INTERNATIONAL STANDARD

ISO 13586

Second edition
2018-08

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)

Reference number
ISO 13586:2018(E)

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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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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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).

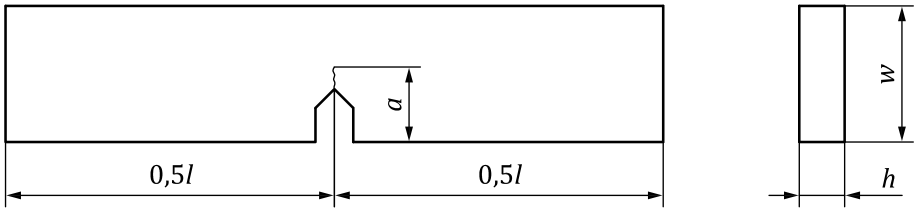
4 Test specimens

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

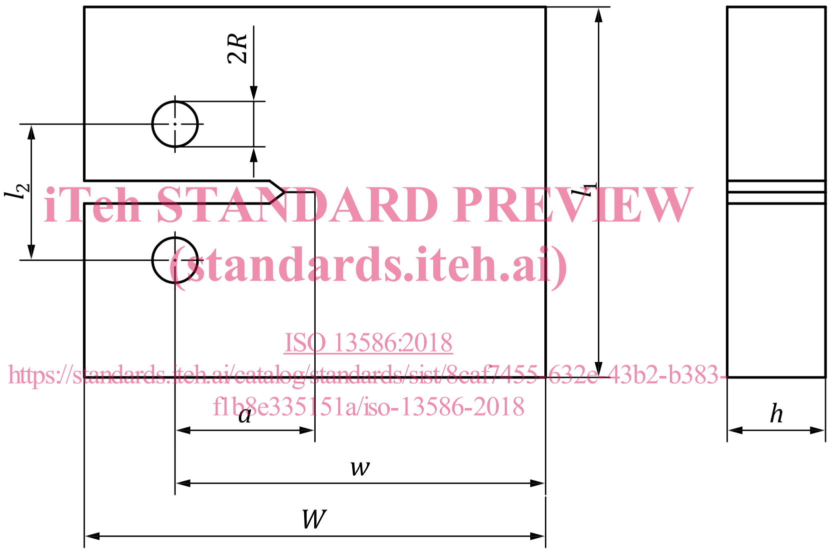
Test specimens shall be prepared in accordance with the relevant material International Standard for the material under test and in accordance with ISO 2818. In the case of anisotropic specimens, take care to indicate the reference direction on each test specimen.



Key

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

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	$0{,}45w \leq a \leq 0{,}55w$

(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).

