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Test method for fibre-reinforced cementitious composites — Load-deflection curve using circular plates

Méthode d'essai des composites à base de ciment renforcés par des fibres — Courbe de charge-déformation utilisant des plaques circulaires

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Foreword

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This document was prepared by Technical Committee ISO/TC 71, *Concrete, reinforced concrete and pre-stressed concrete*, Subcommittee SC 6, *Non-traditional reinforcing materials for concrete structures*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Test method for fibre-reinforced cementitious composites — Load-deflection curve using circular plates

1 Scope

This document specifies a test method for evaluating flexural performance of fibre-reinforced cementitious composites (FRCCs) using derived parameters. These parameters are derived from the load-deflection curve obtained by testing a circular specimen supported on a concentric ring and loaded by another ring with a smaller diameter. The performance of FRCCs tested by this method is characterized for biaxial properties.

This test method provides for the determination of first-cracking load and the corresponding stress. It also provides for the determination of specimen toughness based on the area under the load-deflection curve up to the deflections at the first-cracking and peak loads. For determining the toughness value, this test method is intended primarily for use with FRCCs that exhibit deflection hardening behaviour. This test method is not intended for materials that exhibit deflection-softening behaviour.

2 Normative reference

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1920-3:2004, *Testing of concrete — Part 3: Making and curing test specimens*

ISO 1920-4, *Testing of concrete — Part 4: Strength of hardened concrete*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
load-deflection curve
plot of load versus *net deflection* (3.2) obtained from the test of a flexural circular specimen

3.2
net deflection
deflection measured at the centre of a flexural circular specimen exclusive of any extraneous effects due to seating or twisting of the specimen on its supports or deformation of the support and loading system

3.3
toughness
energy absorbed by the specimen equivalent to the area under the *load-deflection curve* (3.1) between the load and a specified *net deflection* (3.2)

3.4
equibiaxial flexural strength
stress that a material is capable of sustaining when it is subjected to an equibiaxial stress state

Note 1 to entry: This equibiaxial stress state is caused by the pure biaxial flexure of the circular specimen loaded by the inner loading ring and outer support ring. The equibiaxial flexural strength is calculated from the *first-cracking load* (3.5) of a biaxial test carried to rupture, the original dimensions of the test specimen and Poisson's ratio.

3.5
first-cracking load
load value on the *load-deflection curve* (3.1) at the end of linear elasticity, at which cracking initiates

3.6
first-cracking deflection
δ_c
net deflection (3.2) value on the *load-deflection curve* (3.1) at the *first-cracking load* (3.5)

Note 1 to entry: This is expressed in mm.

3.7
first-cracking strength
f_t
stress value obtained when the *first-cracking load* (3.5) is inserted in the formula for modulus of rupture

Note 1 to entry: This is expressed in MPa.

3.8
peak load
maximum load on the *load-deflection curve* (3.1)

3.9
peak-load deflection
δ_p
net deflection (3.2) value on the *load-deflection curve* (3.1) at the *peak load* (3.8)

Note 1 to entry: This is expressed in mm.

3.10
Poisson's ratio
υ
negative value of the ratio of transverse strain to the corresponding axial strain in the elastic range of deformation

4 Symbols

Symbol	Unit	Description
t	mm	thickness of the circular specimen
r_0	mm	radius of the loading ring
r_1	mm	radius of the specimen
r_2	mm	radius of the support ring
f	mm	$r_1 - r_2$
P_c	N	first cracking load
P_p	N	peak load
R	N/min	loading rate
S	MPa/min	rate of the equibiaxial stress
ψ	mm^{-2}	ratio of stress to load

5 Test specimens

5.1 Geometry

The nominal maximum size of aggregate and the thickness of the test specimens shall be in accordance with ISO 1920-3:2004, 4.1. The thickness and diameter of test specimens shall be at least three times the maximum fibre length.

The preferred size for a circular specimen with FRCCs is 210 mm in radius and 50 mm in thickness tested on a 400 mm span. A specimen with dimensions different from the preferred specimen sizes is permissible.

Circular specimens are tested in flexure between two concentric rings, as shown in Figure 1.

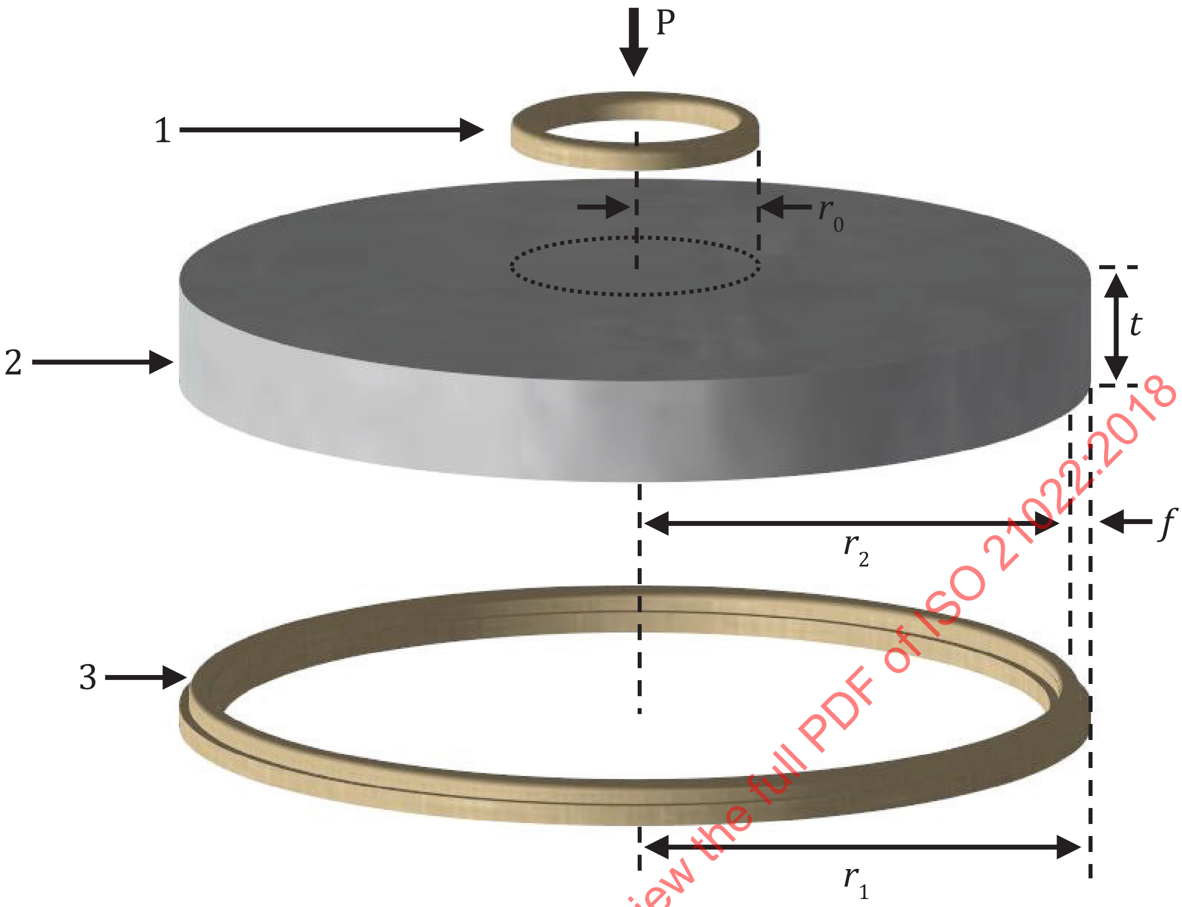
Damaged specimens shall not be tested.

a) The ratio of t to r_2 shall be 0,25.

b) The ratio of r_0 to r_2 shall be 0,25.

c) The difference, f, should be 0,05 times r_2. A large value of f would cause an effect of end confinement on the equibiaxial flexural strength. This difference needs to be minimized.

d) The thickness and diameter of individual specimens should not vary by more than 2 mm of the mean value.



Key

1 loading ring
2 specimen
3 support ring
P load

Figure 1 — Specimen dimensions

5.2 Fabrication of specimens

a) Moulds (see Figure 2) for the production of specimens shall consist of a base and side made of either non-reactive metal or coated plywood. The base and side shall be sufficiently rigid so as not to vibrate or permanently distort during casting. The interior face of the moulds shall be uniform so that a screed can be run directly across the surface to produce a specimen of correct thickness. Moulds shall be watertight and non-absorbent.

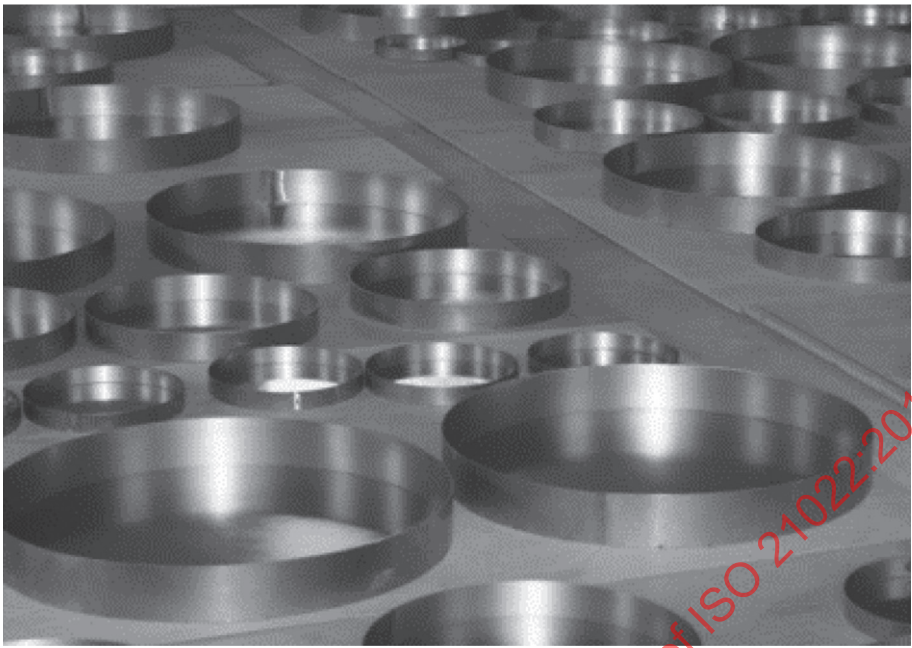


Figure 2 — Moulds

b) The diameter of the moulds shall be controlled through careful attention to manufacture. Maintenance of the correct thickness is subject to the skill of personnel charged with finishing the specimens.

c) At least six specimens shall be prepared for each batch of composites tested, and the thickness of each specimen shall be measured.

d) FRCCs shall be placed in a single placing sequence without joints.

e) Curing of test specimens shall be in accordance with ISO 1920-3.

f) Moulds shall be removed when the composite has attained sufficient strength so that the specimen can be placed into the testing position without being damaged.

g) For specimens stored in water, excess moisture shall be wiped from the surface of the specimen before placing in the testing machine.

h) The time between the extraction of the specimen from the humidity chamber or the water tank until the test shall be as short as possible and not more than 3 h. During the time the specimen is outside the humidity chamber or water tank, it shall be protected from drying, e.g. by covering with wet burlap.

6 Testing machine and measuring devices

6.1 Testing machine

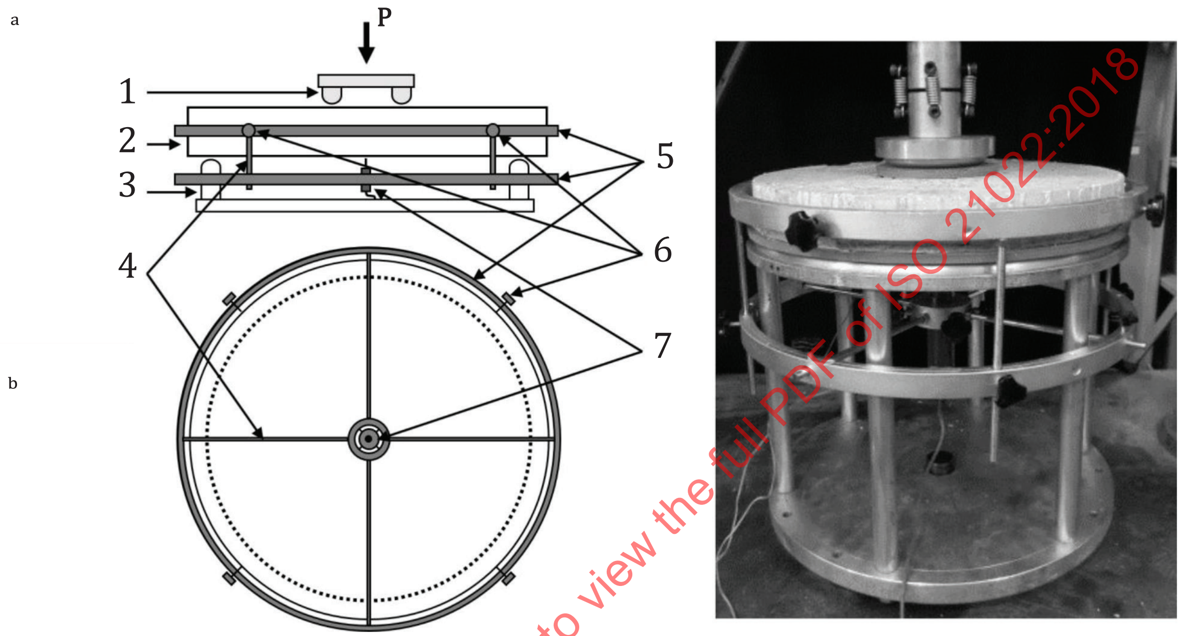
The test shall be carried out using a compression-testing machine conforming to ISO 1920-4. The test machine shall be in calibration at the time of the test with no more than a year after the last calibration.

The testing machine shall have a loading capacity in excess of the flexural capacity of the test specimen and shall be capable of applying loading at the required loading rate. To avoid unstable behaviour after cracking, the stiffness of the testing machine inclusive of load frame, load cell, and support fixture shall greatly exceed that of the specimen. Load controlled test machines incorporating one-way hydraulic valves or screw mechanisms lacking an electronic feed-back loop for automatically controlling the rate of increase in displacement shall not be used.

6.2 Loading fixtures for concentric ring testing

6.2.1 General

A drawing of the loading fixtures and a test specimen is shown in Figure 3.



Key

1 loading ring
2 specimen
3 support ring
4 aluminium bar
5 aluminium ring
6 pin
7 LVDT
P load
a Side view.
b Bottom view.

Figure 3 — Schematic of a suitable apparatus for flexure test of FRCCs for concentric ring loading

6.2.2 Loading and support rings

For test specimens the loading/support rings shall be made of steel.

The ratio of r_0 to r_2 shall be 0,25. The rings are sized to the thickness and diameter of the test specimens.

6.2.3 Compliant layer and friction elimination

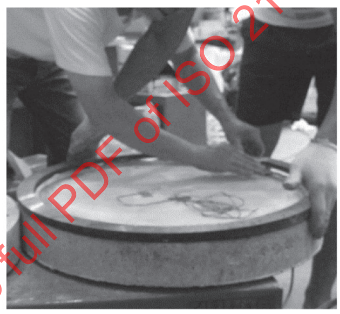
The brittle nature of FRCCs and the sensitivity to misalignment, contact stresses and friction may require a compliant interface between the loading/support rings and the test specimen, especially if the test specimen is not flat. Line or point contact stresses and frictional stresses can lead to crack initiation and fracture of the test specimen at stresses other than the actual equibiaxial flexural strength.

To minimize the effects of friction at the loading ring interface, place a sheet of carbon foil or polytetrafluoroethylene (PTFE) tape between the compressive surface of the test specimen and the loading ring. The thickness of the sheet shall be 0,3 mm ± 0,1 mm. Alternatively, an appropriate lubricant (anti-seizing com pound or TFE-fluorocarbon oil) may be used to minimize friction at the loading ring.

A rubber pad shall be positioned between the specimen and the support ring to distribute the load evenly. The intended load-bearing surface in contact with the support ring may be prepared by capping in accordance with ISO 1920-4 to improve the contact, as shown in Figure 4. The recommended thickness of the rubber pad is (10 ± 2) % of the specimen thickness. The hardness of the rubber pad shall be (65 ± 5) IRHD.

The boundary conditions of the specimens have a strong influence on the resulting fracture pattern. This results in either over or under estimation of energy absorption.

a) Capping and strain gages placed on the bottom of the test specimen



b) Positioning of the support ring

Figure 4 — Preparation of the specimen

6.3 Alignment

The loading ring and support ring shall be aligned concentrically to 0,2 % of the support ring diameter. The test specimen shall be concentric with the loading and support rings to 0,5 % of the support ring diameter.

6.4 Measuring device for loads

The load shall be measured using a load cell with an accuracy of 1 % of the estimated peak load or better. The load cell shall be fixed to the testing machine.

6.5 Measuring device for deflection

Devices such as electronic transducers or electronic deflection gages shall be located to ensure accurate determination of the net deflection at the centre exclusive of the effects of seating or twisting of the specimen on its supports. One acceptable arrangement employs a ring jig, which surrounds the specimen and is directly clamped at mid-depth of the specimen using four screws, and other ring frame suspended for the first ring frame, where an electronic displacement transducer is mounted (Figure 3). The average of the measurements represents net deflection.

The accuracy of electronic transducers shall be ±0,05 mm, where possible.

6.6 Data acquisition

As a minimum, an autographic record of applied load versus time shall be obtained. Either analog chart recorders or digital data acquisition systems can be used for this purpose although a digital record is recommended for ease of later data analysis. Ideally, an analog chart recorder or plotter should be used in conjunction with the digital data acquisition system to provide an immediate record of the test as a supplement to the digital record.

An X-Y plotter coupled directly to electronic outputs of load and deflection is an acceptable means of obtaining the relationship between load and net deflection — that is, the load-deflection curve. A data acquisition system capable of digitally recording and storing load and deflection data at a sampling frequency of at least 2,5 Hz is an acceptable alternative. After the net deflection corresponding to the peak load has been exceeded, it is permissible to decrease the data acquisition sampling and recording frequency to 1 Hz.

7 Test procedure

7.1 Preparation and positioning of specimens

The test specimen shall be placed centrally in the testing machine and loading and support rings. The test specimen shall be mounted in the test apparatus by placing the moulded face onto the support ring.

The specimen shall remain centred when the load is first applied, and no load shall be applied until loading ring and support ring are resting evenly against the test specimen.

7.2 Loading

The load shall be applied without shock and shall be increased continuously at a constant rate until peak load is reached. The testing machine shall be operated at a constant rate to the maximum load. The maximum load indicated shall be recorded.

Apply the load at a rate that increases the equibiaxial stress between 0,85 and 1,15 MPa/min. The loading rate is calculated with Formula (1):

$$R = \frac{S}{\psi} \tag{1}$$

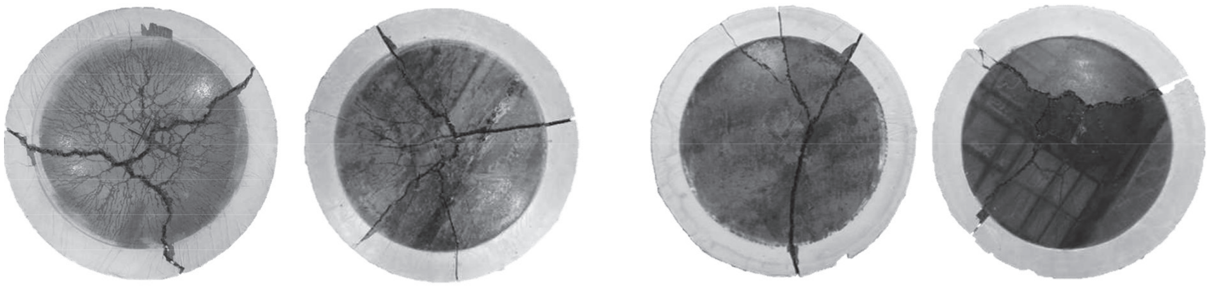
where

$$\psi = \frac{0{,}2387}{t^2}\left[2(1+\nu)\ln\frac{r_2}{r_0} + \frac{(1-\nu)\left(r_2{}^2 - r_0{}^2\right)}{r_1{}^2}\right]$$

7.3 Assessment of fracture patterns

The main position of the fracture origin in the specimens shall be determined (See Figure 5). Results shall be discarded if the fracture origin is outside the loading ring.

NOTE Fractures occurring near on the inside of the loading ring can be due to factors such as friction or contact stresses introduced by the load fixtures, the non-uniform fibre dispersion, or misalignment of the test specimen rings. Such fractures constitute invalid tests and generally lead to low energy absorption.



a) Fracture origin inside the loading ring — High energy **b) Fracture origin outside the loading ring — Low energy**

Figure 5 — Typical fracture patterns in specimens

8 Calculations

Load and net deflection are monitored and recorded at first cracking and peak loads. Data are recorded and plotted by means of an X-Y plotter or digitally and subsequently used to plot a load-deflection curve. Points termed first-cracking and peak loads are identified on the curve and are used to calculate flexural performance parameters.

a) Determine the first-cracking load as the value of load corresponding to the first point on the load-deflection curve where cracking initiates. Determine the corresponding deflection value.

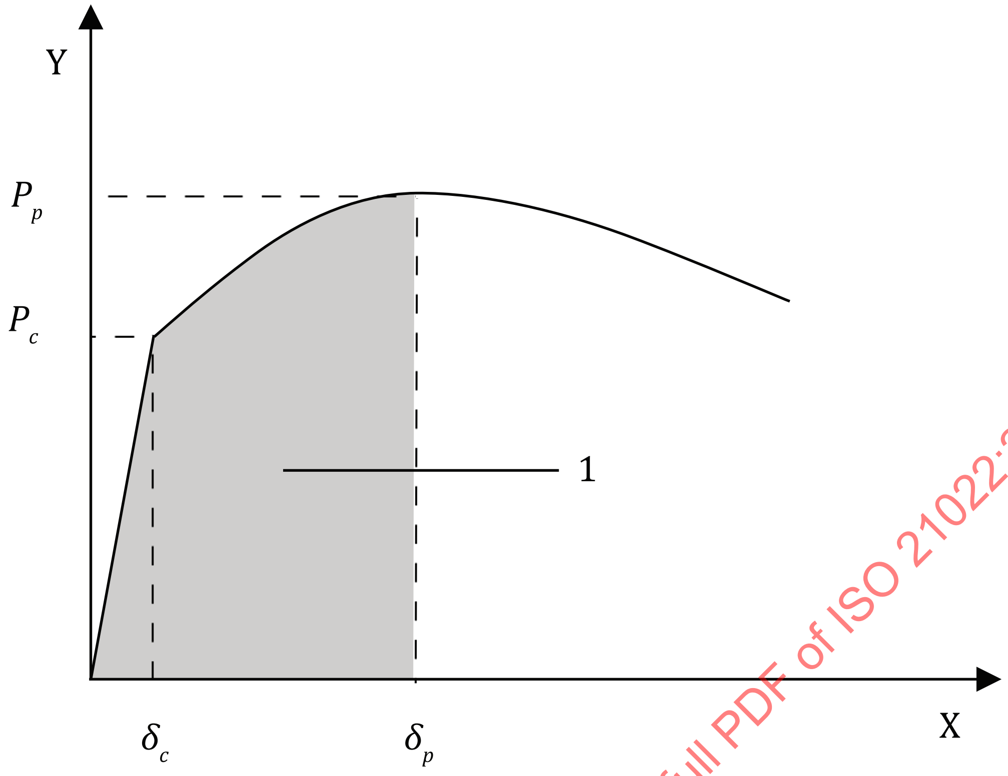
b) Calculate f_t using P_c, and ψ from Formula (1). The equibiaxial flexural stress value of a circular specimen caused by loading at the inner loading ring and outer support ring is calculated from Formula (2):

$$f_t = \psi P_c \quad (2)$$

c) Determine the peak load as the value of load corresponding to the point on the load-deflection curve with the greatest value of load obtained prior to reaching the end-point deflection. Determine the corresponding deflection value.

d) When P_p is greater than the P_c calculate the total area under the load-deflection curve up to net deflections corresponding to first-cracking and peak load (See Figure 6). Record the number rounded to the nearest joule as toughness.

e) When P_c is equal to P_p, calculate the total area under the load-defection curve up to net deflections corresponding to first-cracking or first-peak load (See Figure 7).



Key

1 total area under the load-deflection curve up to net deflections corresponding to first-cracking and peak loads
X net deflection
Y load

Figure 6 — Total area under the load-deflection curve ($P_p > P_c$)

