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Plastics — Determination of mode I plane-strain crack-arrest toughness

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National foreword

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Plastiques — Détermination de la ténacité d'arrêt de fissure en déformation plane

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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.

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 on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

Introduction

There has been much interest in a better understanding of the fracture behaviour of polymeric materials and, as a consequence, several International Standard methods for evaluating the fracture properties have been developed. In the light of the fact that these standard methods provide critical information on fracture prevention of structures and products made from polymeric materials, as well as give directions for the research and development of materials, any additional test methods of importance to fracture need to be added to the list. In line with such importance, in particular, a test method for evaluating the resistance to rapid crack propagation in terms of a material's ability to arrest the fast-running crack would be of interest for polymers.[1]-[4][10]-[12][14]

The value of the stress intensity factor, K, during the short time interval in which a fast-running crack arrests is a measure of the ability of materials to arrest such a crack. The values of the stress intensity factor of this kind, which are determined using the dynamic methods of analysis, provide a value for the crack-arrest fracture toughness, K_A. To ease complexity arising from the dynamic effects, static methods of analysis, which are much less complex, can often be used to determine the stress intensity factor at a short time (1 ms to 2 ms) after crack arrest. The estimate of the crack-arrest fracture toughness obtained in this fashion is termed K_a and the difference between K_A and K_a can be made small by minimizing the macroscopic dynamic effects during the test.[5]-[8] For cracks propagating under the conditions of crack-front plane-strain, in situations where the dynamic effects are also known to be small, K_{Ia} determinations using laboratory-sized specimens have been used successfully to estimate whether, and at what point, a crack arrests in a structure.[9]-[11] Depending upon the component design, the loading compliance, and the crack-jump length, a dynamic analysis of a fast-running crack propagation event can be necessary in order to predict whether crack arrest will occur and the arrest position. In such cases, values of K_{Ia}, determined by this International Standard can be used to identify those values of K below which the crack speed is zero. More details on the use of dynamic analyses can be found in Reference [8].

This International Standard describes a method for mode I plane-strain crack-arrest toughness measurement for polymers.

INTERNATIONAL STANDARD ISO 29221:2014(E)

Plastics — Determination of mode I plane-strain crack-arrest toughness

1 Scope

This International Standard specifies a method for the determination of the plane-strain crack-arrest fracture toughness, K_{Ia}, of polymeric materials by using a side-grooved, crack-line-wedge-loaded compact tension specimen to obtain a rapid crack run-arrest segment of flat-tensile separation with a satisfactory crack front. This International Standard employs a static fracture analysis determination of the stress intensity factor at a short time after crack arrest. The estimate is denoted as K_a and when certain size requirements are met, the test result provides an estimate, termed as K_{Ia}, of the plane-strain crack-arrest toughness of the polymer. The specimen size requirements provide for in-plane dimensions large enough to allow the specimen to be modelled by linear elastic analysis. If the specimen does not exhibit rapid crack propagation and arrest, K_a cannot be determined.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 16012, *Plastics — Determination of linear dimensions of test specimens*

ISO 18872, *Plastics — Determination of tensile properties at high strain rates*

3 Terms and definitions

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

3.1
conditional value of the plane-strain crack-arrest fracture toughness
K_{Qa}
conditional value of K_{Ia}, calculated from the test result and subject to the validity criteria specified for the side-grooved, crack-line-wedge-loaded specimen used

Note 1 to entry: The calculation of K_{Qa} is based upon the measurements of both the arrested crack length and of the crack-mouth opening displacement prior to the initiation of a fast-running crack and shortly after crack arrest.

Note 2 to entry: It is expressed as $N \cdot m^{-3/2}$.

3.2
crack-arrest fracture toughness
K_a
value of the stress intensity factor, *K,* shortly after crack arrest

Note 1 to entry: The in-plane specimen dimensions shall be large enough for adequate enclosure of the crack-tip plastic zone by a linear-elastic stress field.

Note 2 to entry: It is expressed as $N \cdot m^{-3/2}$.

3.3
plane-strain crack-arrest fracture toughness
K_{Ia}
value of the crack-arrest fracture toughness, K_a, for a crack that arrests under the conditions of crack-front plane-strain

Note 1 to entry: The requirements for attaining the conditions of crack-front plane-strain are specified in the procedures of this International Standard.

Note 2 to entry: It is expressed as $N \cdot m^{-3/2}$.

3.4
stress intensity factor at crack initiation
K_o
value of K at the onset of rapid fracturing

Note 1 to entry: Only a nominal estimate of the initial driving force is needed. For this reason, K_o is calculated based on the initial crack (or notch) length and the crack-mouth opening displacement at the initiation of a fast-running crack.

Note 2 to entry: It is expressed as $N \cdot m^{-3/2}$.

4 Principle

This International Standard estimates the value of the stress intensity factor, K, at which a fast-running crack arrests. In this test method, a wedge is forced into a split pin, which applies an opening force across the crack starter notch in a modified compact specimen, causing a crack run-arrest segment of crack extension. The rapid run-arrest event suggests the need for a dynamic analysis of test results. However, experimental observations indicate that, for this test method, an adjusted static analysis of test results provides a useful estimate of the value of the stress intensity factor at the time of crack arrest.[1]-[2]

The calculation of nominal stress intensity at initiation, $K_{o,}$ is based on the measurements of the initial notch length and the crack-mouth opening displacement at initiation. The value of K_a is based on the measurements of the arrested crack length and the crack-mouth opening displacements prior to initiation and shortly after crack arrest.

5 Apparatus

5.1 General

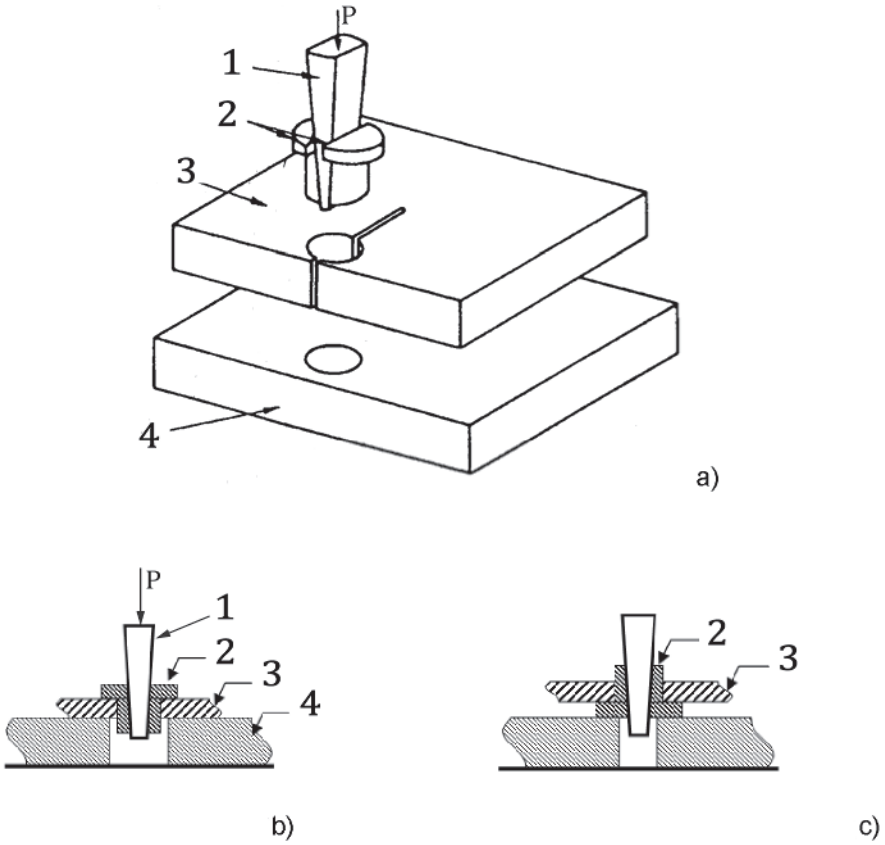
The procedure involves testing the modified compact specimens that have been notched by machining. To minimize the introduction of additional energy into the specimen during the crack run-arrest event, the loading system shall have a low compliance compared with the test specimen. For this reason, a wedge and split-pin assembly is used to apply a load on the crack line. This loading arrangement does not permit easy measurement of the opening loads. Consequently, the opening displacement measurement, in conjunction with crack size and compliance calibrations, is used for calculating K_o and K_a.

5.2 Loading arrangement

A typical loading arrangement is shown in Figure 1. The specimen is placed on a support block whose thickness should be adequate to allow the completion of the test without interference between the wedge and the lower crosshead of the testing machine. The support block should contain a hole that is aligned with the specimen hole, and whose diameter should be between 1,05 and 1,15 times the diameter of the hole in the specimen. The load that forces the wedge into the split pin is transmitted through a load cell.

The surfaces of the wedge, split pin, support block, and specimen hole should be lubricated if necessary. The lubricant used shall not affect the polymer being tested. It can be also helpful to have the sliding surfaces of the wedge, the split pin, and the support block matte-finished (grit-blasted), so as to prevent

possible galling. A low-taper-angle wedge and split-pin arrangement is used. The split pin shall be long enough to contact the full specimen thickness, and the radius should be large enough to avoid plastic indentations of the test specimen. In all cases, it is recommended that the diameter of the split pin shall be 0,10 mm less than the diameter of the specimen hole. The wedge shall be long enough to develop the maximum expected opening displacement and any air or oil-hardening tool steel is suitable for making the wedge and split pins. Hardness in the range from Rc45 to Rc55 has been used successfully. The dimensions of a wedge and split-pin assembly suitable for use with a 25 mm diameter loading hole are shown in Figure 2. The dimensions should be scaled when other hole diameters are used.



Key

P load
1 wedge
2 split pin or bushing
3 test specimen
4 support block

Figure 1 — Schematic illustration of the wedge-loading system — Specimen assembly: a) pictorial view, b) standard arrangement, and c) arrangement in case high friction between the support block and specimen exists

Dimensions in millimetres

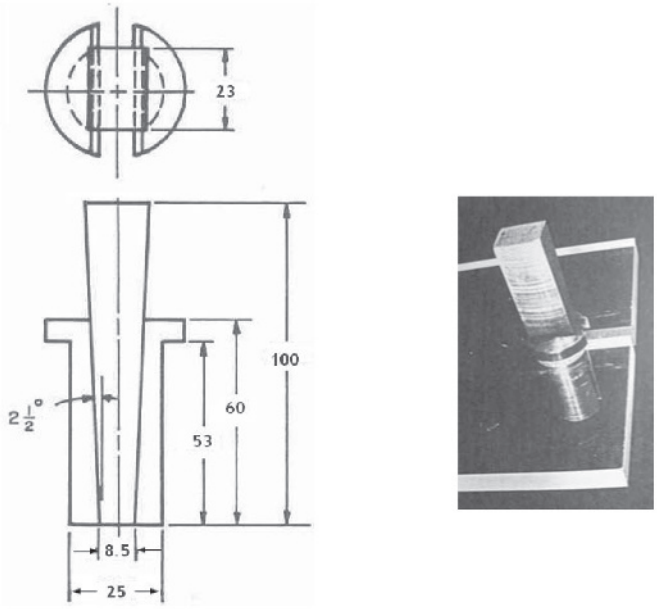
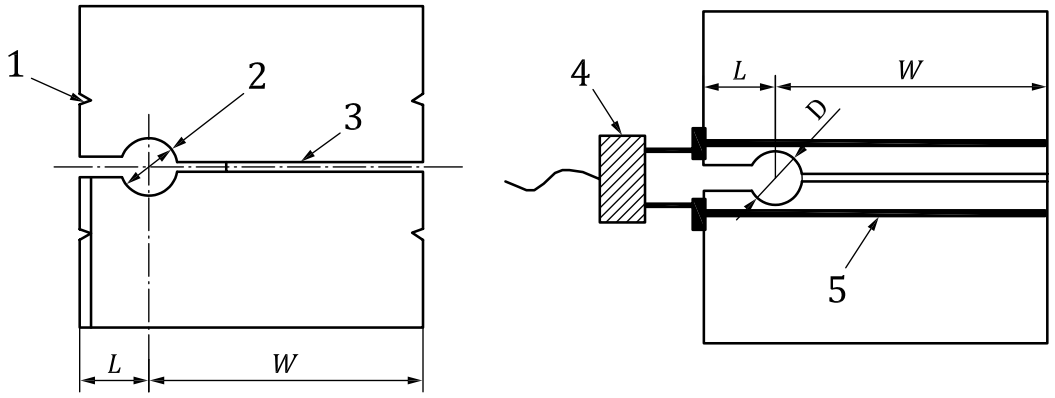


Figure 2 — Suggested geometry and dimensions of wedge and split-pin assembly

NOTE The dimensions given are suitable for use with a 25 mm diameter loading hole in 25-mm to 50-mm thick test specimens.

5.3 Displacement gauge

A displacement gauge is used to measure the crack-mouth opening displacement at $L = 0{,}25\ W$ measured from the load-line, which is the centre line of the wedge loading hole, with distance L away from the specimen edge (Figure 3). Accuracy to within 2 % over the working range is required. Either the gauge described in ISO 13586 or a similar gauge is satisfactory. It is necessary to attach the gauge in a fashion such that the seating in contact with the specimen is not altered by the jump of the crack. The methods that have proven satisfactory for doing this are shown in Figure 3. The gauge can be affixed to the specimen by using elastic bands, either a gauge edge flat on the specimen, or a gauge with knife edges sliding into v-grooves in the specimen.



Key

1 v-groove
2 loading hole
3 side groove
4 displacement gauge
5 elastic band

Figure 3 — Methods of positioning and attaching the displacement gauge to the specimen

The more recommended choice is the use of v-grooves along with elastic bands to fix the gauge as this provides better gauge-holding stability as well as consistency in initial gauge opening.

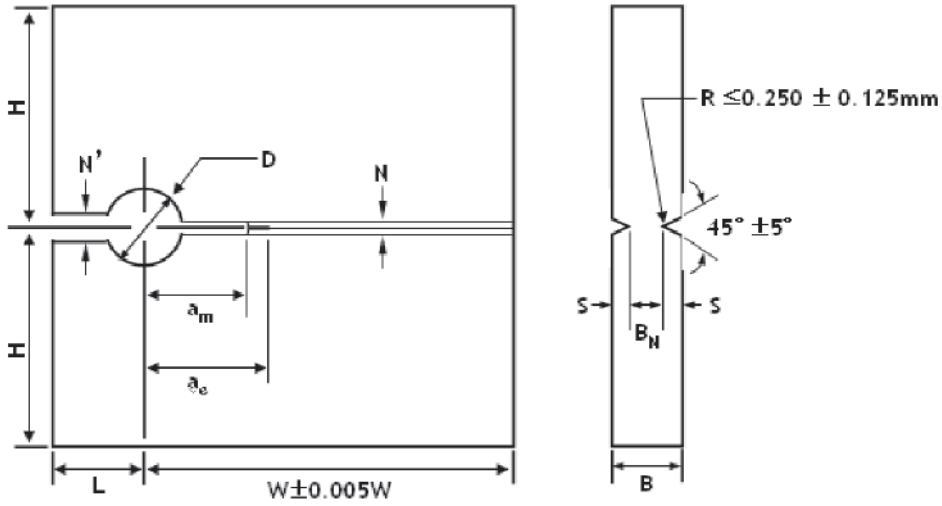
6 Test specimen

6.1 General

The shape of the compact-crack-arrest test specimen is shown in Figure 4. It is a double-cantilever-type flat specimen having side grooves introduced along the plane containing the initial notch of the specimen. The side grooves are known to help create the plane-strain condition at the crack front and to keep the running crack in a straight manner throughout the crack run-arrest segment.

6.2 Dimensions

The dimensions shall be such that the extent of plastic deformation in the specimen prior to crack initiation shall be limited. For this, certain size requirements should be met, which depend upon the specimen yield strength and K_a, as well as the K_0 needed to achieve an appropriate crack run-arrest event. In addition, the in-plane specimen dimensions shall be large enough to allow for the linear elastic analysis employed by this test method. These requirements are given in 8.2, in terms of allowable crack-jump lengths. For a test result to be termed plane-strain K_{Ia} by this test method, the specimen thickness, B, shall meet the requirement also given in 8.2. Side grooves of depth $B/8$ per side shall be used. The specimen width, W, shall be within the range $2\,B \leq W \leq 10\,B$. Other specimen dimensions of importance are illustrated in Figure 4.



Key

D loading hole

R side groove notch radius

a_o initial crack (or notch) length

a_m machined notch length

$H = 0{,}6\ W \pm 0{,}005\ W$; $S = (B - B_N)/2 \pm 0{,}01\ B$; $N \leq W/10$; $0{,}15\ W \leq L \leq 0{,}25\ W$; $0{,}20\ W \leq a_o \leq 0{,}40\ W$; $0{,}125\ W \pm 0{,}005\ W \leq D \leq 0{,}250\ W \pm 0{,}005\ W$.

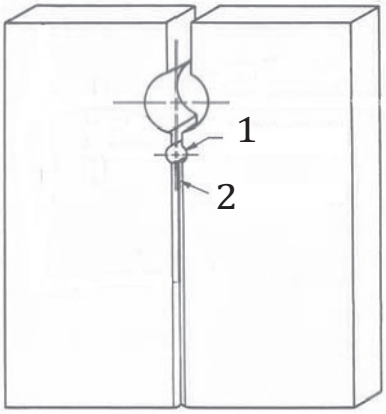
NOTE For more brittle polymers, a final razor notch might not be necessary, and $a_o = a_m$.

Figure 4 — Suggested geometry and dimensions of a crack-line-wedge-loaded compact-crack-arrest test specimen

6.3 Starter notch

The function of the starting notch is to produce a crack initiation at an opening displacement (or wedging force) that permits an appropriate length of rapid crack extension prior to crack arrest. Different polymers can require different starter notches and preparation procedures. Typically, however, the final starter notch is generally made after the initial machine notching, either through the use of razor blade or fatigue cracking, or by other means appropriate. It was shown that in case of razor notching, the notching speed should be as such that the notch tip is not damaged.

In the case of relatively brittle polymers, such as polystyrene and polymethylmethacrylate, a straight-machined notch (e.g. a_m in Figure 4) was shown to be effective enough to cause crack initiation without yielding. For polycarbonate, a straight notch allows sufficient yielding such that on reaching the onset opening displacement, the crack propagates through the whole specimen width without arresting. It has been shown that this problem can be eliminated by using a chevron notch (see References [10] and [14]). The determination of the initial crack length, a_o, for the chevron notch is given in Annex A. For polymers such as polyacetal, nylon, and polyethylene, the chevron notch is not sufficient to create a running crack. In this case, the starter notch can be cooled in the liquid nitrogen below Tg to allow yielding suppression and cause the initiation of a self-arresting crack. To do this effectively, a technique is described (see Reference [14]) wherein a hole is drilled just adjacent to the final razor notch through which liquid nitrogen is circulated via copper tube placed through the drilled hole, as shown in Figure 5. It has been shown that by using this technique, a straight razor notch is enough to effectively cause brittle crack initiation. A thermocouple placed near the side groove at a location about 10 mm ahead of the notch-tip would be useful for the crack-tip temperature monitoring prior to the specimen loading. A small hole drilled to the depth of 0,25 B is appropriate for accommodating the thermocouple wire.



Key

1 notch tip cooling hole

2 razor notch

Figure 5 — Modified crack-arrest test specimen for crack-tip low-temperature exposure

7 Procedure

7.1 Measurements of specimen dimensions

Measure and record the dimensions, as appropriate, in accordance with ISO 16012. Specimen thickness, B, and the crack plane thickness, B_N, shall be measured to an accuracy of ±1 % of B. Also, the specimen width shall be measured to an accuracy of W to ±1 % of W.

7.2 Conditioning

The specimens can be moulded in various ways and machining and notching follow to make them into predetermined dimensions of compact tension crack-arrest specimen. Newly prepared specimens shall be preconditioned in accordance with the requirement of specific polymers to be evaluated so as to prevent any anomalies that can arise from the specimen preparation. Test specimens shall be conditioned at the test temperature for 24 h prior to carrying out the test.

7.3 Loading

Position the wedge-loading system and specimen assembly to a testing machine that is capable of applying the load at a constant rate of traverse. Attach the displacement gauge to the specimen using appropriate means, as described in 5.2. Apply loads to the specimen through the wedge-split pin assembly in contact with the specimen until a fast-running crack initiates. Throughout the load application, wedge load versus crack-mouth opening displacement should be recorded. A typical crack run-arrest record is illustrated in Figure 6. The load should be applied with the crosshead speed of 2 mm/min to 25 mm/min.

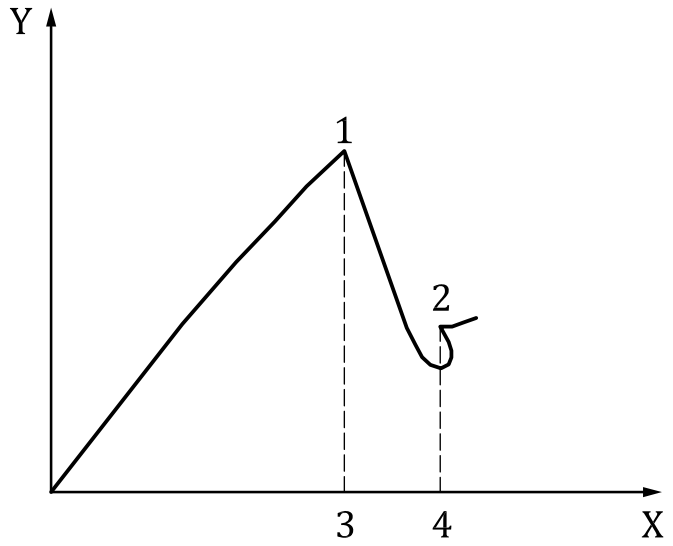
To measure K_a, a segment of unstable crack extension shall occur. The occurrence of unstable crack extension normally becomes apparent, both audibly and as an abrupt load drop on the test record. After the event, the load on the wedge should be removed to avoid further crack propagation.

If on loading, attempts to increase the opening displacement are accompanied by either a constant, or a decrease in the applied wedge load, then a substantial crack tip yielding or stable tearing maybe occurring. For these cases, it is unlikely that the specimen will exhibit rapid crack run-arrest fracturing.

It is recommended that under these circumstances, the test be discontinued. A new specimen should be used with the starter notch techniques described in 6.2.

NOTE 1 While it is expected that a_o values for the starting notch typically lie in the range 0,30 $W \leq a_o \leq$ 0,40 W, it is sometimes useful to utilize values as low as 0,20 W. The lower initial value of a_o/W results in a greater and quicker drop in the crack driving force as the crack extends. This can aid in arresting the running crack by a shorter final crack length and could be useful for conditions where the crack extension is too great with larger initial a_o/W values.

NOTE 2 When the notch-tip cooling method is used to initiate the self-arresting crack, K_a at the test temperature is calculated, but not K_o.



Key

X crack-mouth opening displacement, δ (mm)
Y applied load on the wedge, P (N)
1 maximum load, P_{max} (N)
2 load short time after crack arrest, P_{arrest} (N)
3 displacement at maximum load, δ_o (mm)
4 displacement short time after crack arrest, δ_a (mm)

Figure 6 — Typical experimental wedge-load versus crack-mouth-opening-displacement curve for crack run-arrest segment

In this method, the load is applied to the wedge until a rapid crack initiates and, hence, does not allow direct measurement of the opening loads applied to the specimen by the wedge and split-pin assembly. The load applied to the specimen is therefore obtained from the measurements of the crack-mouth opening displacement. Thus, it becomes important to carefully arrange the seating of the specimen, the load train, and the displacement gauge at the mouth opening, which can all affect the measurement of the opening displacement.

7.4 Displacement measurement

From the wedge load versus crack-mouth-opening-displacement record (see Figure 6), determine the displacements corresponding to the onset of unstable crack-initiation (δ_o) and crack arrest (δ_a).

7.5 Arrested crack length (a_a) measurement

The crack-arrest length in a specimen having undergone crack run-arrest event can be determined by first breaking the specimen completely into two and then measuring the length from the crack-load-line to the position of crack arrest on the fracture surface. The tested specimen can be broken with

the wedging apparatus used for testing the specimen and is greatly facilitated by cooling them in dry ice or liquid nitrogen. The fracture surface should first be examined to determine whether it displays irregularities serious enough to warrant exclusion of the test result. The occurrence of tunnelling, a failure to follow the side grooves on one or both sides, and the presence of large, unbroken ligaments on the fracture surface are all behaviours that can give erroneous results for K_a. Although for most polymers, the arrest position is relatively simple to determine (see Figure 7), where it is not apparent, any means of identification are applicable as long as the method being utilized in any way does not affect the measurement of the location of the arrest position.

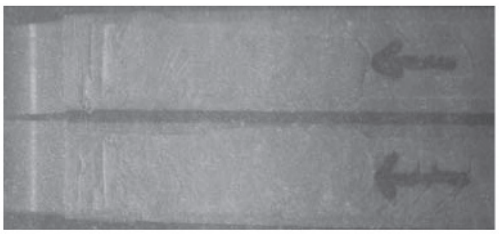


Figure 7 — Fracture surface of two halves of crack run-arrest specimen indicating the crack-arrest position

The average of three measurements defines the arrested crack length, a_a. These measurements are to be made on the fracture surface, to within 1 %, at the following positions: at the centre (mid-thickness) of the specimen and midway between the centre and the bottom of the side groove, on each side. Since crack front irregularities can make it difficult to determine the crack length at the specified locations, it is suggested that the measurement be taken as a visual average across a strip of width, $B_N/4$, centred at each measurement location, as shown in Figure B.1.

NOTE It is recommended to include a photographic record of the fracture surface in the test report, particularly, if there are any unusual perturbations in the crack front contours. Descriptive comments can also be helpful.

7.6 Number of tests

It is recommended that at least three valid test results be obtained at a given temperature.

8 Calculation and validation of results

8.1 Calculation of K_o and K_{Qa}

Calculate K_o and K_{Qa} using Formula (1):

$$K = E\delta f(\varphi)(B / B_N)^{0,5} / W^{0,5} (\mathrm{Nm}^{-3/2}) \quad (1)$$

where

$$f(\phi) = (1 - \phi)^{0,5} (0,748 - 2,176x + 3,56x^2 - 2,55x^3 + 0,62x^4) \quad (2)$$

and

$$\varphi = a / W \quad (3)$$

The definitions of terms in Formulae (1) to (3) are as follows:

E is the tensile modulus (N/m^2);

a is the initial crack length, a_o, or final arrested crack length, a_a, as determined in 7.5 (m);

W is the specimen width (m);

B is the specimen thickness (m);

B_N is the specimen thickness at crack plane (m);

δ is the crack-mouth opening displacement (m).

NOTE The expression for $f(\varphi)$ used in this International Standard is based on a curve fit to boundary value collocation results and an exact limit solution.[15] The curve fit is considered to be accurate within 1 % over the range $0,20 \leq \varphi \leq 1$ and is in close agreement with the experimental compliance result.[16]

To determine the value of K_o, use $a = a_o$ and $\delta = \delta_o$. Similarly, for K_{Qa}, use $a = a_a$ and $\delta = \delta_a$.

8.2 Validity requirement

The value of K_{Qa}, which is calculated using Formula (2), can be considered a linear-elastic, plane-strain value, K_{Ia}, provided that the criteria described in Table 1 are satisfied.

Table 1 — Summary of criteria used to ensure that K_{Qa} is a linear-elastic, plane-strain value

Feature	Criterion
Unbroken ligament	(A) $W - a_a \geq 0{,}15\ W$
Unbroken ligament	(B) $W - a_a \geq 1{,}25\ (K_a/\sigma_{YD})^2$
Thickness	(C) $B \geq 1{,}0\ (K_a/\sigma_{YD})^2$
Crack-jump length	(D) $a_a - a_o \geq 2\ N$
Crack-jump length	(E) $a_a - a_o \geq (K_o/\sigma_{YS})^2/2\pi$

NOTE Use is made in the following of σ_{YD}, a formal dynamic yield strength estimate (ISO 18872) for appropriate loading times. For plastics, σ_{YD} is generally somewhat greater than the static yield strength, σ_{YS}, as measured by ISO 527-1. The high strain rates associated with yielding near the tip of a fast-running crack and abrupt nature of crack arrest suggest that the true elevation of σ_{YD} over σ_{YS} should be greater. The value of σ_{YD} that is being used in this International Standard is therefore thought to substantially underestimate the actual effective resistance to plastic flow at crack arrest.[7]

9 Precision

It has not been possible to include a statement on the precision of the measurements in this edition of this International Standard, but it is intended to include such a statement when the information becomes available.

10 Test report

10.1 Test details

The test report shall include, at least, the following information:

a) a reference to this International Standard (i.e. ISO 29221:2013);

b) the date of the test;

c) the type of materials and complete identification of the sample;

d) the sample preparation details (moulding, machining, and notching details);

e) the mechanical property data [tensile modulus, yield strength as determined by ISO 527-1, and dynamic yield strength (ISO 18872) used in 8.2];

f) the type of notch (razor, chevron, etc.) and preparation details;

g) the side groove width, N, and the groove root radius, R;

h) the diameter of the hole for notch tip cooling, if any, and the location from the crack-load-line;

i) the specimen thickness, B, the thickness at crack plane, B_N, the thickness ratio, B_N/B, and the width, W;

j) the specimen conditioning details;

k) the method used for separating the specimen into two parts to reveal the fracture surface;

l) the method used to measure the crack length;

m) the crack length at machined notch, a_m, and the initial notch, a_o;

m) the arrested crack length, a_a (see Annex B):

1) at mid-thickness ($B_N/2$), a_{a2};

2) at 1/4 points of the net thickness ($B_N/2 \pm B_N/4$), a_{a1}, and a_{a3};

3) average crack length at arrest, $a_a = (a_{a1} + a_{a2} + a_{a3})/3$;

o) the load-displacement records from the run-arrest test;

p) the displacements measured from the load-displacement records (at the onset of unstable crack growth, δ_o, and at the crack arrest, δ_a;

10.2 Calculations

— the calculated values of K_o, and K_{Qa} (K_{Ia})

10.3 Validity requirements (see Table 1)

a) uncracked ligament length compared to 0,15 W and to 1,25 $(K_{Qa}/\sigma_{YD})^2$

b) thickness compared to 1,0 $(K_{Qa}/\sigma_{YD})^2$

c) crack-jump length compared to 2 N and to $(K_o/\sigma_{YS})^2/2\pi$

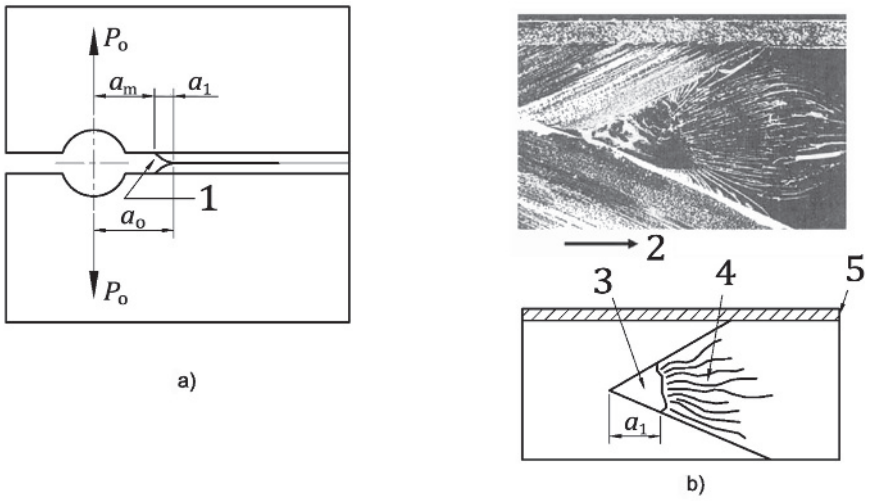
10.4 Photographic record of fracture surface and descriptive comments (optional)

— the photographic record of fracture surface and descriptive comments

Annex A
(informative)

Determination of the initial crack length, a_o, when using the chevron notch

When using the chevron notch, the initial crack length, a_o, is determined from the fracture surface. Figure A.1 b) shows the photograph and schematic illustration of a fracture surface of polycarbonate containing the chevron notch. On loading, the crack initiates at the apex of the chevron notch, first in a stable manner, then unstable, as indicated by the fracture surface in Figure A.1 b). In this case, a_o is taken as the sum of the distance from the crack-load-line to the tip of machined chevron notch (a_m) plus the distance covered by the stable crack growth, a_1, as indicted in Figure A.1 a). The length a_1 should be determined as an average value in cases where the boundary of zone I is not a straight line as shown. Figure A.2 illustrates the crack run-arrested fracture surface of polyethylene, where a chevron notch was employed.



Key

P_o loading direction
1 chevron notch
2 crack propagation direction
3 zone I: crack propagates slowly
4 zone II: crack propagates rapidly
5 side groove

Figure A.1 — The chevron notch: a) initial crack length, a_o, and b) illustration of the fracture surface

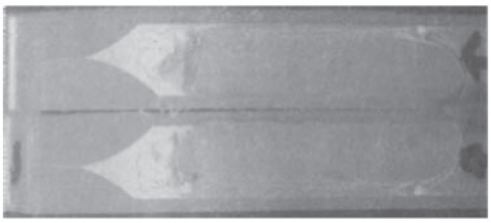
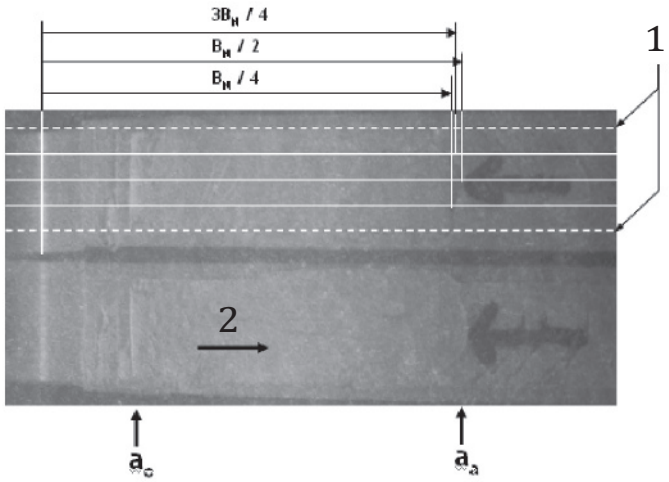


Figure A.2 — An example of the fracture surface of a polyethylene run-arrested specimen with a chevron notch

Annex B
(informative)

Procedure for measuring the arrested crack length (a_o)

As mentioned in 7.5, the arrested crack length, a_o, is taken to be the average of three measurements made on the fracture surface of the specimen. These measurements are to be made at the centre of the specimen ($B_N/2$) and halfway between the centre of the specimen and the edge of the side groove, on each side ($B_N/2 \pm B_N/4$). It is further stated that, at each measurement location, the measurement should be taken as a visual average of the position of the crack front across a strip of width $B_N/4$, centred at the measurement location. The visual average is specified to avoid taking the measurements at a point that may not accurately represent the local average position of the crack front in the vicinity of the measurement location.



Key
1 side groove tips
2 crack propagation direction

Figure B.1 — Example of arrested crack length determination

Average value of the arrested crack length: $a_a = (a_{a1} + a_{a2} + a_{a3})/3$

where

a_{a2} is the crack length at mid-thickness ($B_N/2$);

a_{a1}, a_{a3} are the crack length at 1/4 points of the net thickness ($B_N/2 \pm B_N/4$).

Annex C
(informative)

Fracture surface acceptability

The idealized fracture of a crack-arrest specimen is flat, continuous, and straight fronted. Although this idealization can be closely approached in practice as evidenced in Figure C.1, fracture surfaces of crack-arrest specimen can be complicated by features that, when present in excess, can lead to questionable results for the determination of the crack-arrest fracture toughness of the polymer under consideration. Deviations from the ideal fracture surface appearance generally fall into three categories. These are the presence of remaining ligaments (Figure C.2), a lack of crack front straightness (e.g. slanted crack front and tunnelling as shown in Figure C.3), and crack propagation out of the plane of the side groove (Figure C.2). The extent to which one or more of these behaviours can occur without adversely affecting the test result cannot easily be quantified at the present time and, therefore, mostly rest on the judgment and experience of the individual(s) performing and evaluating the test. It is important therefore to establish guidelines for assessing the acceptable fracture surface through the round robin programme, where the fracture surface acceptability can be investigated in detail.

Figure C.1 — Straight-arrested crack front observed on crack-arrested specimen

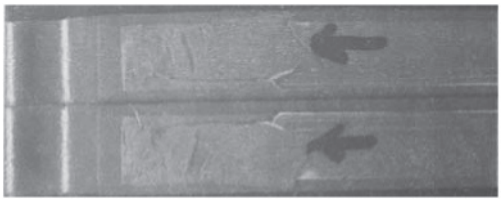


Figure C.2 — Crack deviation from the plane of the side groove and the remaining ligament are seen on the fracture surface

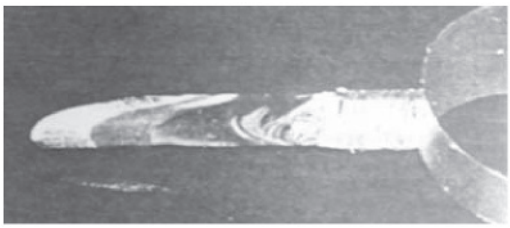


Figure C.3 — Crack-arrest specimen exhibiting the lack of crack front straightness (tunnelling)

Annex D
(informative)

Comment on precision statement

In an attempt to establish a precision statement for this method, an international round robin test was carried out. Eight countries participated; however, only four countries were able to produce results. Among them, results from two countries were meaningful as such that the precision statement is to wait until more results become available.

The results from two countries are summarized in Table D.1.

Table D.1 — Summary of the round robin test

Specimen number	Crack-arrest toughness ($MN \cdot m^{-3/2}$)		
	Country A	Country B-1	Country B-2
1	1,312	1,369	1,370
2	1,531	1,702	1,548
3	1,634	1,511	1,486
4	1,373	1,698	1,677
5	1,422	1,627	1,625
Mean	1,454	1,581	1,541
SD	0,128	0,142	0,120

A mean value for all specimens is 1,526 $MN \cdot m^{-3/2}$ with a standard deviation of ±0,133 $MN \cdot m^{-3/2}$.

A and B utilized a mechanical extensometer and a non-contact optical extensometer, respectively.

B-1 and B-2 are results from the same country, having used different lubricants on wedge surfaces.

Bibliography

[1] Takahashi K., & Arakawa K. Dependence of Crack Acceleration on the Dynamic Stress Intensity Factor in Polymers, *Experimental Mechanics*, **27**, 1987, p. 2,

[2] Popelar C.H., & Kanninen M.I. A Dynamic Viscoelastic Analysis of Crack Propagation and Crack-Arrest in Arrest in A DCB Test Specimen, *Crack Arrest Methodology and Applications. ASTM Spec. Tech. Publ.*, **711**, 1980, G.T. Hahn and M.F. Kanninen, eds., pp. 5–23

[3] Kobayashi T., & Dally J.W. Relation Between Crack Velocity and the Stress Intensity Factor in Birefringent Polymers, *Fast Fracture and Crack Arrest*. *ASTM Spec. Tech. Publ.,* **627**, 1977, G.T. Hahn and M.F. Kanninen, eds., pp. 257–273

[4] Kalthoff J., Beinert J., Winkler S., Klemm W. Experimental Analysis of Dynamic Effects in Different Crack Arrest Specimen, *Crack Arrest Methodology and Applications*. *ASTM Spec. Tech. Publ.*, **711**, 1980, G. T. Hahn and M. F. Kanninen, eds., pp. 109–127

[5] Crosley P.B., Fourney W.L., Hahn G.T., Hoagland R.G., Irwin G.R., Ripling E.J. Final Report on Cooperative Test Program in Crack Arrest Toughness Measurements. In: *NUREG.CR-3261*. University of Maryland, College Park, MD, April 1983

[6] Barker D.B., Chona R., Founey W. L., Irwin G.R. A Report on the Round Robin Program Conducted to Evaluate the Proposed ASTM Test Method for Determining the Crack Arrest Fracture Toughness, Kla of Ferritic Materials, NUREG/CR-4996 (ORNL/Sub/79-7778/4), University of Maryland, College Park, MD, January 1988

[7] Rosenfield A. R. Validation of Compact-Specimen Crack-Arrest Data, *Journal of Engineering Materials Technology*, Vol **106**, 1984, pp. 207–208

[8] Kanninen M.F., & Popelar C.H. *Advanced Fracture Mechanics*. Oxford University Press, NY, 1985

[9] Cheverton R. D., Ball D. G., Bolt S. E., Iskander S. K., Nanstad R. K. Pressure Vessel Fracture Studies Pertaining to the PWR Thermal Shock Issue: Experiments TSE-5, TSE-5A, and TSE-6, *NUREG/CR-4249(ORNL-6163),* Oak Ridge National Laboratory, Oak Ridge, TN, June 1985

[10] Rolland L. Surface Embrittlement of Polymers, Ph.D. Dissertation, Illinois Institute of Technology, Chicago, 1983

[11] Kobayashi A.S., & Mall S. Rapid Crack Propagation and Arrest in Polymers. *Polym. Eng. Sci.* 1979, **19** (2) pp. 131–135

[12] Kanazawa T., Machida S., Teramoto T. Preliminary Approaches to Experimental and Numerical Study on Fast Crack Propagation and Crack Arrest, *Fast Fracture and Crack Arrest-*. *ASTM Spec. Tech. Publ.* 1977, **627**, 1977, G.T. Hahn and M.F. Kanninen, eds., pp. 39–58

[13] ASTM E 1221-96 (reapproved 2002), Standard Test Method for Determining Plane-Strain Crack Arrest Toughness, K_{Ia}, of Ferritic Steels

[14] Broutman L. J., & Choi S-W. Surface Embrittlement of Polyethylene Pipe Grade Resins, Annual Report. Gas Research Institute, GRI-83/0070, 1984

[15] Underwood J.H., Burch I.A., Ritter J.C. Crack Arrest and Static Fracture Toughness Test of a Ship Plate Steel. In: *Rapid Load Fracture Testing, ASTM STP 1130*, Chona R., & Corwin W.R. eds., 1992, pp. 147–160.

[16] Crosley P. B., & Ripling E. J. Development of a Standard Test for Measuring K_{Ia} with a Modified Compact Specimen, *NUREG/CR2294 (ORNL/Sub81/7755/1)*, Materials Research Laboratory,Glenwood, IL, August 1981

[17] Rosenfield A.R., Mineer P.N., Marschall C.W., Markworth A.J. Recent Advances in Crack-Arrest Technology, Fracture Mechanics: Fifteenth Symposium. *ASTM Spec. Tech. Publ.* **833**, 1984, Sandford R.J. ed., pp. 149–164

[18] ISO 13586, *Plastics — Determination of fracture toughness (GIC and KIC) — Linear elastic fracture mechanics (LEFM) approach*

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