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Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) — Linear elastic fracture mechanics (LEFM) approach

Plastiques — Détermination de la ténacité à la rupture (G_{IC} et K_{IC}) — Application de la mécanique linéaire élastique de la rupture (LEFM)

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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical behaviour*.

This second edition cancels and replaces the first edition (ISO 13586:2000), which has been technically revised. It also incorporates the Amendment ISO 13586:2000/Amd.1:2003, with the introduction of a new Annex B.

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.

Introduction

This document is based on a testing protocol developed by the European Structural Integrity Society (ESIS), Technical Committee 4, *Polymers, Polymer Composites and Adhesives*, who carried out the preliminary enabling research through a series of round-robin exercises which covered a range of material samples, specimen geometries, test instruments and operational conditions. This activity involved nearly 10 laboratories from different countries. See References [1] and [3].

Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) — Linear elastic fracture mechanics (LEFM) approach

1 Scope

This document specifies the principles for determining the fracture toughness of plastics in the crack-opening mode (mode I) under defined conditions. Two test methods with cracked specimens are defined, namely three-point-bending tests and compact-specimen tensile tests in order to suit different types of equipment available or different types of material.

The methods are suitable for use with the following range of materials, including their compounds containing short fibres of the length ≤ 7,5 mm:

— rigid and semi-rigid thermoplastic moulding, extrusion and casting materials;

— rigid and semi-rigid thermosetting moulding and casting materials.

In general, short fibre lengths of 0,1 mm to 7,5 mm are known to cause heterogeneity and anisotropy in the crack tip fracture process zone. Therefore, where relevant, Annex B offers some guidelines to extend the application of the same testing procedure, with some reservations, to rigid and semi-rigid thermoplastic or thermosetting plastics containing such short fibres.

Certain restrictions on the linearity of the load-displacement diagram, on the specimen width and on the thickness are imposed to ensure validity (see 6.4) since the scheme used assumes linear elastic behaviour of the cracked material and a state of plane strain at the crack tip. Finally, the crack needs to be sharp enough so that an even sharper crack does not result in significantly lower values of the measured properties.

2 Normative references

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 527-1, *Plastics — Determination of tensile properties — Part 1: General principles*

ISO 604, *Plastics — Determination of compressive properties*

ISO 2818, *Plastics — Preparation of test specimens by machining*

ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

ISO 9513, *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

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
energy release rate
G
change in the external work δU_{ext} and strain energy δU_s of a deformed body due to enlargement of the cracked area δA

$$G = \frac{\delta U_{ext}}{\delta A} - \frac{\delta U_s}{\delta A}$$

Note 1 to entry: It is expressed in joules per square metre, J/m^2.

3.2
critical energy release rate
G_{IC}
value of the *energy release rate* (3.1) in a precracked specimen under plane-strain loading conditions, when the crack starts to grow

Note 1 to entry: It is expressed in joules per square metre, J/m^2.

3.3
stress intensity factor
K
limiting value of the product of the stress $\sigma(r)$ perpendicular to the crack area at a distance r from the crack tip and of the square root of $2\pi r$, for small values of r

$$K = \lim_{r \to 0} \sigma(r) \times \sqrt{2\pi r}$$

Note 1 to entry: It is expressed in Pa × √m.

Note 2 to entry: The term factor is used here because it is common usage, even though the value has dimensions.

3.4
critical stress intensity factor
K_{IC}
value of the *stress intensity factor* (3.3) when the crack under load actually starts to enlarge under a plane-strain loading condition around the crack tip

Note 1 to entry: It is expressed in Pa × √m.

Note 2 to entry: The critical stress intensity factor K_{IC} of a material is related to its critical energy release rate G_{IC} by the formula:

$$G_{IC} = K_{IC}^2 / E$$

where E is the modulus of elasticity, determined under similar conditions of loading time (up to crack initiation) and temperature.

In the case of plane-strain conditions:

$$E = \frac{E_t}{1 - \mu^2}$$

where

E_t is the tensile modulus (see ISO 527-1);

μ is Poisson's ratio (see ISO 527-1).

3.5
displacement
displacement of the loading device

Note 1 to entry: It is expressed in metres, m.

Note 2 to entry: In the fracture test, the displacement of the loading device is designated as s_a. The displacement of the loading device corrected as specified in 5.4, is designated as s.

Note 3 to entry: In the indentation test, the displacement of the loading device is designated as s_{ai}.

3.6
stiffness
S
initial slope of the force-displacement diagram

$$S = \left(\frac{\mathrm{d}F}{\mathrm{d}s}\right)_{s \to 0}$$

Note 1 to entry: It is expressed in newtons per metre, N/m.

3.7
force
F_Q
applied load at the initiation of crack growth

Note 1 to entry: It is expressed in newtons, N.

Note 2 to entry: See also 6.1.

3.8
energy
W_B
input energy when crack growth initiates

Note 1 to entry: It is expressed in joules, J.

Note 2 to entry: W_B is based upon the corrected load-displacement curve.

3.9
crack length
a
crack length up to the tip of the initial crack

Note 1 to entry: It is expressed in metres, m.

Note 2 to entry: The initial crack is prepared as specified in 4.3.

Note 3 to entry: For three-point-bending test specimens, the crack length is measured from the notched face. For compact tensile-test specimens, the crack length is measured from the load line, i.e. from the line through the centres of the holes for the loading pins (see Figures 1 and 2).

Note 4 to entry: The crack length a is normalized by the width w of the test specimen ($\alpha = a/w$).

3.10
energy calibration factor
ϕ
factor to account for the crack length dependent stiffness of the test specimen, given by the formula:

$$\phi(a/w) = -S\left(\frac{\mathrm{d}S}{\mathrm{d}\alpha}\right)^{-1}$$

where

S	is the stiffness of the specimen;
α (= a/w)	is the normalized crack length (see 3.9).

Note 1 to entry: Values of ϕ (a/w) are given in Annex A for both types of specimen.

3.11
geometry calibration factor
f
factor to account for the configuration and the dimensions of the test specimen

Note 1 to entry: Values of f (a/w) are given in Annex A for both types of specimen.

3.12
characteristic length
$\bar{r}$
size of the plastic deformation zone around the crack tip

Note 1 to entry: It is required for checking fulfilment of the size criteria (see 6.4).

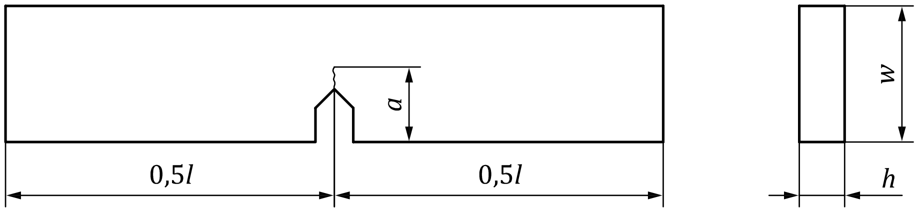
4 Test specimens

4.1 Shape and size

Test specimens for three-point-bending tests [also called single-edge-notch bending (SENB)] and for compact tensile (CT) tests shall be prepared in accordance with Figure 1 and Figure 2, respectively. It is usually convenient to make the thickness h of the test specimens equal to the thickness of a sheet sample and to make the test specimen width w equal to $2h$. The crack length a should preferably be in the range given by $0{,}45 \leq a/w \leq 0{,}55$.

4.2 Preparation

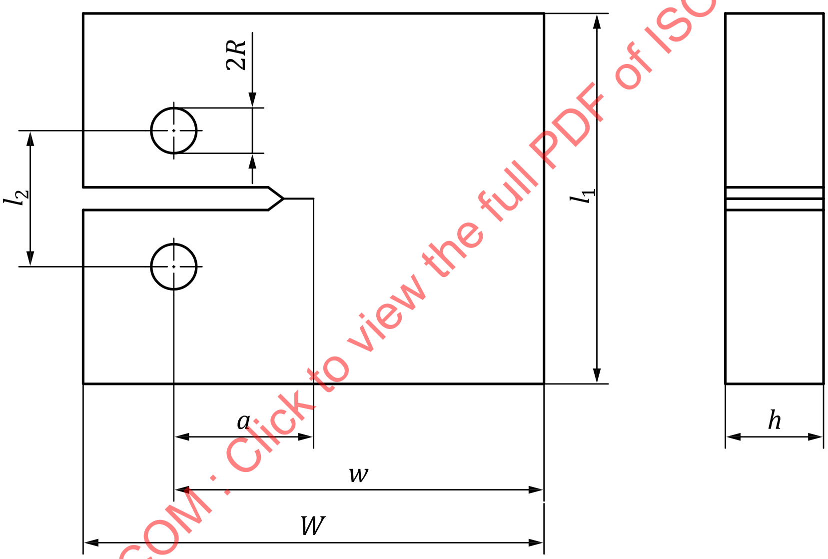
Test specimens shall be prepared in accordance with the relevant material International Standard for the material under test and in accordance with ISO 2818. In the case of anisotropic specimens, take care to indicate the reference direction on each test specimen.



Key

w	width	
l	overall length	$l > 4{,}2w$
h	thickness	$w/4 < h < w/2$
a	crack length	$0{,}45w \le a \le 0{,}55w$

Figure 1 — Three-point-bending (SENB) test specimen



Key

w	width	
W	overall width	$W = 1{,}25w \pm 0{,}01w$
l_1	length	$l_1 = 1{,}2w \pm 0{,}01w$
l_2	distance between centres of two holes located symmetrically to the crack plane	$l_2 = 0{,}55w \pm 0{,}005w$
R	radius	$R = 0{,}125w \pm 0{,}005w$
h	thickness	$0{,}4w < h < 0{,}6w$
a	crack length	$0{,}45w \le a \le 0{,}55w$

(The loading pins and holes shall be smooth and a loose fit to minimize friction.)

Figure 2 — Compact tensile (CT) test specimen

4.3 Notching

Method a), b) or c) can be used for notching.

a) Machine a sharp notch into the test specimen and then generate a natural crack by tapping on a new razor blade placed in the notch (it is essential to practice this since, in brittle test specimens, a natural crack can be generated by this process, but some skill is required in avoiding too long a crack or local damage). The length of the crack thus created shall be more than four times the original notch tip radius.

b) If a natural crack cannot be generated, as in tough test specimens, then sharpen the notch by sliding a razor blade across the notch. Use a new razor blade for each test specimen. The length of the crack thus created shall be more than four times the original notch tip radius.

c) Cooling tough test specimens and then performing razor tapping is sometimes successful.

Pressing the blade into the notch is not recommended because of induced residual stresses.

4.4 Conditioning

Condition test specimens as specified in the International Standard for the material under test, unless otherwise agreed upon by the interested parties. In the absence of this information, the preferred atmosphere is (23 ± 2) °C and (50 ± 10) % relative humidity, except when the properties of the material are known to be insensitive to moisture, in which case humidity control is unnecessary.

5 Testing

5.1 Testing machine

The machine shall comply with ISO 7500-1 and ISO 9513, and meet the specifications given in 5.2 to 5.4.

5.2 Load indicator

The load measurement system shall comply with class 1 as defined in ISO 7500-1. The load indicator shall show the total load carried by the test specimen. This device shall be essentially free from inertia lag at the test speeds used. It shall indicate the load with an accuracy of at least 1 % of the actual value.

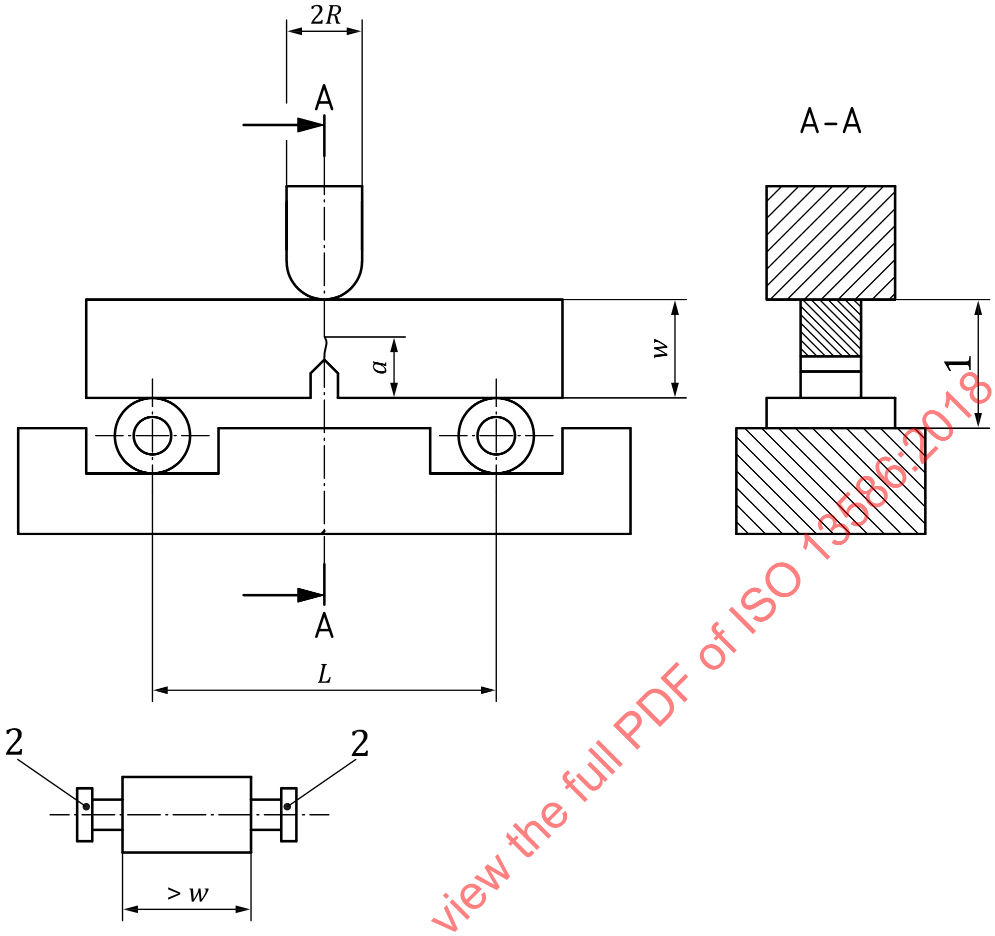
5.3 Displacement transducer

The displacement is recorded during the test. The continuously measuring displacement transducer shall be essentially free from inertia lag at the test speeds used. It shall be able to measure the relevant displacement within class 1 of ISO 9513 or better. The effects of the displacement transducer on the load measurement shall be < 1 % of the load reading or they shall be corrected.

5.4 Loading rigs

A rig with moving rollers is used for three-point-bending (SENB) tests, as shown in Figure 3. Indentation into the test specimen is minimized by the use of rollers with a large diameter (>w/2). The measurement of the displacement shall be taken at the centre of the span L (see Figure 3).

For the compact tensile test, the test specimen is loaded by means of two pins in holes in the specimen. The displacement of the load points during the test is measured, for example by a clip gauge near the pins (see 5.3).



Key

L	span between rollers	$L = 4w \pm 0{,}1w$	1	distance monitored by displacement transducer
R	radius	$w/8 < R < w/2$	2	bosses for rubber bands
h	thickness			

Figure 3 — Rig with two rollers and displacement transducer for three-point-bending (SENB) tests

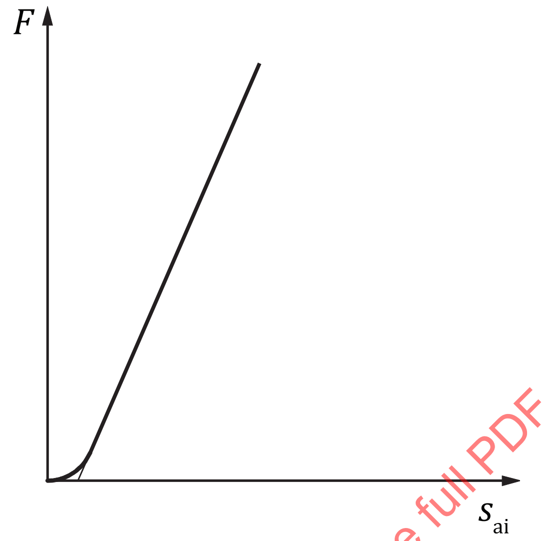
5.5 Displacement correction

The measured displacement s_a shall be corrected for the indentation of the loading pins, compression of the test specimen and the machine compliance in order to determine properly the stiffness S of the specimen and the work W_B at crack growth initiation. The calibration of the test system shall be performed as follows.

The load-displacement correction curve (see Figure 4) is generated by analogy with the fracture test but by using unnotched test specimens, as indicated in Figure 5 and Figure 6. The rollers of the three-point-bending rig are moved together to reduce even further the small flexing of the unnotched test specimen under load. The displacement correction shall be performed for each material and at each different temperature and test speed since polymers are generally sensitive to temperature and test speed. The degree of loading-pin penetration and specimen compression can vary with changes in these variables. The indentation tests shall be performed such that the loading times are the same as in the fracture tests. This will involve lower test speeds to reach the same load in the same time, for example about half the speed.

In practice, a linear correction curve is usually obtained up to loads even exceeding the fracture load of cracked test specimens (see Figure 4). Any initial nonlinearity due to penetration of the loading pins into the specimen is observed during both the calibration test and the actual fracture test. Therefore, the initial nonlinearity is effectively corrected for by the following proposed method.

At corresponding load, the displacement s_j taken from the correction curve is subtracted from the displacement s_a in the actual fracture test with a notched test specimen. In this way, the corrected load-displacement curve is constructed. The stiffness S and the energy W_B at crack growth initiation are derived from this curve (see Figure 7). The corrections s_j of the displacements usually amount to less than 20 % of the measured displacement s_a.



Key

s_{ai} indentation displacement

F load

Figure 4 — Load-indentation curve determined on an unnotched test specimen

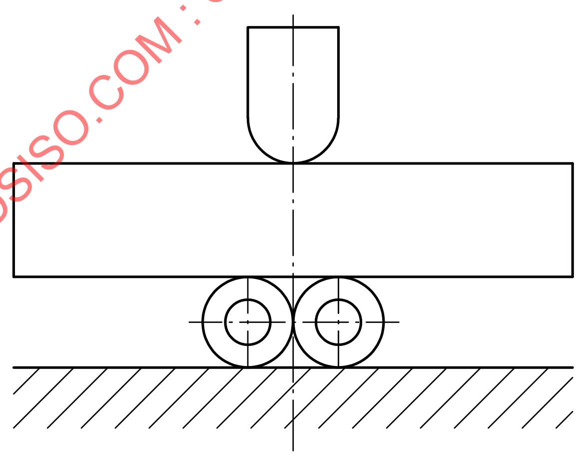


Figure 5 — Arrangement for determining the indentation displacement of a bending-test specimen

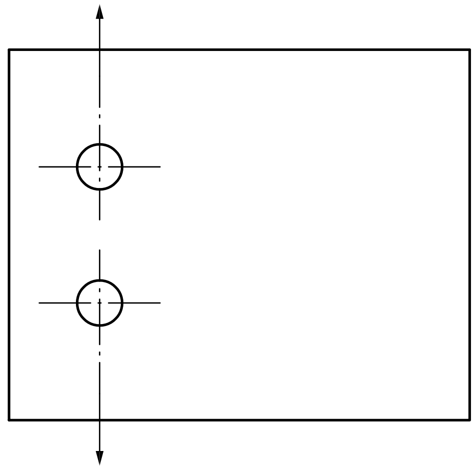
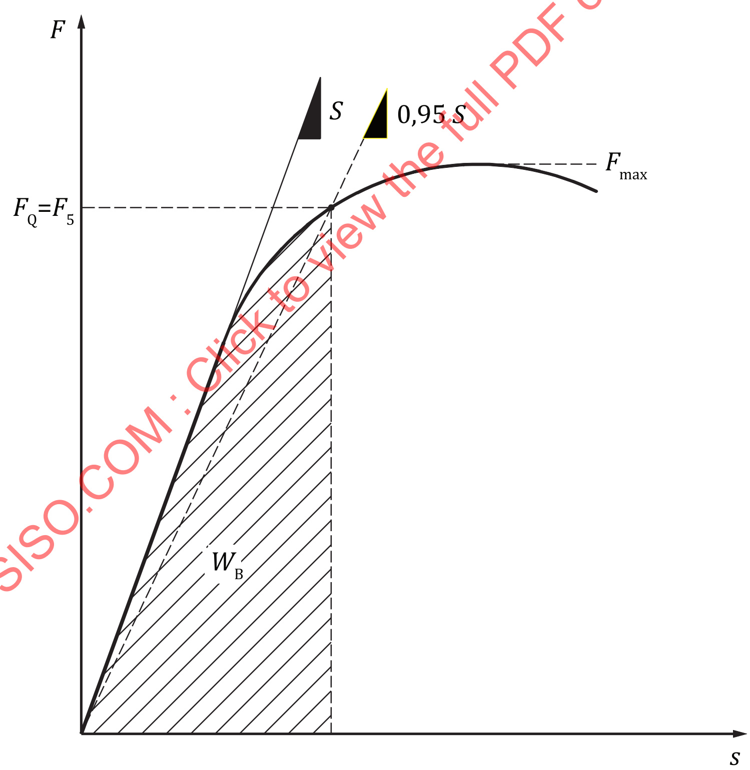


Figure 6 — Arrangement for determining the indentation displacement of a compact tensile specimen



Key

s displacement

F load

S stiffness

F_Q is the load at crack growth initiation

W_B is the energy to break

Figure 7 — Load-displacement curve for a notched test specimen (the displacement has been corrected for indentation effects)

5.6 Test atmosphere

Conduct the test in the same atmosphere as used for conditioning, unless otherwise agreed upon by the interested parties, for example for testing at elevated or low temperatures.

5.7 Thickness, width and crack length of test specimens

Measure the thickness h and width w of each test specimen to the nearest 0,02 mm. Record an approximate reading of the crack length a which will be corrected on completion of the test. Usually crack tip lines are visible on the two fracture surfaces. Calculate the mean value of five readings of the crack length taken along the original crack front. These shall be taken at the edges, the centre and half way between. The crack length shall differ by no more than 10 % over the entire crack front. If differences larger than 10 % are found, reject the test. Care shall be taken that it is the original crack tip which is being observed since slow growth can occur.

5.8 Test conditions

It is recommended that (23 ± 2) °C and a test speed of (10 ± 20 %) mm/min be used as the basic test conditions. In all cases, the loading time and the test temperature shall be measured. Speeds greater than 0,1 m/s and loading times less than 10 ms should preferably be avoided since dynamic effects may cause errors.

Carry out at least three tests for each set of conditions. If it is not possible to obtain valid results at 23 °C (see 6.4), it is often possible to do so by decreasing the temperature. Usually, a reduction in the test temperature does not change K_{IC} greatly but increases the yield stress of the polymer, rendering the fractures more brittle. If this procedure is used, both temperature and loading time shall be stated in the test report.

6 Expression of results

6.1 Determination of F_Q

In an ideal material, the load-displacement curve is a linear one with an abrupt drop in the load at the instant of crack growth initiation. In such rather rare cases, F_Q can be identified with the maximum load.

In most cases, there is some nonlinearity in the curve and this can be due to plastic deformation at the crack tip, nonlinear elasticity, general visco-elasticity or stable crack growth after initiation but prior to instability. The first three effects violate the linear elastic fracture mechanics (LEFM) assumption and the fourth one means that the true initiation load is not defined by the maximum. In order to circumvent a doubtful definition of initiation, an arbitrary rule is used here. The zero-point tangent is drawn to the curve in Figure 7 to determine the initial stiffness S. This stiffness is reduced by 5 % and a further line is drawn accordingly. If the maximum of the load-displacement curve falls within these two lines, then F_{max} shall be called F_Q (the load at crack growth initiation). If the second line intersects the load curve at F_5 prior to the maximum, then F_5 shall be called F_Q. Referring to Figure 7, the conditions of LEFM are assumed to be met if:

$$\frac{F_{max}}{F_5} < 1,1$$

If this condition of 10 % nonlinearity is violated, the test shall be rejected.

6.2 Provisional result G_Q

Calculate the critical energy release rate from the energy W_B up to the instant of crack growth initiation, where the load is F_Q and the original crack length is a:

$$G_Q = \frac{W_B}{h \times w \times \phi(a/w)} \tag{1}$$

where

W_B is the energy to break;

h is the test specimen thickness;

w is the test specimen width;

$\phi(a/w)$ is the energy calibration factor, depending on the crack length a.

Calculate ϕ as shown in Annex A. Tables with values of $\phi(a/w)$ for both types of test specimen are also given in Annex A.

6.3 Provisional result K_Q

Calculate the critical stress intensity factor K_Q from the load F_Q at crack growth initiation and the original crack length a:

$$K_Q = f(a/w)\frac{F_Q}{h\sqrt{w}} \tag{2}$$

where

F_Q is the load at crack growth initiation;

h is the test specimen thickness;

w is the test specimen width;

$f(a/w)$ is the geometry calibration factor, depending on the crack length a.

Calculate f as shown in Annex A. Tables with values of $f(a/w)$ for both types of test specimen are also given in Annex A.

6.4 Size criteria and validation of results

The test is valid only if the dimensions of the test specimen are significantly larger than the plastic zone around the crack tip, characterized by the length $\bar{r}$. Appropriate test specimens for plane-strain fracture tests shall meet the following size criteria:

— thickness h $> 2{,}5 \times \bar{r}$

— crack length a $> 2{,}5 \times \bar{r}$

— ligament width $(w - a)$ $> 2{,}5 \times \bar{r}$

With the specimen dimensions proposed in this document, all the criteria are usually satisfied simultaneously. The criteria cover two limitations in that h must be sufficient to ensure plane strain but $(w - a)$ has to be sufficient to avoid excessive plasticity in the ligament. If $(w - a)$ is too small, the test will usually violate the linearity criterion, but will not necessarily do so. If the linearity criterion is violated, a possible option is to increase w for the same h. Values of w/h of up to 4 are permitted.

Calculate the characteristic length $\bar{r}$ from either of the two provisional results G_Q or K_Q:

$$\bar{r} = \frac{2f^2\phi S G_Q}{h\sigma_y^2} \tag{3}$$

or

$$\bar{r} = \frac{K_Q^2}{\sigma_y^2} \tag{4}$$

where

- h is the test specimen thickness;
- f is the geometry calibration factor;
- ϕ is the energy calibration factor;
- S is the test specimen stiffness, derived from the corrected curve (see 5.5);
- σ_y is the uniaxial tensile yield stress (determined in accordance with ISO 527-1) or, alternatively, 0,7 times the compressive yield stress (determined in accordance with ISO 604).

If the criteria are met, the results of the test are valid, and thus

$G_Q = G_{IC}$ and $K_Q = K_{IC}$

6.5 Cross-check of results

A cross-check on the accuracy of the results can be made since the modulus of elasticity E is related to the stiffness S and to the mechanical fracture properties G_{IC} and K_{IC} as follows:

$$E_{stiff} = \frac{2f^2\phi S}{h} \tag{5}$$

$$E_{fract} = \frac{K_{IC}^2}{G_{IC}} \tag{6}$$

where

- E is the modulus of elasticity (see 3.4);
- f is the geometry calibration factor (see Annex A);
- ϕ is the energy calibration factor (see Annex A);
- h is the test specimen thickness;
- S is the test specimen stiffness;
- K_{IC} is the critical stress intensity factor;
- G_{IC} is the critical energy release rate.

Usually, E_{stiff} is slightly larger than E_{fract}. If the difference exceeds 15 %, the results obtained for G_{IC} and K_{IC} shall be examined for possible errors.

7 Precision

Table 1 gives a set of data obtained by nine groups on a nylon. Most of the data was obtained in SENB testing, and two forms of notching were used: razor sliding and razor tapping. The means of five tests are given together with the standard deviations. The average standard deviations are 5 % for K_{IC} and 12 % for G_{IC}.

Table 1 — K_{IC} and G_{IC} measurements on a nylon

Group No.	Specimen type	Notching	K_{IC} (mean) MPa × √m	G_{IC} (mean) kJ/m²	E_{stiff} GPa	E_{fract} GPa
1	SENB	RS RT	4,14 ± 0,17 4,03 ± 0,10	4,76 ± 0,98 3,92 ± 0,15	3,65 4,14	3,65 4,14
2	SENB	RT	3,79 ± 0,08	4,01 ± 0,17	2,24[a]	3,58
3	SENB	RS RT	3,84 ± 0,17 4,21 ± 0,26	4,48 ± 0,70 4,82 ± 0,73	3,32 3,64	3,33 3,71
4	SENB	RT	4,10 ± 0,35	5,14 ± 0,67	3,30	3,28
5	SENB	RS	3,82 ± 0,21	4,20 ± 0,41	3,63	3,32
6	CT	RT	4,46 ± 0,13	5,82 ± 0,24	3,57	3,42
7	SENB	RT	3,99 ± 0,10	4,80 ± 0,46	—	3,32
8	SENB	RT	3,9 ± 0,3	4,7 ± 0,8	3,22	3,21
9	SENB	RT	4,10 ± 0,22	6,40 ± 0,8[b]	—	2,63[b]
		Mean	4,03 ± 0,19	4,82 ± 0,56		

[a] Error suspected.

[b] Without indentation correction.

RS Razor sliding.

RT Razor tapping.

8 Test report

The test report shall contain the following:

a) a reference to this document i.e. ISO 13586;

b) all details necessary for complete identification of the material tested, including source and history;

c) the test specimen shape (SENB or CT) and dimensions;

d) the notching method used;

e) the test temperature and speed;

f) one example of a load-displacement curve;

g) the number of specimens tested;

h) the ratio F_{max}/F_5, if relevant (see 6.1), and the loading time;

i) the yield stress determination procedure used and the loading time;

j) the results of the size criteria assessment;

k) the critical energy release rate G_{IC} and critical stress intensity factor K_{IC};

l) the values of E_{stiff} and E_{fract};

m) any deviations from the requirements of this document;

n) the date of testing.

Annex A
(normative)

Calibration factors

Table A.1 — Calibration factors f and ϕ for single-edge-notch bending (SENB) test specimens: L/w = 4 (values calculated using Reference [6])

α	f	ϕ
0,05	2,50	1,502
0,10	3,39	0,857
0,15	4,07	0,641
0,20	4,70	0,526
0,25	5,36	0,449
0,30	6,09	0,391
0,35	6,93	0,345
0,40	7,93	0,307
0,45	9,14	0,275
0,50	10,65	0,246
0,55	12,57	0,220
0,60	15,09	0,195
0,65	18,51	0,170
0,70	23,40	0,145
0,75	30,84	0,120
0,80	43,21	0,096
0,85	66,76	0,072
0,90	123,30	0,049
0,95	351,62	0,025
L is the span $\alpha = a/w$ where a is the crack length; w is the width. Interpolation is recommended.		

Formulae used for the calculation (SENB): $0 < \alpha < 1$:

$$f = 6\alpha^{1/2} \frac{1{,}99 - \alpha(1-\alpha)\left(2{,}15 - 3{,}93\alpha + 2{,}7\alpha^2\right)}{(1+2\alpha)(1-\alpha)^{3/2}}$$

$$\phi = \frac{A + 18{,}64}{\mathrm{d}A/\mathrm{d}\alpha}$$

$$A = \frac{16\alpha^2}{(1-\alpha)^2}\left(8{,}9 - 33{,}717\alpha + 79{,}616\alpha^2 - 112{,}952\alpha^3 + 84{,}815\alpha^4 - 25{,}672\alpha^5\right)$$

$$\frac{dA}{d\alpha}=\frac{16\alpha^2}{(1-\alpha)^2}\left(-33{,}717+159{,}232\alpha-338{,}856\alpha^2+339{,}26\alpha^3-128{,}36\alpha^4\right)+$$

$$\frac{32\alpha}{(1-\alpha)^3}\left(8{,}9-33{,}717\alpha+79{,}616\alpha^2-112{,}952\alpha^3+84{,}815\alpha^4-25{,}672\alpha^5\right)$$

Table A.2 — Calibration factors f and ϕ for compact tensile (CT) test specimens (values calculated using Reference [7])

α	f	ϕ
0,25	4,92	0,199
0,30	5,62	0,208
0,35	6,39	0,213
0,40	7,28	0,213
0,45	8,34	0,208
0,50	9,66	0,199
0,55	11,36	0,186
0,60	13,65	0,170
0,65	16,86	0,152
0,70	21,55	0,133
0,75	28,86	0,112
$\alpha = a/w$ where a is the crack length; w is the width. Interpolation is recommended.		

Formulae used for the calculation (CT): $0{,}2 < \alpha < 0{,}8$:

$$f=\frac{(2+\alpha)}{(1-\alpha)^{3/2}}\left(0{,}886+4{,}64\alpha-13{,}32\alpha^2+14{,}72\alpha^3-5{,}6\alpha^4\right)$$

$$\phi=\frac{A(1-\alpha)}{B+2A}$$

$$A=\left(1{,}911\,8+19{,}118\alpha-2{,}512\,2\alpha^2-23{,}226\alpha^3+20{,}54\alpha^4\right)$$

$$B=\left(19{,}118-5{,}024\,4\alpha-69{,}678\alpha^2+82{,}16\alpha^3\right)(1-\alpha)$$

Annex B
(informative)

Testing of plastics containing short fibres

B.1 General

This document is suitable for plastics that are substantially homogeneous and isotropic at the scale of the fracture process (characterized by the length $\bar{r}$, representing the size of the plastic deformation zone that normally develops ahead of the crack tip prior to fracture, as defined in 3.12). Plastics containing short fibres, i.e. fibres having lengths in the range of about 0,1 mm to 7,5 mm (currently identified as ‘short fibre-polymer composites’), do not generally meet these two conditions: they can be borderline in respect of the homogeneity requirement [condition a)], as the fracture process zone has dimensions comparable to the length of the fibres, and are generally not isotropic [condition b)] at a scale even larger than the scale of the fracture process zone. Nevertheless, while the theoretical background that underpins this document does not rigorously apply to this class of materials, data obtained by tests performed according to the same may be useful under some limiting conditions.

The conditions to be met for tests on materials of this class to yield data useful for characterizing their behaviour are the following.

a) Fibre dispersion to be substantially uniform, i.e. local fibre concentration to be substantially constant throughout the sample (quasi-homogeneity). Should the material under test contain fibres or fillers of different kinds (‘hybrid’ fibre composites), this requirement is intended to be met by each of the individual components.

b) Fibre orientation to be essentially “in-plane” and substantially uniform throughout each layer of the planar test piece (see Note 1) even though orientation varies from layer to layer through the thickness of the plate.

c) Fibre orientation distribution through the thickness of the plate, characterizing the layered microstructure of the material, to be substantially symmetrical with respect to the mid-plane of the planar test piece.

These conditions are generally met in ordinary short fibre-polymer composites that are produced by compounding polymer matrix and fibres and subsequently formed into the final product by ordinary forming processes such as injection moulding, extrusion and lamination. However, both processes, compounding and forming, can affect the internal microstructure of the material, in particular as to fibre length and orientation, which significantly influence the mechanical properties of these materials (see Note 2). The property determined by the test is therefore intended to be referred to the specific microstructure of the material in the sample being tested.

NOTE 1 Consideration is limited here to material samples in the form of substantially plane plates with in-plane dimensions greatly larger than the plate thickness.

NOTE 2 For this, the range of fibre length relevant to this testing, i.e. 0,1 mm to 7,5 mm, refers to the material sample under test, that is after processing.

B.2 Test specimens

B.2.1 Shape and size

Both test configurations recommended by this document, namely single-edge notched bending (SENB), also called three-point-bending (TPB), and compact-tension (CT) can be used, with test specimen shape and size conforming to the general specifications given in Clause 4.

However, with structured and anisotropic materials of the kind considered in this annex it is necessary to specify the position of the initial crack (i.e. location of the crack plane and crack front line and direction of crack growth) in relation to the inner structure of the material in the particular configuration chosen for the test.

Furthermore, due to the local heterogeneity and anisotropy of the material, it may occur that the crack front advances unevenly and the fracture plane deviates from the initial crack plane, in an unpredictable way. Therefore, toughness shall be determined at fracture initiation only and shall be referred to the initial position of the crack (crack plane and crack front line) before any crack growth has occurred.

B.2.2 Configuration

With plane plates produced by conventional plastics forming technologies (e.g. injection moulding, extrusion, lamination) three main, mutually perpendicular, directions can be envisaged as relevant:

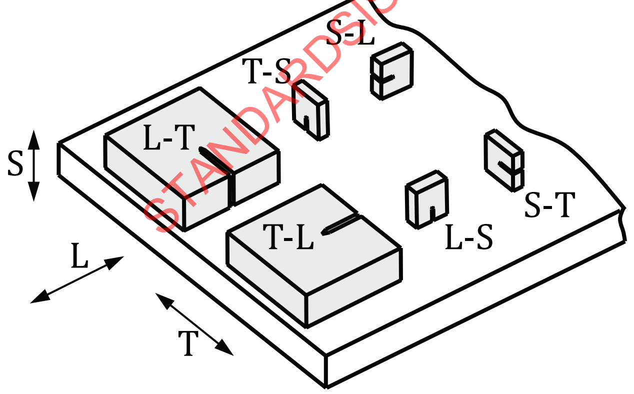
— L Longitudinal, i.e. the forming machine direction or mould filling direction.

— T Transverse, i.e. the forming machine width or mould width direction.

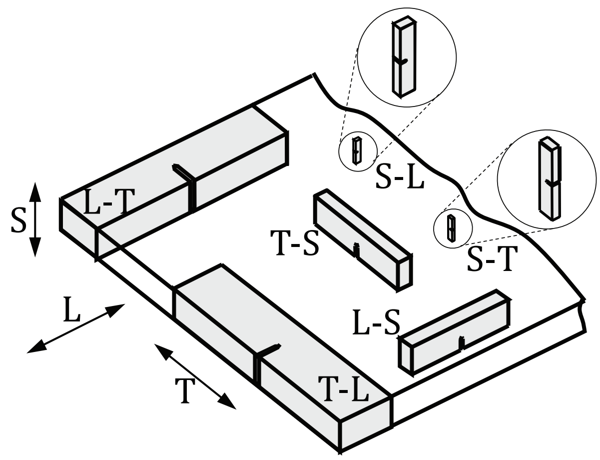
— S Short transverse, i.e. the through-thickness direction.

Six main specimen configurations can thus be identified, designated L-T, T-L, L-S, S-L, T-S and S-T (see Figure B.1), whereby the first letter designates the direction normal to the crack plane and the second letter designates the expected direction of crack propagation. In practice, it is usually convenient to cut the specimens with a thickness equal to the thickness of the plate produced, so only the L-T and T-L specimens are normally examined.

NOTE This will provide limited assessment of toughness dependence on orientation.



a) CT specimen



b) SENB specimen

NOTE The meaning of the letters is provided in B.2.2.

Figure B.1 — Specimen configurations in respect of the plate directions

