WEDGE SPLITTING TEST METHOD (WST): 
FRACTURE TESTING OF FIBRE-REINFORCED CONCRETE (MODE I)

Key words: Fibre-reinforced concrete, fracture testing, wedge-splitting test method, round-robin test

1 SCOPE AND FIELD OF APPLICATION
This method specifies a procedure for determining/characterizing the mode I tensile fracture behaviour of fibre-reinforced concrete by means of the Wedge Splitting Test (WST) method on notched specimens.

2 REFERENCES
NT BUILD 201 Concrete: Making and curing moulded test specimens for strength tests.

3 SYMBOLS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tbody>
<tr>
<td>$V_F$</td>
<td>Volume fraction of fibres</td>
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<tr>
<td>$W_F$</td>
<td>Work of fracture</td>
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<tr>
<td>$b$</td>
<td>Width of the specimen/ligament</td>
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<tr>
<td>$d_x$</td>
<td>The horizontal distance between the loading points</td>
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<tr>
<td>$d_y$</td>
<td>The vertical distance from the bottom of the specimen to the point where the splitting load is applied</td>
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<tr>
<td>$f_{fr}$</td>
<td>Residual tensile stress</td>
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<tr>
<td>$h_c$</td>
<td>Depth of the ligament under the notch</td>
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<td>$m$</td>
<td>Total weight of the specimen</td>
</tr>
<tr>
<td>$w$</td>
<td>Crack opening</td>
</tr>
<tr>
<td>$x$</td>
<td>Height of the compressive zone</td>
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<tr>
<td>$\alpha$</td>
<td>Wedge angle = 15°</td>
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4 SAMPLING
The test is performed on moulded test specimens. The standard testing age is 28 days, but the method can also be used at other ages. Moreover, the test method can also be used for core-drilled samples.

The size of the specimen depends on the purpose of the test and shall, if relevant, be sufficient for the result to be treated statistically and representative. The
dimensions of the specimen (height, width, and thickness) should preferably be four times the maximum fibre length (at a minimum, three and a half times).

5 TESTING

5.1 Principle

In Figure 1 and Figure 2 the specimen geometry and loading procedure are clarified. The specimen is equipped with a groove (to be able to apply the splitting load) and a starter notch (to ensure the crack propagation). Two steel platens with roller bearings are placed partly on top of the specimen partly into the groove, and through a wedging device the splitting force, \( F_{sp} \), is applied. During a test, the load in the vertical direction, \( F_v \), and the crack mouth opening displacement (CMOD) are monitored.

5.2 Test specimen geometry

For standard testing on cast specimens, the specimen geometry is based on standard cube specimens provided with a cast groove and a sawn starter notch.

The depth of the starter notch shall be equal to half the height of the specimen depth (cut to a precision of ±1 mm). The width of the notch shall not be greater than 5 mm.

The dimensions of the specimen shall not vary more than 2 mm on all sides. Additionally, the differences in overall dimensions on opposite sides of the specimen shall not be greater than 2 mm.

The size of the specimen depends on the maximum fibre length (\( L_{f\text{,max}} \)) – or maximum size of the aggregate (\( D_{\text{max}} \)) – it is recommended that the dimension of the specimen (height, width, and thickness) should be at least three and a half (3.5) times larger than the maximum fibre length.

Furthermore, to minimize the influence of wall effects at the formwork surfaces, a guide notch is to be sawed. Moreover, the guide notch is also beneficial as it prevents horizontal cracks from occurring, which may be a problem for high fibre content. The depth of the guide notch is 25 ± 1 mm. See Figure 3 for example of specimen geometries.

5.3 Test specimen preparation

The specimens are to be produced according to the principles given in NT BUILD 201.

After casting and before de-moulding, the specimens are kept in the moulds at +20 ± 2 °C and covered with a plastic sheet to prevent evaporation. After de-moulding, not earlier
than 16 hours and not later than 48 hours after casting, the specimens are constantly kept in lime-saturated water (+20 ± 2 °C) until less than 60 minutes before testing. The notch shall be sawn under wet conditions not earlier than 3 days after casting and not later than 1 day before testing.

5.4 Equipment

Equipment to support and load the specimen according to Figure 1 is required. The wedge splitting equipment consists of: two steel platen-loading devices (with roller bearings), a linear support, and a wedging device. The testing system consists of: frame, actuator, load cell, clip gauge (or other measuring device), controller and data acquisition equipment as a minimum. Whereas it is preferable to have a closed-loop controlled machine, this is not required. The load shall be measured with an accuracy of ±1% of the maximum load value in the test. The displacement-measuring device, measuring the CMOD, shall have an accuracy better than ±0.01 mm.

5.5 Testing environment

The specimens may be removed from the water 60 minutes prior to starting the test.

5.6 Test procedure

Immediately before the test the weight of the specimen is measured with an accuracy of ±10g. After weighing, the specimen is placed on the support, according to Figure 1, the wedge is lowered and the specimen is pre-loaded to a level of 50 to 100 N. Thereafter the test can begin and the testing machine should be operated so that, in the beginning of the test, the measured CMOD increases at a constant rate of 25 to 50 µm/min for CMOD from 0 to 0.2 mm. For CMOD between 0.2 and 2 mm a constant rate of 0.25 mm/min should be applied. When the CMOD is larger than 2 mm, the rate of loading may be increased to 0.5 mm/min. The changes in the loading rate should be made progressively in such a way that it does not influence the test result – i.e. the changes should not be to abrupt as it may result in an increased load resistance. The load-CMOD diagram is determined by continuously measuring and logging corresponding values of the vertical load, \( F_v \), and the CMOD. During the first two minutes, data shall be logged with a frequency not less than 5 Hz; thereafter, up to the end of the test, the frequency shall no be less than 1 Hz.

For the test to be valid it is required that the load-CMOD response in stable.

After the test, the depth, \( h_c \), and the width, \( b \), of the ligament over the notch are measured with an accuracy of ±0.1 mm.

5.7 Evaluation of the test

The splitting force, \( F_{sp} \), is calculated as:

\[
F_{sp} = \frac{F_v}{2\tan(\alpha)}
\]

where \( \alpha \) is the angel between the wedge and the vertical load line and \( \mu \) is the coefficient of friction of the rollers that are used to guide the wedge. As the influence of the friction is small, the relationship may be approximated by:

\[
F_{sp} = \frac{F_v}{2\tan(\alpha)}
\]

The work of fracture, \( W_f \), is calculated as the area under the splitting load-CMOD curve \( (F_{sp} - \text{CMOD}) \). At a specific CMOD the energy dissipated during fracture, \( W_{f,\text{CMOD}} \), is normalised with respect to the total ligament area, \( A_{lg} \), at complete fracture. This intermediate, specific fracture energy is denoted \( G_{f,\text{CMOD}} \) [N/m²], and may be determined directly from the test result by performing the calculation:

\[
G_{f,\text{CMOD}} = \frac{W_{f,\text{CMOD}}}{A_{lg}}
\]

where, \( W_{f,\text{CMOD}} \) is the area under the splitting load-CMOD curve and \( A_{lg} \) is the area of the ligament (all of the expected total cracked area).

In the WST-method, no measurements are made of the real crack opening – this is often due to measurement technique or due to specific test conditions. As can be seen in Figure 4, while the CMOD is measured at some distance from the tip of the notch the CTOD is the crack opening at the tip of the notch. The crack tip opening displacement (CTOD), however, represents a ‘true’ crack opening and, thus, is an important parameter when evaluating the fracture properties.

![Figure 4](image-url)
For WST-specimens with the dimensions 150x150 mm², the following expression (based on five mixes with the fibre content varying between 0.5% and 1.0%) has been evaluated for the relationship between the CMOD and the CTOD:

$$\text{CTOD} = 0.551 \cdot \text{CMOD} - 0.0084 [\text{mm}]$$

For WST-specimens with the dimensions 200x200 mm², the following expressions have been evaluated for the relationship between the CMOD and the CTOD:

$$\text{CTOD} = 0.533 \cdot \text{CMOD} - 0.0110 [\text{mm}]$$

A simplified approach to determine a residual tensile stress is to use the given relationships between CMOD and CTOD to calculate crack opening w. With a assumption of the height of the compressive zone, it is then possible to determine the residual tensile stress, $f_{fr}$, at a specific CMOD and calculate the corresponding crack opening, w. If a constant residual tensile stress $f_{fr}$ is assumed and that the height of the compressive zone is given by:

$$x = \frac{h^*}{10}$$

then the residual tensile stress, $f_{fr}$ can be calculated by solving the equilibrium equation of forces and the equilibrium equation of moment with respect to the position of the neutral axis (see Figure 4):

$$F_{fr} - F_{c} - F_{sp} = 0$$

$$F_{fr} \left( \frac{h_y - x}{2} \right) + F_{c} \left( \frac{2}{3} x \right) - F_{sp} \left( d_{y} - x - \frac{(\text{CMOD}/2)^2}{d_{y} - x} \right) = 0$$

$$\Rightarrow f_{fr} = \frac{F_{fr}}{(h_y - x) \cdot b}$$

where: $d_{x}$ is the horizontal distance between the loading points (for the undeformed specimen); $d_{y}$ is the vertical distance from the bottom of the specimen to the point where the splitting load is applied; $h_{y}$ is the depth of the ligament; and $b$ is the width of the ligament.

6 TEST REPORT

The test report shall include the following information.

I. General information
   a) Address of the testing laboratory and name of the person responsible.
   b) Identification number of the test report.
   c) Name and address of the organisation, or person, who ordered the test.
   d) Purpose of the test.
   e) Date of the test.

II. Description of the material tested
   f) Description of the method of producing the specimens.
   g) Description of the tested concrete.
   h) Age of the tested specimens.

III. Test method
   i) Individual geometry of the specimens.
   j) Device and set-up for loading, support, measurements, and recording.
   k) Rate of CMOD or rate of vertical displacement.
   l) Climate in test laboratory.
   m) Any deviation from this standard.

IV. Test results
   n) Test result in the form of splitting load-CMOD curves.
   o) The energy dissipated during fracture.
   p) Total number of fibres, $N_{f}$, crossing the fracture plane, and a note on the fibre distribution.

Depending on the purpose of the test and the number of specimens, it may be also relevant to include, e.g. the load-CMOD curve of each specimen and statistical evaluation of the test.

7 LITERATURE


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