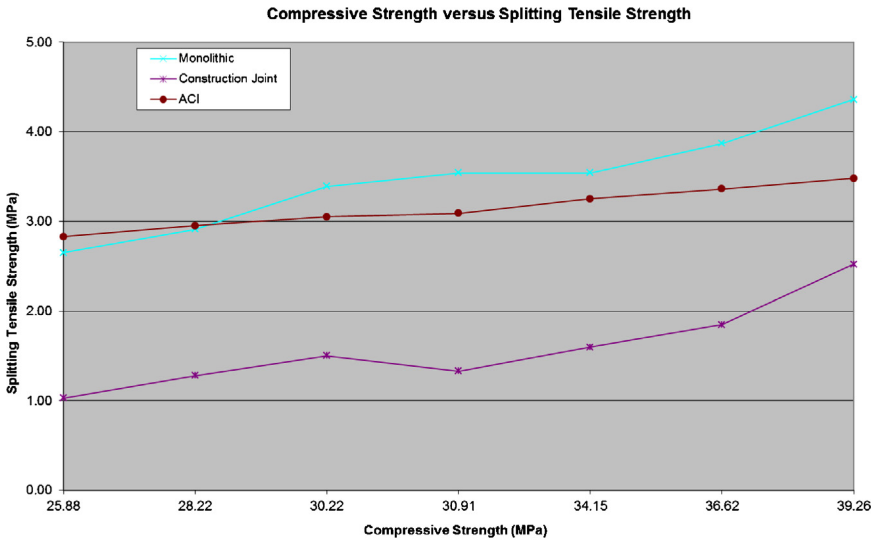

Fig. 7. Splitting tensile strength (T) vs. compressive strength (f'_c).

4. Analysis of results

Using the average compressive stress (f'_c) for each mix design in Table 1 and Eq. (1), the calculated values of the splitting tensile strength (T) are summarized in Table 4 and displayed in Fig. 7. In the situation of monolithic construction, it can be deduced from these results that for the cases where the f'_c is equal and greater than 30 MPa, the calculated values are underestimated, where in cases that the f'_c is less than 30 MPa, the calculated values are overestimated. Comparing the results of the monolithic experimental to the construction joint experimental, it is deduced that an average reduction of 55% exists in T which replicates the very same reduction value determined by Issa et al. (2014) using vertical construction joints tested according to ASTM C78 (ASTM Standard C78, 2002) beam specimen loaded at third-point loading.

Based on Eq. (1) and the average reduction of 55% in T for construction joints, it is proposed to use the following equation in case a construction joint exist:

$$T_{CJ} = 0.25\sqrt{f'_c} \quad (5)$$

where
T_{CJ} = construction joint splitting tensile strength in MPa.
f'_c = compressive strength of concrete in MPa.

5. Conclusions

Construction joints (CJ) are used to facilitate construction works in the construction execution process. All concrete structures contain construction joints. CJ would definitely affect the splitting tensile strength (T) of concrete. The purpose of this study is to understand the effect of a CJ on T with respect to the compressive strength (f'_c). ACI introduces an equation for T relating it to f'_c which only assumes monolithic structures. Experiments were conducted following ASTM testing methods and standards, which lead to the demonstration of the real effect of a CJ on the splitting tensile strength and coming up with a new equation relating the splitting tensile strength T with a construction joint to the compressive strength (f'_c).

Thus, based on the conducted experimental, the following conclusions could be drawn:

- As the strength of concrete increases so does its corresponding tensile splitting strength, regardless if it is containing a construction joint or not.
- Having a construction joint reduces the splitting tensile strength of a monolithic specimen by approximately 55%.
- Relating T for construction joints to f'_c is expressed as $T_{CJ} = 0.25\sqrt{f'_c}$ vs. for monolithic construction expressed as $T = \sqrt{f'_c}/1.80$.
- It is recommended, that when designing the steel reinforcement, the increase in the amount of steel placed in the presence of construction joints should compensate for the 55% reduction of the splitting tensile strength. Thus in order to compensate for this weakness in the strength of concrete, the amount of steel should be doubled.

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References

ACI Committee 318, 2008. Building Code Requirements for Structural Concrete (ACI 318M-08) and Commentary (ACI 318RM-08). American Concrete Institute, Farmington Hills, MI, U.S.A.
ACI, 1995. Committee Report 224.3R-95, Joints in Concrete Construction. American Concrete Institute, Farmington Hills, MI, U.S.A, pp. 1–44.
ASTM Standard C496, 2002. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. ASTM International, West Conshohocken, PA, U.S.A.
ASTM Standard C192/C192M, 2002. Making and Curing Concrete Test Specimens in the Laboratory. ASTM International, West Conshohocken, PA, U.S.A.
ASTM Standard C39/C39M, 2005. Compressive Strength of Cylindrical Concrete Specimens. ASTM International, West Conshohocken, PA, U.S.A.
ASTM Standard C617, 2002. Capping. ASTM International, West Conshohocken, PA, U.S.A.
ASTM Standard C78, 2002. Standard Test Method for Flexural Strength of Concrete. ASTM International, West Conshohocken, PA, U.S.A.
Bazant, Z.P., Kazmi, M.T., Hasegawa, T., Mazars, J., 1991. Size effect in Brazilian split-cylinder test measurement and analysis. ACI Mater. J. 88, 325–332.
Issa, Camille A., Gerges, Nagib N., Fawaz, Samer, 2014. The effect of concrete vertical construction joints on the modulus of rupture. J. Case Stud. Constr. Mater. 1 (1), 25–32.
RILEM, 1994. Tension Splitting of Concrete Specimen, CPC6, 1975, Rilem Technical Recommendation for the Testing and Use of Construction Materials. E & FN Spon, London, pp. 21–22.
Tang, T., Shah, S.P., Ouyang, C., 1992. Fracture mechanics and size effect of concrete in tension. ASCE J. Struct. Eng. 118, 3169–3185.