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Plastics — Determination of tension-tension fatigue crack propagation — Linear elastic fracture mechanics (LEFM) approach

Plastiques — Détermination de la propagation de fissure par fatigue en traction — Approche de la mécanique linéaire élastique de la rupture (LEFM)

Reference number
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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.

The main task of technical committees is to prepare International Standards. 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.

ISO 15850 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Plastics — Determination of tension-tension fatigue crack propagation — Linear elastic fracture mechanics (LEFM) approach

1 Scope

This International Standard specifies a method for measuring the propagation of a crack in a notched specimen subjected to a cyclic tensile load varying between a constant positive minimum and a constant positive maximum value. The test results include the crack length as a function of the number of load cycles and the crack length increase rate as a function of the stress intensity factor and energy release rate at the crack tip. The possible occurrence of discontinuities in crack propagation is detected and reported.

The method is suitable for use with the following range of materials:

— rigid and semi-rigid thermoplastic moulding and extrusion materials (including filled and short-fibre-reinforced compounds) plus rigid and semi-rigid thermoplastic sheets;

— rigid and semi-rigid thermosetting materials (including filled and short-fibre-reinforced compounds) plus rigid and semi-rigid thermosetting sheets.

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, *Plastics — Standard atmospheres for conditioning and testing*

ISO 527 (all parts), *Plastics — Determination of tensile properties*

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

ISO 13586, *Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) — Linear elastic fracture mechanics (LEFM) approach*

3 Terms and definitions

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

3.1
cycle
smallest segment of a load-time or stress-time function which is repeated periodically

NOTE The terms fatigue cycle, load cycle and stress cycle are also commonly used.

3.2
number of cycles completed
N
number of load cycles since the beginning of a test

3.3
waveform
shape of the load-time curve within a single cycle

3.4
maximum load
P_{max}
highest value of the load during a cycle

NOTE 1 It is expressed in newtons.

NOTE 2 Only positive, i.e. tensile, loads are used in this test method.

3.5
minimum load
P_{min}
lowest value of the load during a cycle

NOTE 1 It is expressed in newtons.

NOTE 2 Only positive, i.e. tensile, loads are used in this test method.

3.6
load range
ΔP
difference between the maximum and the minimum loads in one cycle, given by:

$$\Delta P = P_{max} - P_{min}$$

3.7
load ratio
stress ratio
R
ratio of the minimum to the maximum load in one cycle, i.e.:

$$R = P_{min}/P_{max}$$

3.8
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 $2\pi r$, as r tends to zero:

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

NOTE 1 It is expressed in pascal root metres ($Pa \cdot m^{1/2}$).

NOTE 2 The term factor is used here because it is in common usage, even though the quantity has dimensions.

[ISO 13586]

3.9
maximum stress intensity factor
K_{max}
highest value of the stress intensity factor in one cycle

3.10
minimum stress intensity factor
K_{min}
lowest value of the stress intensity factor in one cycle

3.11
stress intensity factor range
ΔK
difference between the maximum and minimum stress intensity factors in one cycle, given by:

$$\Delta K = K_{max} - K_{min}$$

3.12
energy release rate
G
difference between the external work δU_{ext} done on a body to enlarge a cracked area by an amount δA and the corresponding change in strain energy δU_S:

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

NOTE 1 It is expressed in joules per square metre.

NOTE 2 Assuming linear elastic behaviour, the following relationship between the stress intensity factor K and the energy release rate G holds:

$$G = \frac{K^2}{E'}$$

where

$E' = E$ for plane stress, and $E' = \dfrac{E}{1-\nu^2}$ for plane strain conditions;

E and ν are the tensile modulus and Poisson's ratio respectively.

3.13
maximum energy release rate
G_{max}
highest value of the energy release rate in one cycle

3.14
minimum energy release rate
G_{min}
lowest value of the energy release rate in one cycle

3.15
energy release rate range
ΔG
difference between the maximum and minimum energy release rates in one cycle, given by:

$$\Delta G = G_{max} - G_{min}$$

3.16
notch
sharp indentation made in the specimen, generally using a razor blade or a similar sharp tool, before a test and intended as the starting point of a fatigue-induced crack

3.17
initial crack length
a_0
length of the notch (3.16)

NOTE 1 It is expressed in metres.

NOTE 2 For compact tensile (CT) specimens, it is measured from the line joining the load-application points (i.e. the line through the centres of the loading-pin holes) to the notch tip (see Figure 2). For single-edge-notched tensile (SENT) specimens, it is measured from the edge of the specimen to the notch tip. Details of the measurement procedure are given in 7.3.

3.18
crack length
a
total crack length at any time during a test, given by the initial crack length a_0 plus the crack length increment due to fatigue loading

NOTE It is expressed in metres.

3.19
fatigue crack growth rate
da/dN
rate of crack extension caused by fatigue loading and expressed in terms of average crack extension per cycle

NOTE It is expressed in metres per cycle.

3.20
stress intensity calibration
mathematical expression, based on empirical or analytical results, that relates the stress intensity factor to load and crack length for a specific specimen geometry

3.21
gauge length
L_0
⟨single-edge-notched tensile (SENT) specimen⟩ free distance between the upper and lower grips after the specimen has been mounted in the test machine

NOTE It is expressed in metres.

4 Principle

A constant-amplitude cyclic tensile load is imposed on a specimen under suitable test conditions (specimen shape and size, notching, maximum and minimum loads, load cycle frequency, etc.), causing a crack to start from the notch and propagate.

The crack length a is monitored during the test and recorded as a function of the number N of load cycles completed.

Numerical differentiation of the experimental function $a(N)$ provides the fatigue crack growth rate da/dN which is reported as a function of stress intensity factor and energy release rate at the crack tip.

5 Significance and use

Fatigue crack propagation, particularly when expressed as the fatigue crack growth rate da/dN as a function of crack-tip stress intensity factor range ΔK or energy release rate range ΔG characterizes a material's resistance to stable crack extension under cyclic loading. Background information on the fatigue behaviour of plastics and on the fracture mechanics approach to fatigue for these materials is given in [1] and [2] (see the Bibliography).

Expressing da/dN as a function of ΔK or ΔG provides results that are independent of specimen geometry, thus enabling exchange and comparison of data obtained with a variety of specimen configurations and loading conditions. Moreover, this feature enables da/dN versus ΔK or ΔG data to be utilized in the design and evaluation of engineering structures. The concept of similitude is assumed, which implies that cracks of differing lengths subjected to the same nominal ΔK or ΔG will advance by equal increments of crack extension per cycle.

Fatigue crack propagation data are not geometry-independent in the strict sense since thickness effects generally occur. The potential effects of specimen thickness have to be considered when generating data for research or design.

Anisotropy in the molecular orientation or in the structure of the material, and the presence of residual stresses, can have an influence on fatigue crack propagation behaviour. The effect can be significant when test specimens are removed from semi-finished products (e.g. extruded sheets) or finished products. Irregular crack propagation, namely excessive crack front curvature or out-of-plane crack growth, generally indicates that anisotropy or residual stresses are affecting the test results.

This test method can serve the following purposes:

a) to estabilish the influence of fatigue crack propagation on the lifetime of components subjected to cyclic loading, provided data are generated under representative conditions and combined with appropriate fracture toughness data (see ISO 13586) and stress analysis information;

b) to establish material-selection criteria and inspection requirements for damage-tolerant applications;

c) to establish, in quantitative terms, the individual and combined effects of the material's structure, the processing conditions and the loading variables on fatigue crack propagation.

6 Test specimens

6.1 Shape and size

6.1.1 Standard specimens

Two different types of specimen can be used: single-edge-notched tensile (SENT) and compact tensile (CT). Figures 1 and 2 describe their geometrical characteristics.

6.1.2 Thickness and width

When the specimen thickness h is too small compared to the width w, it is difficult to avoid lateral deflections or out-of-plane bending of the specimen. Conversely, with very thick specimens, through-thickness crack curvature corrections are often necessary and difficulties may be encountered in meeting the through-thickness straightness requirement of 8.1.

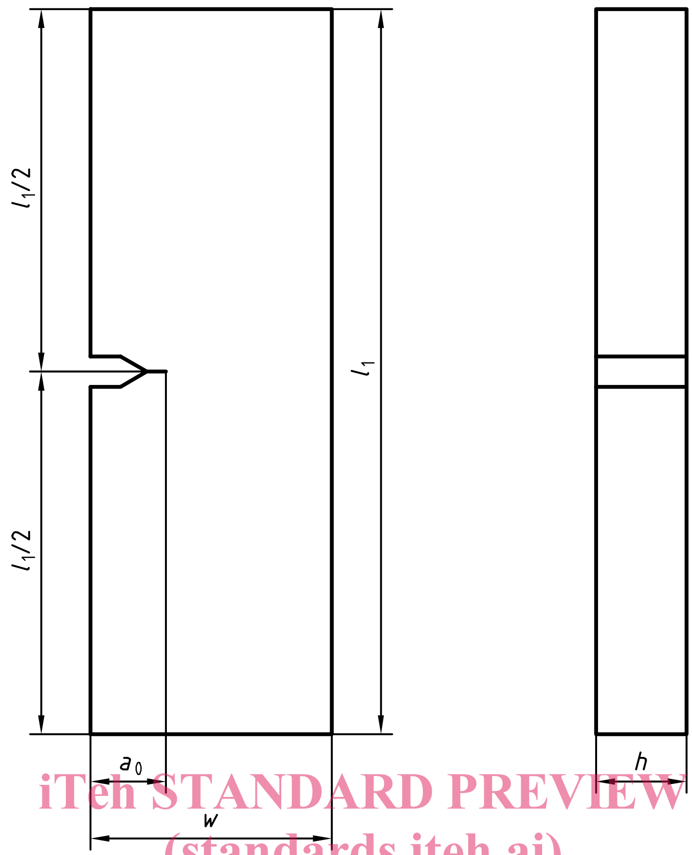
On the basis of these considerations, the following limits are recommended for h and w:

a) for CT specimens, $w/10 \leqslant h \leqslant w/2$;

b) for SENT specimens, $w/20 \leqslant h \leqslant w/4$.

It should be noted that the test results are in general thickness-dependent: specimens obtained from the same material but having different thicknesses are likely to give different responses.

It is usually convenient to make the thickness h of specimens equal to the thickness of the sheet sample from which the specimens are cut.



Key

w Width — $w/20 \leqslant h \leqslant w/4$ (recommended)

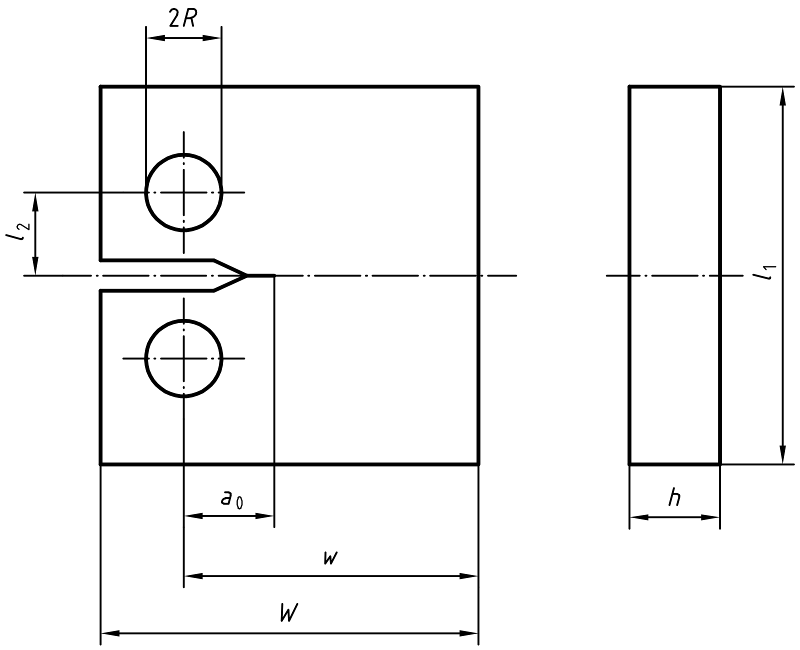
l_1 Length — $l_1 \geqslant 2{,}5w$

h Thickness

a_0 Initial crack length

The notch shall be within $\pm$ 0,01w of the specimen centreline.

Figure 1 — Standard single-edge-notched tensile (SENT) specimen for fatigue crack propagation testing



Key

w	Effective width	$w/10 \leqslant h \leqslant w/2$ (recommended)
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 loading-pin holes located symmetrically to the crack plane to within $\pm 0{,}005w$	$l_2 = 0{,}55w \pm 0{,}005w$
R	Radius of loading-pin hole	$R = 0{,}125w \pm 0{,}005w$
h	Thickness	
a_0	Initial crack length	$a_0 \geqslant 0{,}2w$

The notch shall be within $\pm 0{,}01w$ of the specimen centreline.

Figure 2 — Standard compact tensile (CT) specimen for fatigue crack propagation testing

6.1.3 Size requirements

In order for the results obtained by this test method to be valid, it is required that the material behaviour be predominantly linear elastic at all values of applied load and crack length. Deviations may arise from either viscoelastic behaviour of the material or large-scale plasticity ahead of the crack tip. The former may result in significant non-linearity of the mechanical behaviour, possibly aggravated by a progressive rise of the specimen temperature during the test. The test procedure outlined in this International Standard is therefore recommended only for materials exhibiting very limited viscoelasticity under the loading frequency used and for the expected test duration. Large-scale plasticity of the ligament can be avoided by ensuring that the plastic zone around the crack tip is small compared with the size of the uncracked ligament $(w - a)$. On the basis of previous experience with metallic materials[3], it is required that the following size limits be satisfied in order for the test results to be valid:

$$(w - a) \geqslant (4/\pi)\left(K_{\max}/\sigma_y\right)^2 \quad (1)$$

where

$w - a$ is the uncracked-specimen ligament width;

σ_y is the tensile-yield stress measured in accordance with the relevant part of ISO 527.