# INTERNATIONAL STANDARD

# ISO 13586

First edition
2000-03-01

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

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

Reference number
ISO 13586:2000(E)

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# Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 13586 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Annex A forms a normative part of this of ISO 13586.

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

## 1 Scope

This International Standard 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:

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

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

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 must be sharp enough so that an even sharper crack will not result in significantly lower values of the measured properties.

## 2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 291:1997, *Plastics — Standard atmospheres for conditioning and testing*.

ISO 527-1:1993, *Plastics — Determination of tensile properties — Part 1: General principles*.

ISO 604:1993, *Plastics — Determination of compressive properties*.

ISO 2818:1994, *Plastics — Preparation of test specimens by machining*.

ISO 5893:1993, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Description*.

 

## 3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply:

**3.1**
**energy release rate**
$G$
the change in the external work $\delta U_{\text{ext}}$ and strain energy $\delta U_{\text{S}}$ of a deformed body due to enlargement of the cracked area $\delta A$

$$G = \frac{\delta U_{\text{ext}}}{\delta A} - \frac{\delta U_{\text{S}}}{\delta A} \qquad (1)$$

It is expressed in joules per square metre, J/m$^2$.

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

It is expressed in joules per square metre, J/m$^2$.

**3.3**
**stress intensity factor**
$K$
the 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 $r$

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

It is expressed in Pa·√m.

The term factor is used here because it is common usage, even though the value has dimensions.

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

It is expressed in Pa·√m.

The critical stress intensity factor $K_{\text{IC}}$ of a material is related to its critical energy release rate $G_{\text{IC}}$ by the equation

$$G_{\text{IC}} = K_{\text{IC}}^2 / E \qquad (3)$$

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:

$$E = \frac{E_{\text{t}}}{1 - \mu^2} \qquad (4)$$

 

where

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

$\mu$ is Poisson's ratio (see ISO 527-1-).

**3.5**
**displacement**
$s_a$
the displacement of the loading device, corrected as specified in 5.4

It is expressed in metres, m.

**3.6**
**stiffness**
$S$
the initial slope of the force-displacement diagram

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

It is expressed in newtons per metre, N/m.

**3.7**
**force**
$F_Q$
the applied load at the initiation of crack growth

It is expressed in newtons, N.

See also subclause 6.1.

**3.8**
**energy**
$W_B$
the input energy when crack growth initiates

It is expressed in joules, J.

$W_B$ is based upon the corrected load-displacement curve.

**3.9**
**crack length**
$a$
the crack length up to the tip of the initial crack prepared as specified in 4.3.

It is expressed in metres, m.

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 centres of the holes for the loading pins (see Figures 1 and 3).

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

 

**3.10**
**energy calibration factor**
$\phi$

$$\phi(a/w) = -S\left(\frac{\mathrm{d}S}{\mathrm{d}\alpha}\right)^{-1} \tag{5}$$

where

$S$ is the stiffness of the specimen;

$\alpha\,(= a/w)$ is the normalized crack length (see 3.9).

Values of $\phi\,(a/w)$ are given in annex A for both types of specimen.

**3.11**
**geometry calibration factor**
$f$

Values of $f\,(a/w)$ are given in annex A for both types of specimen.

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

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 Figures 1 and 3, 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 $0{,}45 \leqslant a/w \leqslant 0{,}55$.

### 4.2 Preparation

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

 