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ISO 17281

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Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) at moderately high loading rates (1 m/s)

Plastiques — Détermination de la ténacité à la rupture (G_{IC} et K_{IC}) à vitesses de charge modérément élevées (1 m/s)

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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 17281 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Annexes A and B of this International Standard are for information only.

Introduction

This International Standard is based on a testing protocol developed by ESIS (the European Structural Integrity Society), Technical Committee 4, *Polymers and Composites*, 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 see [3-6]. This activity involved about thirty laboratories from twelve countries.

Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) at moderately high loading rates (1 m/s)

1 Scope

This International Standard provides guidelines for determining the fracture toughness of plastics in the crack-opening mode (Mode I) by a linear elastic fracture mechanics (LEMF) approach, at load-point displacement rates of up to 1 m/s. It supplements ISO 13586 so as to extend its applicability to loading rates somewhat higher than is the case in the scope of the latter International Standard.

Fracture testing at high loading rates presents special problems because of the presence of dynamic effects: vibrations in the test system producing oscillations in the recorded quantities, and inertial loads producing forces on the test specimen different from the forces sensed by the test fixture. These effects need either to be controlled and, if possible, reduced by appropriate action, or else to be taken into account through proper analysis of the measured data.

The relative importance of such effects increases with increasing testing rate (decreasing test duration). At speeds of less than 0,1 m/s (loading times of greater than 10 ms) the dynamic effects may be negligible and the testing procedure given in ISO 13586 can be applied as it stands. At speeds approaching 1 m/s (loading times of the order of 1 ms) the dynamic effects may become significant but still controllable. The procedure given in ISO 13586 can still be used though with some provisos and these are contemplated in this International Standard. At speeds of several meters per second and higher (loading times markedly shorter than 1 ms) the dynamic effects become dominant, and different approaches to fracture toughness determination are required, which are outside the scope of this International Standard.

The general principles, methods and rules given in ISO 13586 for fracture testing at low loading rates remain valid and should be followed except where expressly stated otherwise in this International Standard.

The methods are suitable for use with the same range of materials as covered by ISO 13586.

Although the dynamic effects occurring at high loading rates are largely dependent on the material tested as well as on the test equipment and test geometry used, the guidelines given here are valid in general, irrespective of test equipment, test geometry and material tested.

The same restrictions as to linearity of the load-displacement diagram, specimen size and notch tip sharpness apply as for ISO 13586.

The linearity requirements referred to in 6.1 of ISO 13586:2000, are verified here on the "smoothed" load-displacement curve, to be obtained as specified in 8.1.

2 Normative reference

The following normative document contains 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 edition of the normative document 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 13586:2000, *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 terms and definitions given in ISO 13586 apply.

4 Test specimens

4.1 Specimen geometry and preparation

As for the low-rate testing case covered by ISO 13586, two test configurations are recommended, namely the three-point bending (also called single edge notch bend and denoted SENB) and the compact tension (denoted CT), see Figure 1.

Shape and size, preparation, notching and conditioning of test specimens shall comply with the requirements set out in clause 4 of ISO 13586:2000.

4.2 Crack length and number of test replicates

4.2.1 Determination of K_{IC}

As in the low-rate testing case covered by ISO 13586, measuring test specimens having the same crack length is adequate for determining K_{IC}. The initial crack length a should be in the range $0,45 \leqslant a/w \leqslant 0,55$. However, in view of the lower degree of accuracy to be expected with measurements at high rates of loading as compared with low-rate testing, it is recommended that at least five replicates, with crack lengths in the range specified above, be used to determine K_{IC}, and the results averaged.

4.2.2 Determination of G_{IC}

At variance with the low-rate testing case covered by ISO 13586, a multispecimen procedure, using a series of test specimens with identical dimensions but varying crack-length as specified below, shall be applied for determining G_{IC}.

At least fifteen valid determinations shall be made, with initial crack length varying over the range $0,20 \leqslant a/w \leqslant 0,70$ for the SENB configuration and $0,40 \leqslant a/w \leqslant 0,75$ for the CT configuration. They may include the five determinations made on test specimens having initial crack lengths in the range $0,45 \leqslant a/w \leqslant 0,55$ to obtain K_{IC}. It is then suggested that, of the remaining ten test specimens to be used, six have initial crack lengths in the range $0,20 \leqslant a/w \leqslant 0,45$ and four in the range $0,55 \leqslant a/w \leqslant 0,70$ in the case of the SENB configuration and three have initial crack length in the range $0,40 \leqslant a/w \leqslant 0,45$ and seven in the range $0,55 \leqslant a/w \leqslant 0,70$ in the case of the CT configuration.

4.3 Measurement of test specimen dimensions

Measurement is carried out as described in 5.6 of ISO 13586:2000.

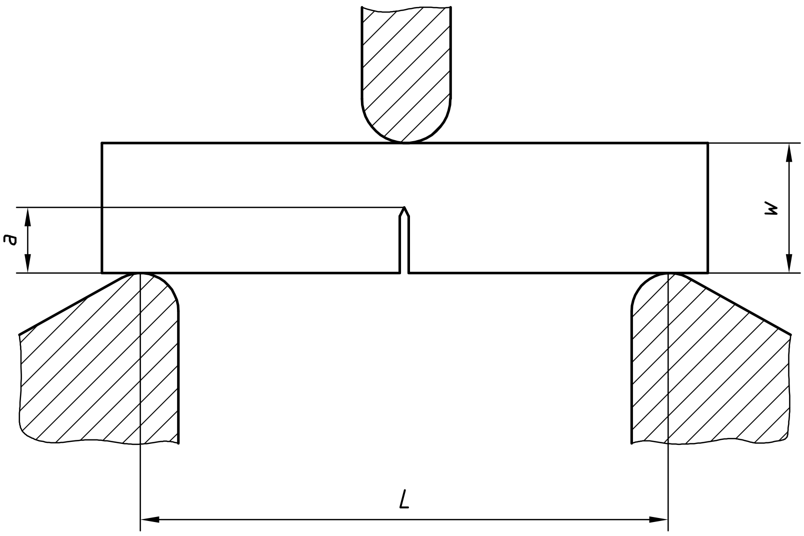
5 Test conditions

5.1 Loading mode

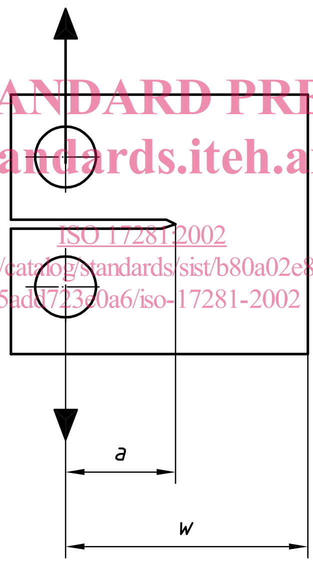
The test shall be performed at constant load-point displacement rate. A maximum variation of 10 % in the load-point displacement rate during the test is allowed (see 6.1).

5.2 Test speed

As a basic test condition, it is recommended that a load-point displacement rate of 1 m/s be used. If a different rate is applied, it shall be quoted in the test report.



a) SENB



b) CT

Figure 1 — Test configurations as specified in 4.1 and 6.2

With rate-sensitive materials such as plastics, a more significant measure of the rate of the experiment is probably its duration, i.e. the time required to bring the test specimen to fracture. The time to fracture, t_f, is understood here as the time interval between the moment when the load starts acting on the test specimen and the point of fracture initiation as defined in 8.1.

With a fixed load-point displacement rate the time to fracture varies with material and specimen geometry. If results at a given time to fracture (e.g. 1 ms) are desired, it is necessary to adapt the load-point displacement rate of the test to each material and specimen geometry (type and dimensions). For this purpose it is expedient to run some preliminary trial tests at different testing speeds (i.e. load-point displacement rates) to determine the testing speed required to obtain the assigned time to fracture under the given test conditions.

In any case, the time to fracture, t_f, shall also be quoted in the test report.

5.3 Test atmosphere and temperature

These are determined as described in 5.5 and 5.7 of ISO 13586:2000.

6 Test equipment

6.1 Loading machine

Any type of loading machine (impact pendulums, falling-weight towers, servohydraulic universal testing machines, etc.) is permitted, provided it is capable of applying an adequate load to bring the test piece to fracture at the required load-point displacement rate and of maintaining this rate constant throughout the test up to fracture initiation. With testing machines of limited capacity, this requirement may need to be verified by preliminary tests, especially when new materials are tested or when new test conditions (e.g. change in specimen size) are used.

Any variation in the load-point displacement rate during the test shall be determined and quoted if it exceeds 10 % of the rate at fracture initiation.

6.2 Loading rigs

Unlike for low-rate testing, the use of fixed anvils rather than moving rollers is preferred for conducting three-point bend (SENB) fracture tests under high rate conditions, as is normally the case with standard impact pendulums. The span between the supports shall be adjustable however, so that specimens of different size can be accommodated, as specified in clause 4 of ISO 13586:2000.

NOTE In the case of three-point bend testing (SENB specimens), improved results can be obtained if the testpiece is held in contact with the anvils by light springs (e.g. rubber bands). These will assist in maintaining the testpiece in position during the sudden load transmission from the machine to the test specimen, and ensure more reproducible records.

6.3 Instrumentation

Acquisition of a complete record of the load/time response of the material sample under test is essential for the determination of K_{IC}. In addition, a means of evaluating the displacement of the moving load-point during the test is necessary for the independent determination of G_{IC}. Instrumentation of the testing machine should thus comprise, basically, a force sensing and recording system and a displacement measuring and recording system or devices to measure and record quantities from which the load and the load-point displacement can also be indirectly determined.

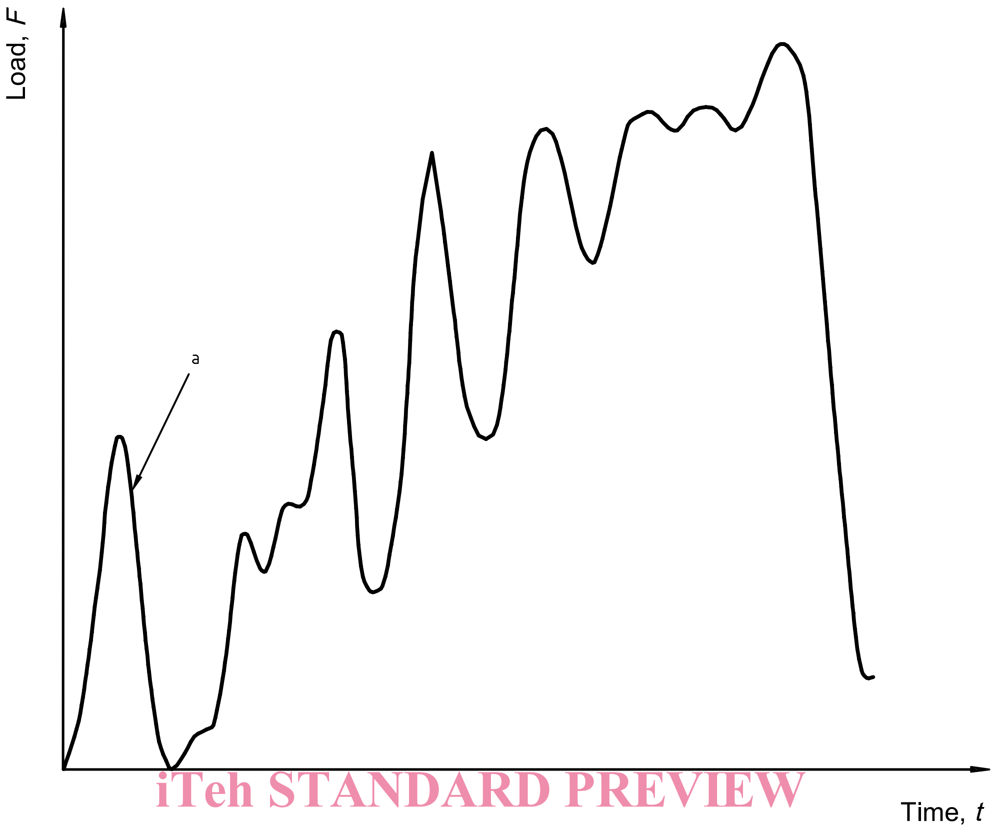
The adequacy of the response of this equipment to the dynamic events occurring in the relevant determinations shall be checked. It can be considered satisfactory if a plain plastic specimen (without any mechanical damping device in place) shows an inertial peak (see Figure 2) larger than 100 N at 1 m/s test speed. The response time shall be $<$ 20 % of the input signal rise time.

If a digital recording system is used, the sampling time should be less than 1/200 of the time to fracture, i.e. at least 200 data points should be collected over the time interval from the first increase of the signal to the point of fracture initiation in order to define the required data curve with sufficient accuracy.

7 Control of dynamic effects

7.1 Electronic filtering

The first manifestation of dynamic effects is the presence of oscillations in the load recording signal. They may complicate the interpretation of the test records up to the point of obscuring the basic response of the specimen under test. It is thus desirable that these effects be contained. Reducing these oscillations artificially, *a posteriori*, by electronic filtering or attenuation can be fallacious however, since it may wipe out some real features of the specimen response. Therefore, electronic filtering or attenuation is not permitted unless the source of the removed “noise” is known and the effect on the data is understood.



a Inertial peak

Figure 2 — Typical load/time record in the absence of signal attenuation and mechanical damping

7.2 Mechanical damping

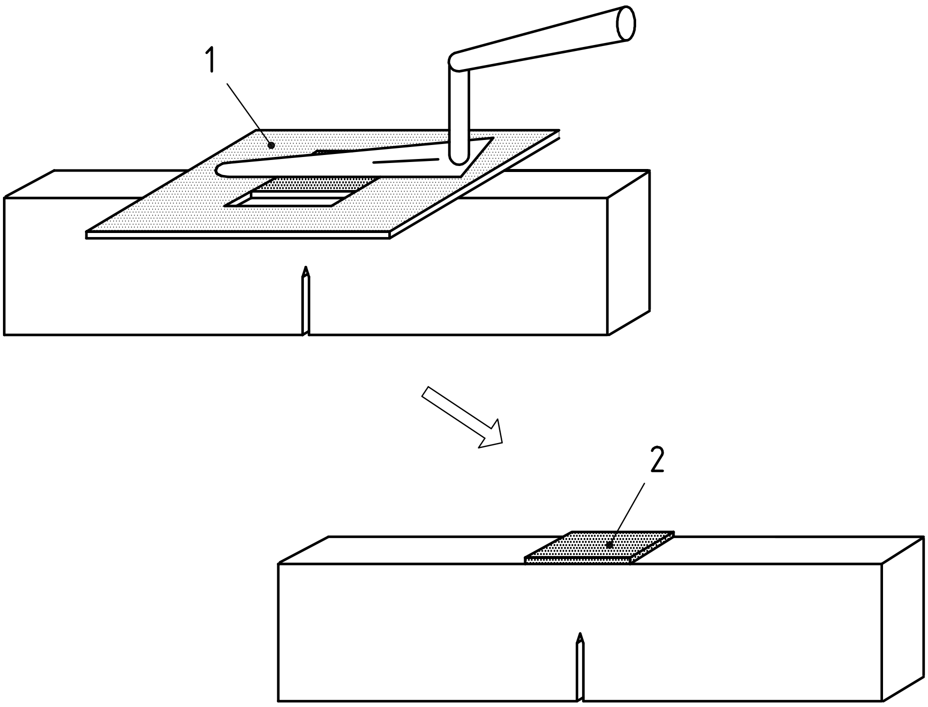
Some control of the effects of inertial loads can be achieved by proper mechanical damping of the load transmission. With impact testing machines the impact may be cushioned by means of a soft pad, placed where the tup strikes the specimen. The pad should reduce the inertial effects by reducing the "contact stiffness". With high-speed testing machines (e.g. servohydraulic), initial acceleration of the specimen can be controlled by means of a damper applied in the motion transmission unit.

With impact testing machines and (SENB) test specimens the damping pad can be made by spreading a layer of a paste or a highly viscous grease over the contact surface either of the tup of the striking hammer or of the test piece. For the sake of reproducibility it is important that the grease be homogeneous and evenly applied, with thickness constant to ± 0,05 mm. This can be obtained by delivering the grease with a spatula through an aluminium stencil having the required thickness, normally a few tenths of a millimetre, as shown in Figure 3.

With high-speed testing machines and (CT) test specimens the damping pad can be more conveniently made of a viscoelastic rubber-like material with a low coefficient of restitution. The rubber-like character should ensure a more or less complete recovery of the pad deformation after each test, thus allowing the same pad to be used repeatedly.

7.3 Damping level

If mechanical damping is applied, it shall be kept to a minimum, sufficient to contain the fluctuations in the force-time trace within the 10 % envelope defined in 8.1. To obtain this optimal result it is advisable to run some preliminary trial tests to gauge the performance of the damper. This can be varied by changing consistency and thickness of the damping material used.



Key

1 Aluminium stencil

2 Damping pad

Figure 3 — Deposition of damping pad on SENB test specimen

If the test specimens are in short supply, it is advisable to use an unnotched specimen to assay the performance of the damper. The dynamic effects that are to be controlled by mechanical damping are in fact largely independent of crack length and the use of an unnotched specimen offers the advantage that it can stand repeated strokes without breaking.

In order to determine the level of damping needed to meet the requirement stated in 8.1, reference should be made to the worst case to be expected in the testing programme, i.e. the case of the specimen with the deepest notch, which will present the lowest fracture resistance and thus the largest force oscillation:fracture load ratio.

7.4 Check on speed

Because of damping, some deviations from the pre-set load-point displacement rate may ensue. Thus, if mechanical damping is applied, the instrument shall be reset to the desired load-point displacement rate and its constancy checked (as requested under 5.2) under the actual test conditions, i.e. with the damping device in place.

If mechanical damping is applied, it shall be recorded in the test report.

8 Data handling

8.1 Analysis of the test records and identification of fracture initiation

These tests, as well as the low speed tests covered in ISO 13586, are designed to characterize the toughness at fracture initiation. Once a fracture test has been performed and the load-time or load-load point displacement curve has been obtained, the question arises of identifying the point of fracture initiation. Several techniques are possible, but in this International Standard it is deduced from the load diagram.