Test Method for the Flexural Strength and Toughness Parameters of Fibre Reinforced Concrete

A Recommendation of the ICI Technical Committee on Fibre Reinforced Concrete (ICI-TC/01)

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1 FOREWORD
For drafting this document, the JSCE-SF4 and ASTM C 1609 standards have been used as the bases.

2 SCOPE
2.1 This standard provides guidelines for evaluating the flexural strength and flexural toughness of fibre reinforced concrete through tests under displacement control, in the third point loading configuration, of (un-notched) moulded specimens.
2.2 This testing method is intended for fibres that are not longer than 60 mm. The method can also be used for a combination of fibres of same or different materials.
2.3 References given in brackets (of ISO/EN/ASTM, etc.) are for guidance.

3 NORMATIVE REFERENCES
IS 516 – 1959 (Reaffirmed 1999), METHODS OF TESTS FOR STRENGTH OF CONCRETE

4 TERMS AND DEFINITIONS
4.1 net deflection, \( \delta \) - the deflection measured at the mid-span of a beam specimen, exclusive of any extraneous effects due to crushing at the loading points, seating or twisting of the specimen on its supports or due to the deformation of the support and loading system.
4.2 load-deflection curve - the plot of load versus net deflection of a beam specimen loaded to the end-point deflection.
4.3 first-peak load, \( P_{\text{max}} \) - the load value at the first point on the load-deflection curve where the slope is zero.
4.4 first-peak deflection, $\delta_{\text{max}}$ - the net deflection value at first-peak load.

4.5 flexural strength, $f_{ct}$ - the stress value obtained when the peak load value is used in the equation of modulus of rupture.

4.6 equivalent flexural load, $P_{e,n}$ - the load value representing the average load-carrying capacity in the post peak region up to a specified deflection of $L/n$.

4.7 equivalent flexural strength, $f_{e,n}$ - the stress value representing the average flexural strength in the post peak region up to a specified deflection of $L/n$ obtained when $P_{e,n}$ is used in the equation of modulus of rupture.

4.8 equivalent flexural strength ratio, $R_{me,n}$ - value of the mean equivalent flexural strength normalized with respect to mean flexural strength.

5 PRINCIPLE

The flexural response of fibre reinforced concrete is evaluated by the enhanced post cracking capacity expressed in terms of a set of toughness parameters obtained from the load-deflection ($P-\delta$) curve in the third-point loading test of an unnotched moulded specimen.

6 APPARATUS

6.1 Moulds: Standard beam moulds for producing hardened concrete specimens, of non-absorbent, rigid material, not chemically attacked by cement paste, of a size $150 \text{ mm} \times 150 \text{ mm} \times 700 \text{ mm}$. Moulds of shorter length, not less than $550 \text{ mm}$, can be used to decrease the weight of the specimen.

6.2 Calipers, capable of reading the dimensions of test specimens to an accuracy of 0.1 mm.

6.3 Rule (ruler/scale), capable of reading the dimensions of test specimens to an accuracy of 1 mm.

6.4 Testing machine that shall meet the machine Class 1 requirements in EN 12390-4, capable of operating in a (closed-loop) controlled manner, i.e., producing a constant rate of displacement (deflection), and with sufficient stiffness to avoid unstable zones in the load-deflection curve. Testing machines that use piston (stroke) displacement control or load control are not suitable for establishing the portion of the load-deflection curve immediately after first-peak.

Note: Different types of closed-loop machines are available and some of them may be incapable of controlling the stability during the testing of FRC beams. Obtaining a stable curve requires a testing machine that can react fast enough, has high stiffness and accuracy, and adequate responsiveness of the LVDTs or other extensometers used for feedback control. Hence, based on experience, testing FRC beams can only be done with appropriate equipment chosen to get reliable output. Further, to obtain reliable results, the expertise of the testing machine operators and other members of the team is very important.
6.5 The loading and specimen support system shall be capable of applying third-point loading to the specimen without eccentricity or torque. The fixtures normally used for flexural testing are suitable with the qualification that supporting rollers shall be able to rotate about their axes and shall not be placed in grooves or have other restraints that prevent their free rotation (see Figure 1).

![Loading arrangement for test specimen](image)

**Figure 1 - Loading arrangement for test specimen**

6.6 It is preferred that all rollers are manufactured from steel and shall have a circular cross-section with a diameter of 30 mm ±1 mm. They shall be at least 10 mm longer than the width of the test specimen. They shall have clean and smooth surfaces, greased to ensure free movement. All rollers (shown in Figure 1), including the upper ones, shall be capable of rotating freely about their axes. At least one of the lower support rollers shall be capable of being inclined in a plane perpendicular to the longitudinal axis of the test specimen. For the requirements of roller for supports or load; refer to IS 9399.

6.7 The distance between the centres of the lower supporting rollers (i.e. the span length) shall be set equal to 450 mm. All rollers shall be adjusted to their correct position with all distances having an accuracy of ±1 mm.

6.8 Load measuring device shall be capable of measuring loads to an accuracy of 10 N.
6.9 Net deflection measurement: Devices such as electronic transducers or electronic deflection gages shall be located in a manner that ensures accurate determination of the net deflection at the mid-span, exclusive of the effects of seating or twisting of the specimen on its supports (see sketches of a typical yoke in Figure 2). Accordingly, it is recommended that two transducers or similar digital devices mounted on the horizontal bars of the yoke at mid span, one on each side, be used to measure deflection through contact with appropriate brackets (preferably S-shaped) glued onto the specimen at the top surface and placed along the vertical faces of the specimen, at mid span. The yoke frames shall be fixed using screw heads placed at the mid-depth of the specimen to ensure that the distance between the two yoke frames does not change during deflection of the specimen (see Figure 1). The horizontal bars of the yoke shall rest on the yoke frames without restriction against horizontal movement. The accuracy of the transducers should be equal to or better than 1 micron.

Figure 2 – Sketches of a typical yoke used in the measurement of net deflection

6.10 Data recording system: A data acquisition system capable of digitally recording and storing load and deflection data at least 10 times per second (i.e., a sampling frequency of 10 Hz) is suitable.
6.11 Equipment: All measuring and testing equipment shall be calibrated and regularly inspected according to documented procedures, frequencies and criteria. Devices for calibration (such as standard weights and measures, proving rings etc.) shall be authenticated by a competent authority and be certified.

7 TEST SPECIMENS

7.1 The specimen should have a cross section dimension of 150 mm × 150 mm, with a length between 550 and 700 mm. These dimensions are valid for concretes having aggregates with maximum grain size of up to 25 mm and fibres of up to 60 mm in length.

7.2 The tolerances on the cross-section of the test specimens shall be within ± 2%.

7.3 Preparation and curing of test specimens

7.3.1 The procedure to be followed for filling the mould with fibre reinforced concrete is indicated in Figure 3; the quantity of concrete being added in the central portion at a time (increment 1) should be more than twice that of increment 2. The mould shall be filled full in the middle and up to approximately 90% of the height of the mould in the end portion. Filling can be done in two layers (for a 150 mm × 150 mm section), before compaction. The mould shall be topped up and levelled off while being compacted with minimum disturbance to the middle portion.

7.3.2 Compaction shall be carried out by external vibration and external tapping. Internal tamping is not recommended since this can lead to non-uniform fibre and aggregate distributions, which can give high variability in the material behavior and low toughness values. The use of an internal (needle/poker) vibrator should be avoided.

7.3.3 A high frequency vibrating table suitable for compaction of the concrete in beam moulds shall be used. Care should be taken not to allow fibres to segregate (by sinking / floating up) by too long a duration of vibration. Care shall also be taken to avoid realignment of fibres from the random nature.

7.3.4 In the case of self-compacting fibre concrete, the mould shall be filled and levelled off without any compaction.

7.3.5 The test specimens shall be cast and cured in compliance with IS 516 (ISO 1920-3, EN 12350-1 and EN 12390-1&2) unless specified otherwise. The concrete
specimens shall be cured in the moulds for 24 h after casting at (27 ±2)°C, either under polyethylene sheeting or at not less than 95% relative humidity, then demoulded and cured for a further period as per requirement (normally for the next 27 days) under moist conditions of 95% relative humidity. Testing shall normally be performed at 28 days (or at the specified age of the specimen).

7.4 During transportation of the specimens from field to test laboratory, care should be taken to avoid jerks and heavy vibrations, or damage to the surface.

8 TESTING PROCEDURE

8.1 Preparation and positioning of test specimens

8.1.1 The average width of the specimen and distance between the centre of the beam and the top of the specimen in the mid-span section shall be determined from two measurements to the nearest 0.1 mm, using calipers.

8.1.2 The span length shall be 450 mm, which shall be ensured to the nearest 1 mm, using a ruler.

8.1.3 The test specimen must be turned on a side perpendicular to the position as cast, before placing it on the supports. The specimen shall be placed in the testing machine, correctly centred and with the longitudinal axis of the specimen at right angles to the longitudinal axes of the upper and lower rollers.

8.1.4 The deflection measuring set up should be fixed as mentioned in Section 6.9 to avoid any extraneous deformations.

8.1.5 Before applying the load, it shall be ensured that all loading and supporting rollers are resting evenly against the test specimen.

8.2 Rate and range of loading - The rate of loading should be so as to achieve the first peak load within 3 to 4 minutes of the initiation of loading. Beyond the drop in load after the peak, the rate of loading can be increased so as to terminate the test in about 45 minutes. In general, the loading rate should be between 0.025 mm/min to 0.1 mm/min up to the first peak and later about 0.5 to 1 mm/min. However, the optimum rate of loading may be arrived at based on the response of the machine and the sensitivity of the control system. The general deflection limit is 3.5 mm, as the majority of toughness parameters require the area under load-deflection curve up to a deflection of \(L/150\) mm for their calculation.

8.2.1 The rate of loading given above is suggested to get a stable response curve. Higher strength concretes would generally depict greater brittleness and hence a slower rate of loading may be required to avoid sudden failure and to obtain a stable curve. The initial loading rate is a critical parameter and can be reduced by 50% for high strength concrete. Refer to Table 1 for guidance. For concretes up to a flexural strength of 4.5 MPa, adopting lower rates of loading will increase the time required for each test. Whenever a slower rate of loading is adopted, it should noted in the report.
### Table 1: Rate of Increase of Net Deflection as per ASTM C 1609-2010

<table>
<thead>
<tr>
<th>Beam Size (mm)</th>
<th>Up to the net deflection of $L/900$ (mm/min)</th>
<th>Beyond net deflection of $L/900$ (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Strength Concrete 100 × 100 × 350</td>
<td>0.025 to 0.075</td>
<td>0.05 to 0.20</td>
</tr>
<tr>
<td>150 × 150 × 500</td>
<td>0.035 to 0.10</td>
<td>0.05 to 0.30</td>
</tr>
<tr>
<td>High Strength Concrete 100 × 100 × 350</td>
<td>0.0125 to 0.0375</td>
<td>0.05 to 0.20</td>
</tr>
<tr>
<td>150 × 150 × 500</td>
<td>0.0175 to 0.05</td>
<td>0.05 to 0.30</td>
</tr>
</tbody>
</table>

8.3 Tests during which the crack starts outside the middle third shall be rejected.

8.4 Normally, a set of 6 specimens shall be tested to obtain representative values of the parameters. It is likely that one or more specimens may fail without giving a proper response curve. Wherever, based on earlier experience (with a combination of a particular grade of FRC, test equipment and the team carrying out test), it can be assured that a proper response curve can be obtained for all the beams, the size of the sample set can be restricted to 6 specimens. Nevertheless, in most cases, an additional beam is preferable for test setup and trial. However, in all cases, results of all the beams tested, should be reported.

### 9 CALCULATION

9.1 All load and deflection data required for further calculations shall be obtained from the digital data stored from the test.

9.2 The first peak load ($P_{\text{max}}$) is obtained as the load at the point where the slope of the load-deflection curve is first zero.

9.2.1 The flexural strength (or modulus of rupture) is obtained for the first peak load, $P_{\text{max}}$, as:

$$ f_{\text{ct}} = \frac{P_{\text{max}} \times L}{bd^2} \quad (1) $$

where,

- $f_{\text{ct}}$ = the flexural strength of an individual specimen, MPa
- $P_{\text{max}}$ = peak load, N
- $L$ = the span, mm,
- $b$ = the average width of the specimen, as oriented for testing, mm, and
- $d$ = the average depth of the specimen, as oriented for testing, mm.

It should be noted that the value obtained may be significantly different from that obtained in a conventional test carried out under load control, where the specimen fails at the peak load.
9.2.2 The value rounded to the nearest 0.05 MPa as the flexural strength is to be recorded.

9.2.3 The mean value from the set of specimens shall be recorded as \( f_{cm} \).

9.3 Equivalent flexural strength \((f_{e,n})\)

9.3.1 The equivalent flexural strength should be calculated for specified deflections given by \( L/n \) for the values of \( n = 150 \) and 300, and any other intermediate value specified by the client.

9.3.2 The equivalent load up to each specified deflection of \( l/n \) is to be obtained for an individual specimen from the corresponding load-deflection curve as

\[
P_{e,n} = \frac{T_{e,n}}{\delta_n}
\]

(2)

where \( T_{e,n} \) is the area under the load-deflection curve up to the deflection \( L/n \) as shown in the Figure 4 below.

![Figure 4 - Load-deflection curve indicating the area calculation](image)

9.3.3 The equivalent flexural strength corresponding to each specified deflection \( L/n \) is obtained for an individual specimen from the corresponding equivalent load \( (P_{e,n}) \) calculated using Eq. (2) as:

\[
f_{e,n} = \frac{P_{e,n} \times L}{bd^2}
\]

(3)

9.3.4 Each value rounded to the nearest 0.05 MPa as the equivalent flexural strength is to be recorded.

9.3.5 The mean equivalent flexural strength value from the set of specimens shall be recorded for each specified deflection \( L/n \) as \( f_{em,n} \).
9.4 The equivalent flexural strength ratio $R_{me,n}$ is a dimensionless parameter obtained by normalizing the mean equivalent flexural strength $f_{em,n}$ with the mean flexural strength $f_{ctm}$, for each specified deflection limit $L/n$. It is expressed in % using the following equation:

$$R_{me,n} = \frac{f_{em,n}}{f_{ctm}} \times 100\%$$

(4)

10 REPORT

The report on the fibre reinforced concrete tests shall include the following information for each set of specimens:

a) Identification of the test specimen;

b) Details that may be available, such as mix composition, fibre type and dosage, slump in mm, date and time of casting, curing history and storage conditions;

c) Condition of specimens at testing (shape, edge damage, etc.) and moisture condition of specimens at testing (moist/surface dry, etc);

d) Date of testing

e) Average dimension of each specimen, to the nearest 0.1 mm

f) Rate of loading

g) Number of specimens tested;

h) Load-deflection curves for each specimen

i) Flexural strengths of each specimen and the mean flexural strength

j) Equivalent flexural strength of each specimen and the mean equivalent flexural strength for each of the specified deflections;

k) Equivalent flexural strength ratio as % for each of the specified deflections;

l) The number of fibers crossing the fractured section and general comments on fiber distribution;

m) Location of failure (within the center-third or away from the center-third);

n) Reference to this recommendation;

o) Any deviation from this recommendation.