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RILEM TC 162-TDF: TEST AND DESIGN METHODS FOR STEEL FIBRE REINFORCED CONCRETE

Uni-axial tension test for steel fibre reinforced concrete

Recommendations

The text presented hereunder is a draft for general consideration. Comments should be sent to the TC Chairlady: Prof. Dr. ir. Lucie Vandewalle, K.U. Leuven, Departement Burgerlijke Bouwkunde, de Croylaan 2, 3001 Heverlee, Belgium. Fax: +32 16 321976; e-mail: lucie.vandewalle@bwk.kuleuven.ac.be, by 30 June 2001.

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1. SCOPE

The test described in the following is used to determine the so-called stress-crack opening relationship, $\sigma_w(w)$, for Steel Fibre Reinforced Concrete (SFRC). The test method is applicable for steel fibre reinforced cements and steel fibre reinforced concretes that exhibit strain softening behaviour. The method can also be used for other fibre reinforced concretes which exhibit strain softening behaviour as well as plain concrete (which is assumed always to exhibit strain softening behaviour).

The test is not intended for determination of the tensile strength. It is recommended that the tensile strength is determined independently, *e.g.* indirectly from the compressive strength using empirical relations derived from plain concrete.

2. BASICS

The test shall be conducted as a displacement controlled tensile test on a notched specimen. The specimen can be either cast or cored from an existing structure or structural element. The test shall be conducted in a closed loop mechanical testing machine using the average measurement of the displacement over the notch as the feed back signal or in another test setup which ensures stable post cracking response. Both ends of the testing specimen shall be clamped to the testing machine and fixed with respect to rotation in such a way that rotation is sufficiently eliminated. At the same time care shall be taken not to introduce pre-stressing of the specimen. This can, for example, be achieved by providing special fixtures which allow the test specimen to be glued directly into the test machine or by other means providing similar performance. During testing the load and corresponding displacement shall be recorded digitally. The following data interpretation shall be based on at least 6 specimens per test series.

3. SPECIMEN SIZE AND SHAPE

The standard test specimen is cylindrical with a circular cross-section with nominal diameter 150 mm. The specimen is notched with a circumferential notch with a depth of 15 mm +/- 1 mm and a width of 2-5 mm. The notch shall be cut with a diamond saw. Mould induced notches are acceptable in situations where cutting is made difficult, *e.g* when testing at early ages. The nominal length of the specimen shall be equal to 150 mm, see Fig. 1. Only fibre concretes with a maximum aggregate size of 32 mm and a maximum fibre length of 60 mm can be used.

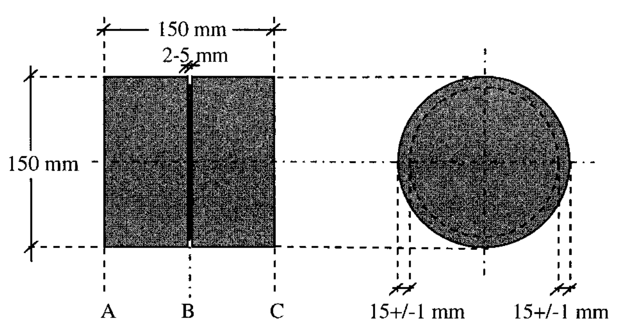

Fig. 1 – The geometry of the standard test specimen for uni-axial tensile testing. Planes A, B and C are parallel. Plane B is a symmetry plane. The total nominal length of the prepared specimen is 150 mm and the nominal diameter of the specimen is 150 mm. A central, circumferential notch with a depth of 15 mm +/- 1 mm is cut with a diamond saw. The resulting, maximum width of the notch is 2-5 mm.

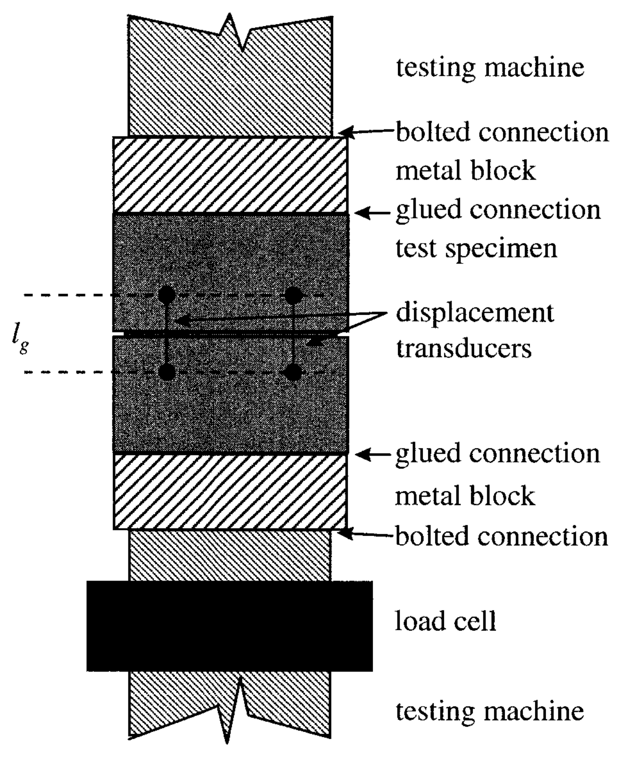

Fig. 2 – An example of the principles of test setup used for uniaxial tension testing.

For special applications where the material characteristics are not well represented by those of the standard specimen it is recommended to use a more appropriate notched specimen. The ability of the test specimen to represent the material in a given application should be based on considerations of fibre distribution, fibre orientation and the relation between structural and test specimen dimensions.

4. SPECIMEN PREPARATION

In general, care must be taken to obtain a fibre orientation in the test specimen which is representative for the orientation in the structural application. The specimens used can be either cast or cored from an existing structure or structural element. The complete procedure for specimen preparation, including fabrication, curing and/or storing, shall always be recorded.

In the case of cast specimens the procedure for filling of the mould and compaction of the concrete shall always be decided on beforehand. Care must be taken not to introduce an interface at the fracture plane when filling the mould. The method of compaction used must be the same as in the practical application. The specimens shall be stored under appropriate conditions until sufficient strength has been achieved to allow de-moulding.

Whenever possible, cored specimens shall be extracted perpendicular to the expected crack plane in the structure or structural element to be examined.

5. TEST SETUP

5.1 Basics

An example of a viable test setup is shown in Fig. 2. The specimen is glued to metal plates that are connected to the testing machine using rigid, bolted connections. The bolts can be pre-stressed to make the connection as stiff as possible.

5.2 Instrumentation

The displacement across the notch shall be measured using no less than 3 displacement transducers arranged at equal distances along the perimeter of the test specimen. The effective gauge length l_g shall not be larger than 40 mm. The resolution of the displacement transducers shall be 1 µm or less and the accuracy 1% or better.

The load shall be measured using a load cell connected in series with the test specimen as shown in Fig. 2. The accuracy of the load cell shall be 1% of the maximum load observed during the experiment, or better.

6. TESTING PROCEDURE

6.1 Basics

The testing procedure contains the following steps, assuming that the specimen is fixed to metal plates in the testing machine using adhesives or a similar approach which eliminates pre-stressing due to clamping, see Fig. 3.

1. Balance the load cell of the test setup.
2. Glue the specimen against the first metal plate and fix and pre-stress the bolts of the plate in the testing machine after the glue is hardened.
3. Fix and pre-stress the bolts of the second metal plate in the testing machine, apply glue on the surface and bring the specimen in contact with the second metal plate.
4. Mount and subsequently balance the displacement transducers after the second glued connection has hardened.
5. Run the test under displacement control at the

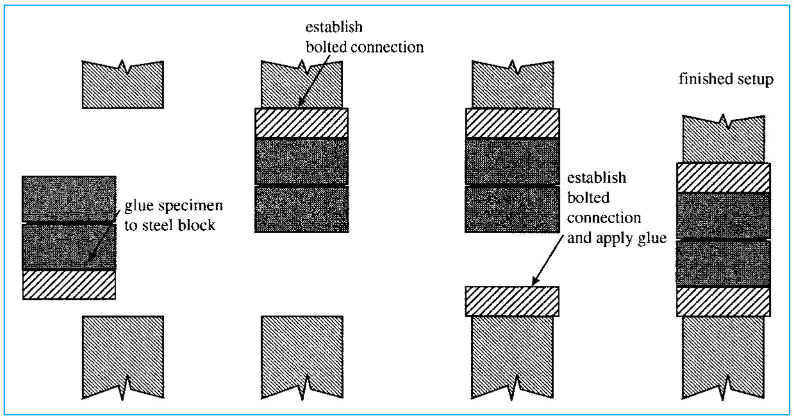

Fig. 3 – Schematic representation of the testing procedure assuming that the specimen is fixed to metal plates in the testing machine using adhesives.

required rate using the average signal of the displacement transducers as control signal.

6. Record the load and the measured displacement by the individual transducers as functions of time.

6.2 Test control and data acquisition

The required displacement rates are: 5 μm/min up to a displacement of 0.1 mm and 100 μm/min until the completion of the test when a displacement of 2 mm is reached.

Throughout the test, data shall be logged with a frequency higher than 0.5 Hz.

6.3 General requirements

The axial stiffness of the testing machine and the grips shall be sufficient to ensure stable testing without any snap-back in the averaged displacement transducer signal. It is not possible to express this requirement quantitatively, since sufficient stiffness is typically achieved through a combination of mechanical stiffness, servo valve performance and performance of the electronic control system.

The bending stiffness of the machine and the grips shall be sufficient to prevent significant rotation of the crack surfaces during testing. This requirement is fulfilled if, at the end of the test, the maximum difference between the individual transducer signals is less than 10% of the mean displacement.

7. INTERPRETATION OF RESULTS

The stress-crack opening relationship is obtained from the raw data of each test in the following way:

Stress σ_w is calculated from the load P simply by dividing with the cross sectional area at the notch A_n:

$$\sigma_w = \frac{P}{A_n} \tag{1}$$

The crack opening w is calculated from the average signal of the displacement transducers by subtracting the average displacement at peak stress, neglecting the elastic unloading. Thus, denoting the displacement readings of the individual n transducers δ_j, $j = 1,2,\ldots,n$, the average signal, $\bar{\delta}$, is calculated from:

$$\bar{\delta} = \frac{1}{n}\sum_{j=1}^{n}\delta_j \tag{2}$$

Denoting the average displacement at peak stress $\bar{\delta}_p$, the crack opening w is calculated from:

$$w = \bar{\delta} - \bar{\delta}_p \tag{3}$$

(see also Fig. 4).

The stress-crack opening relationship $\sigma_w(w)$ is obtained from corresponding values of σ_w and w with $w > 0$.

From a series of tests of at least 6 specimens, the mean stress-crack opening diagram $\bar{\sigma}_w(w)$ shall be reported. Furthermore, a characteristic diagram $\sigma_{w,k}(w)$ can be calculated according to the following procedure:

Calculate from each test the dissipated energy between two crack openings w_i and w_m where w_i is the crack opening corresponding to the situation where the crack has crossed the failure plane, while w_m may be taken equal to the ultimate crack opening, depending on the type of application:

$$W_F = \int_{w_i}^{w_m} \sigma_w(w)\,dw \tag{4}$$

Typically, w_m = 2 mm, while w_i is determined as the smallest value of w where:

$$\delta_j \geq 2\ 10^{-4} l_g \quad \text{for all } j \tag{5}$$

(see also Fig. 5).

From a statistical analysis the characteristic value of

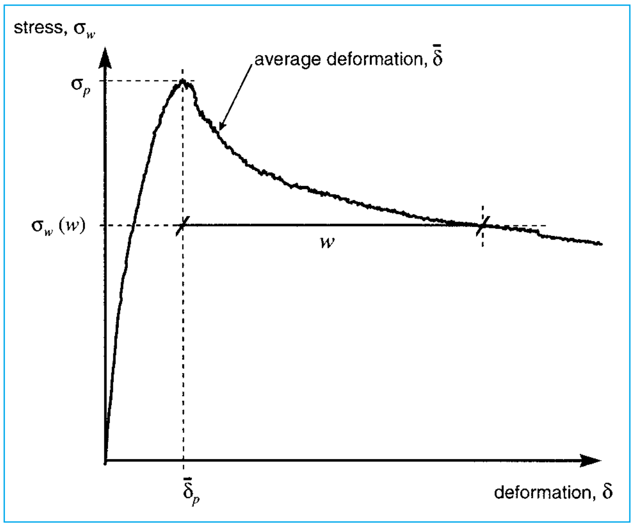

Fig. 4 – Calculation of crack opening w from averaged, measured displacement over the notch.

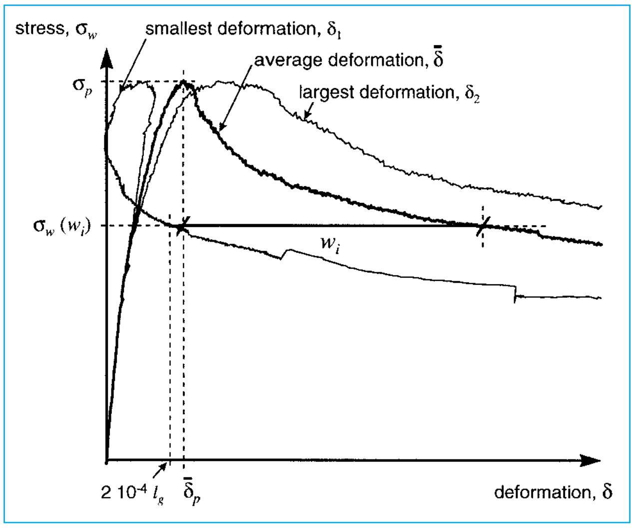

Fig. 5 – Schematic representation of the determination of w_i based on a real data set. For the sake of simplicity only two transducer signals are considered.

the dissipated energy $W_{F,k}$, as well as the mean value $\bar{W}_F$, can be calculated. A characteristic stress-crack opening diagram can then be obtained from the mean diagram based on all tests, $\bar{\sigma}_w(w)$, according to:

$$\sigma_{w,k}(w) = \bar{\sigma}_w(w) \frac{W_{F,k}}{\bar{W}_F} \quad (6)$$

The choice of fractile and confidence level for the calculation of the characteristic value $W_{F,k}$ shall be made in correspondence with national or international safety standards.

Furthermore, a mean value for w_i, $\bar{w}_i$, is defined according to:

$$\bar{w}_i = \frac{1}{t} \sum_{q=1}^{t} (w_i)_q \quad (7)$$

where $(w_i)_q$ is w_i for test q and t is number of tests.

8. TEST REPORT

The test report on a test series shall contain the following items:

- Geometry of all specimens.
- Description of method of placing and compaction of SFRC in the mould (if cast specimens are used).
- Description of coring procedure (if cored specimens are used) and location and orientation of the core relative to the structure or structural element.
- Description of curing and conditioning prior to testing.
- In one diagram all the observed $\sigma_w(w)$ – curves from $w = 0$ to $w = w_m$.
- In one diagram the calculated $\bar{\sigma}_w(w)$ and the $\sigma_{w,k}(w)$ from $w = \bar{w}_i$ to $w = w_m$ along with information about the value of $\bar{w}_i$ and w_m.
- Any other information typically required by the relevant national standards.

Furthermore, it is recommended that the following information is recorded:

- For each specimen observations of uniformity of fibre distribution, preferably in the form of photographic registration of the fracture surface.
- Type of testing equipment.