Materials and Structures/Matériaux et Constructions, Vol. **35**, November 2002, pp 579-582

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

Bending test

Final Recommendation

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1. SCOPE

This test method evaluates the tensile behaviour of steel fibre-reinforced concrete either in terms of areas under the load-deflection curve or by the load bearing capacity at a certain deflection or crack mouth opening displacement (CMOD) obtained by testing a simply supported notched beam under three-point loading.

This standard is not intended to be applied in the case of shotcrete.

This test method can be used for the determination of:

• the limit of proportionality (LOP), *i.e.* the stress which corresponds to the point on the load-deflection or load-crack mouth opening displacement curve (=> F_L) defined in part 5 as limit of proportionality;

• two equivalent flexural tensile strengths which identify the material behaviour up to the selected deflection. These equivalent flexural tensile strengths are determined according to part 5;

• four residual flexural tensile strengths which identify the material behaviour at a selected deflection or CMOD. The residual flexural tensile strengths are calculated according to procedures in part 5.

If the objective of the test is to calculate equivalent flexural tensile strength, it is necessary to measure the deflection. However, if only residual flexural tensile strengths are calculated, one can choose between the measurement of deflection and/or CMOD. A relation between mid-span deflection and CMOD is given in part 6.

2. TEST SPECIMEN

Concrete beams of 150 x 150 mm cross section with a minimum length of 550 mm are used as standard test specimens.

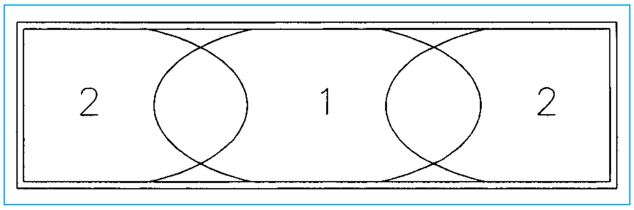

Fig.1 – Production method for casting the specimen.

The standard test specimens are not intended for concrete with steel fibres longer than 60 mm and aggregate larger than 32 mm. The procedure for casting of the specimens and filling of the mould is shown in Fig. 1. It is desirable that portion 1 is twice that of portion 2. The mould shall be filled in one layer up to approximately 90% of the height of the test specimen. The mould shall be topped up and levelled off while being compacted. Compaction shall be carried out by external vibration. In the case of self compacting steel fibre concrete, the mould shall be filled in a single pour and levelled off without any compaction.

The specimens are demoulded between 24 and 48 hours after casting the concrete. Afterwards they are stored at + 20°C and RH ≥ 95% until preparation for testing.

The beams are notched using wet sawing. Each beam is turned 90° from the casting surface and the notch is then sawn through the width of the beam at midspan (see Fig. 2). Following the notching, the same curing conditions for the specimens as before are continued for a minimum of 3 days. The curing can be discontinued not more than 3 hours before testing leaving sufficient time for preparation including any location of measuring devices and transducers. Testing shall normally be performed at 28 days. The width of the notch is not larger than 5 mm and the beam has an unnotched depth h_{sp} of

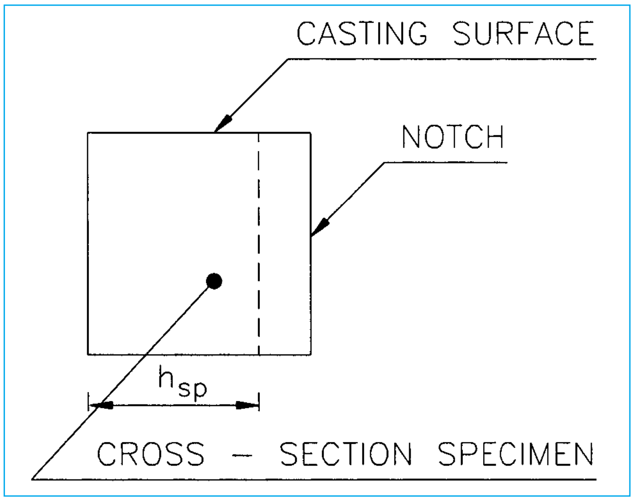

Fig. 2 – Position of tne notch sawn into the test beam.

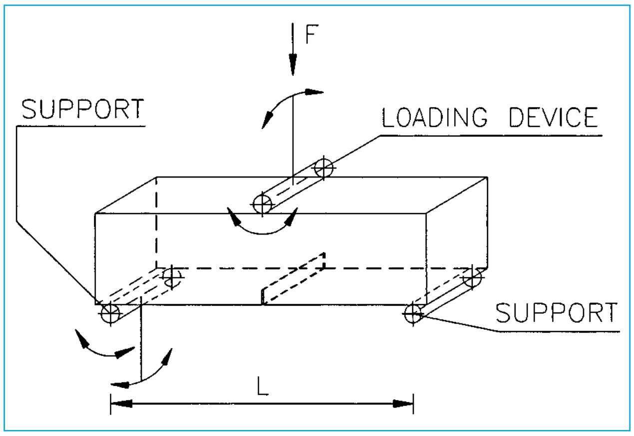

Fig. 3 – Position of the load and supports of the beam specimen.

125 mm ± 1 mm. The device for measuring the dimensions of the specimens has an accuracy of 0.1 mm. The dimensions of the specimen shall not vary by more than 2 mm on all sides. Additionally the difference in overall dimensions on opposite sides of the specimen shall not be greater than 3 mm.

3. APPARATUS

A testing machine which is capable of producing a constant rate of increase of deflection (δ) or CMOD of the test specimen, preferably a closed loop machine, should be used.

The stiffness of the testing equipment has to be large enough to avoid unstable zones in the F-δ (F-CMOD) curve. Tests during which instabilities occur have to be rejected.

The two supports and the device for imposing the displacement are rollers with a diameter of 30 mm ± 1 mm as shown in Fig. 3. All rollers shall be manufactured from steel. Two rollers, including the upper one, shall be capable of rotating freely around their axis and of being inclined in a plane perpendicular to the longitudinal axis of the test specimen.

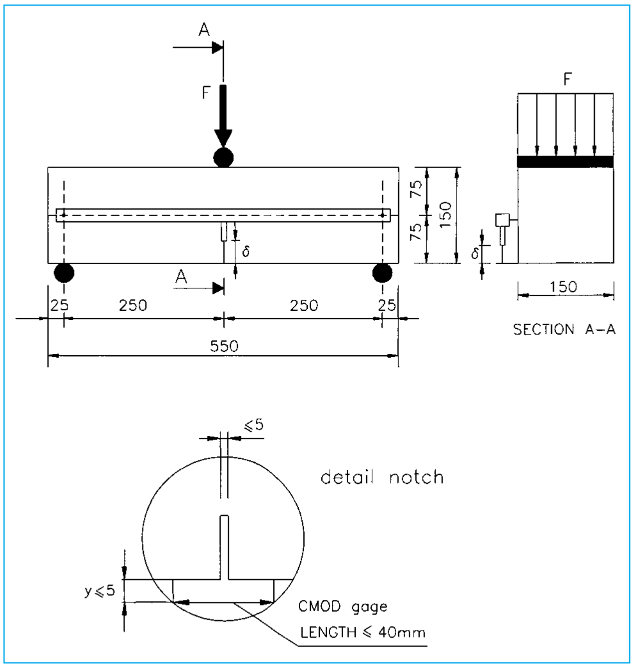

Fig. 4 – Arrangement of displacement monitoring gauges.

The apparatus measuring deflection should be capable of recording accurately the midspan deflection, excluding extraneous deformations due to deformations of the machine and/or of the specimen supports. Normally deflection is measured at one side of the specimen (=> δ) and the transducer has to be carefully mounted in order to minimize the effect of rotation.

A schematic illustration of a possible measuring set-up is shown in Fig. 4.

The original distance between the reference points for the measurement of the opening of the mouth of the notch (CMOD) is not greater than 40 mm (Fig. 4). It is recommended that the notch mouth opening displacement measuring system is installed along the longitudinal axis at the mid-width of the test specimen, so that the distance y between the bottom of the specimen and the axis of the measuring system is 5 mm or less.

The accuracy of the load measuring device is required to be equal to 0.1 kN. The accuracy of the deflection and the notch mouth opening displacement measuring system requires to be 0.01 mm.

4. PROCEDURE

The span length of the three-point loading test is 500 mm (Fig. 4).

The testing machine should be operated so that the measured deflection of the specimen at midspan increases at a constant rate of 0.2 mm/min until the specified final deflection is reached. During testing the value of the load and deflection at midspan (δ) are recorded continuously.

When the test is executed by means of CMOD-control, the machine shall be operated in such a manner that the CMOD increases at a constant rate of 50 µm/min for CMOD from 0 to 0.1 mm, until the end of the test, at a constant rate of 0.2 mm/min.

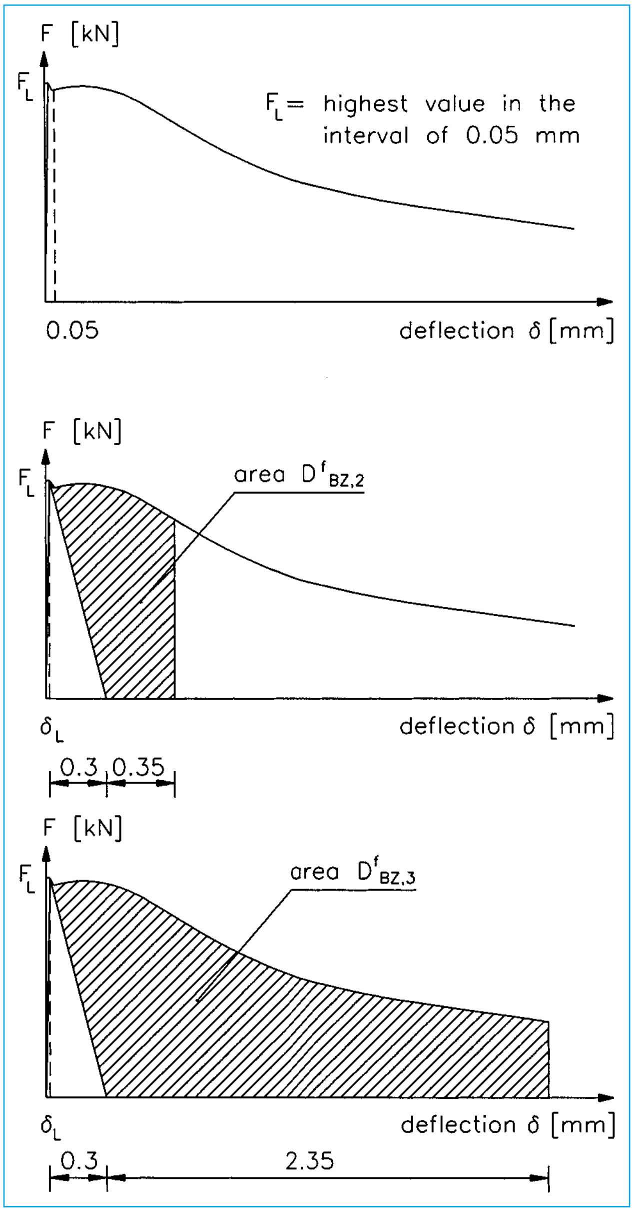

Fig. 5 – Load-deflection diagrams.

During the first two minutes of the test, data shall be logged with a frequency not smaller than 5 Hz; thereafter, up to the end of the test, the frequency shall not be smaller than 1 Hz.

At least 6 specimens shall be tested in the same conditions.

5. CALCULATION

The load at the limit of proportionality (=F_L in N) is determined according to an appropriate diagram in Fig. 5 or Fig. 6. F_L is equal to the highest value of the load in the interval (δ or CMOD) of 0.05 mm. The moment at midspan of the test beam corresponding to F_L is:

$$M_L = \frac{F_L}{2} \cdot \frac{L}{2} \text{ (Nmm)}$$

where L = span of the specimen (mm).

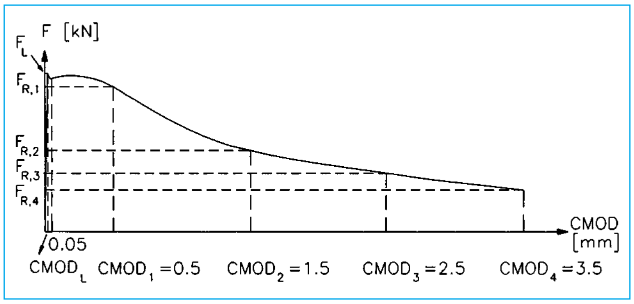

Fig. 6 – Load-CMOD diagram.

Assuming a stress distribution as shown in Fig. 7, the limit of proportionality $f_{fct,L}$ can be calculated using the following expression:

$$f_{fct,L} = \frac{3F_L L}{2 b h_{sp}^2} \text{ } (N/mm^2)$$

where

b = width of the specimen (mm)

h_{sp} = distance between tip of the notch and top of cross section (mm).

The energy absorption capacity $D_{BZ,2}$ ($D_{BZ,3}$) is equal to the area under the load-deflection curve up to a deflection δ_2 (δ_3) (Fig. 5). $D_{BZ,2}$ ($D_{BZ,3}$) consists of two parts:

- plain concrete => D^b_{BZ} (Nmm)
- influence of steel fibres =>$D^f_{BZ,2}$ and $D^f_{BZ,3}$ (Nmm) .

The dividing line between the two parts can be simplified as a straight line connecting the point on the curve corresponding to F_L and the point on the abscissa "δ_L + 0,3 mm". δ_L is the deflection at the limit of proportionality. The deflections δ_2 and δ_3 are in turn defined as:

$\delta_2 = \delta_L + 0.65$ mm (mm)

$\delta_2 = \delta_L + 2.65$ mm (mm).

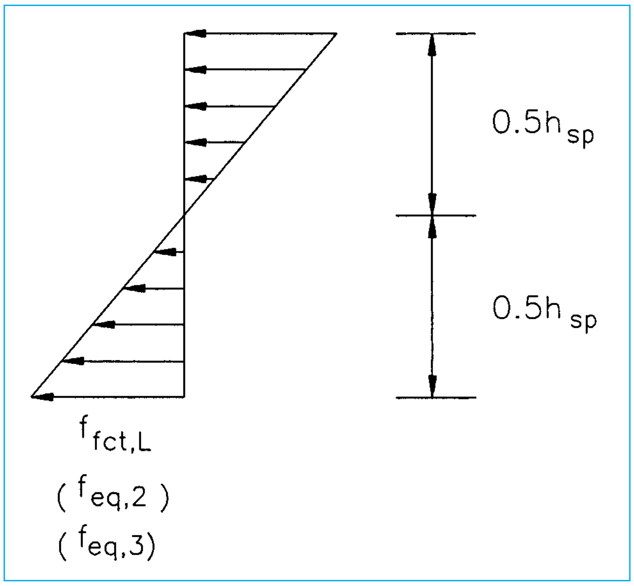

Fig. 7 – Stress distribution assumed.

F_2 (F_3) is equal to the mean force recorded in the shaded area $D^f_{BZ,2}$ ($D^f_{BZ,3}$) and can be calculated as follows :

$$F_2 = \frac{D^f{}_{BZ,2}}{0.50} \ (N)$$

$$F_3 = \frac{D^f{}_{BZ,3}}{2.50} \ (N)$$

The moment at midspan of the test beam corresponding to F_2 (F_3) is:

$$M_2 = \frac{F_2}{2}\frac{L}{2} = \left(\frac{D^f{}_{BZ,2}}{0.50}\right)\frac{L}{4} \ (Nmm)$$

$$M_3 = \frac{F_3}{2}\frac{L}{2} = \left(\frac{D^f{}_{BZ,3}}{2.50}\right)\frac{L}{4} \ (Nmm).$$

Assuming a stress distribution as shown in Fig. 7, the equivalent flexural tensile strength $f_{eq,2}$ and $f_{eq,3}$ can be determined by means of the following expressions:

$$f_{eq,2} = \frac{3}{2}\left(\frac{D^f{}_{BZ,2}}{0.50}\right)\frac{L}{b\,h_{sp}{}^2} \ (N/mm^2)$$

$$f_{eq,3} = \frac{3}{2}\left(\frac{D^f{}_{BZ,3}}{2.50}\right)\frac{L}{b\,h_{sp}{}^2} \ (N/mm^2)$$

Residual flexural tensile strengths $f_{R,i}$ at the following midspan deflections ($\delta_{R,i}$) or crack mouth opening displacements ($CMOD_i$) can additionally be calculated:

$\delta_{R,1}$ = 0.46 mm - $CMOD_1$ = 0.5 mm
$\delta_{R,2}$ = 1.31 mm - $CMOD_2$ = 1.5 mm
$\delta_{R,3}$ = 2.15 mm - $CMOD_3$ = 2.5 mm
$\delta_{R,4}$ = 3.00 mm - $CMOD_4$ = 3.5 mm

$F_{R,i}$ is the load recorded at $\delta_{R,i}$ or $CMOD_i$.

Assuming a stress distribution as shown in Fig. 7, the residual flexural tensile strength $f_{R,i}$ can be determined by means of the following expression:

$$f_{R,i} = \frac{3}{2}\frac{F_{R,i}\,L}{b\,h_{sp}{}^2}.$$

Note: if the crack starts outside the notch, the test has to be rejected.

6. EQUIVALENCE BETWEEN δ AND CMOD

The following average relationship between CMOD and δ was determined :

CMOD = 1.18 δ + β with β = -0.0416 mm.

It must be stressed that this relationship is only applicable in the post-peak region of the load-CMOD (load-δ) curve.

The beam response at CMOD 0.5 mm, 1.5 mm, 2.5 mm and 3.5 mm is of special interest. The corresponding values of δ are mentioned in part 5.

In the case where CMOD is measured at a certain distance y (see Fig. 4) below the beam, resulting in a measurement $CMOD_y$, the following relationship between CMOD and $CMOD_y$ can be adopted:

$$CMOD_y = CMOD\frac{H+y}{H}$$

with H = total height of the beam.