INTERNATIONAL STANDARD

ISO 29221

First edition
2014-01-15

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

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

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ISO 29221:2014
https://standards.iteh.ai/catalog/standards/sist/93873f5e-7176-4073-b645-61929fff84d1/iso-29221-2014

Reference number
ISO 29221:2014(E)

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Published in Switzerland

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Foreword

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

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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].

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

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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.

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

ISO 16012, *Plastics — Determination of linear dimensions of test specimens*

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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 $N \cdot m^{-3/2}$.

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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_0
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_0 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]

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The calculation of nominal stress intensity at initiation, K_0, 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_0 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

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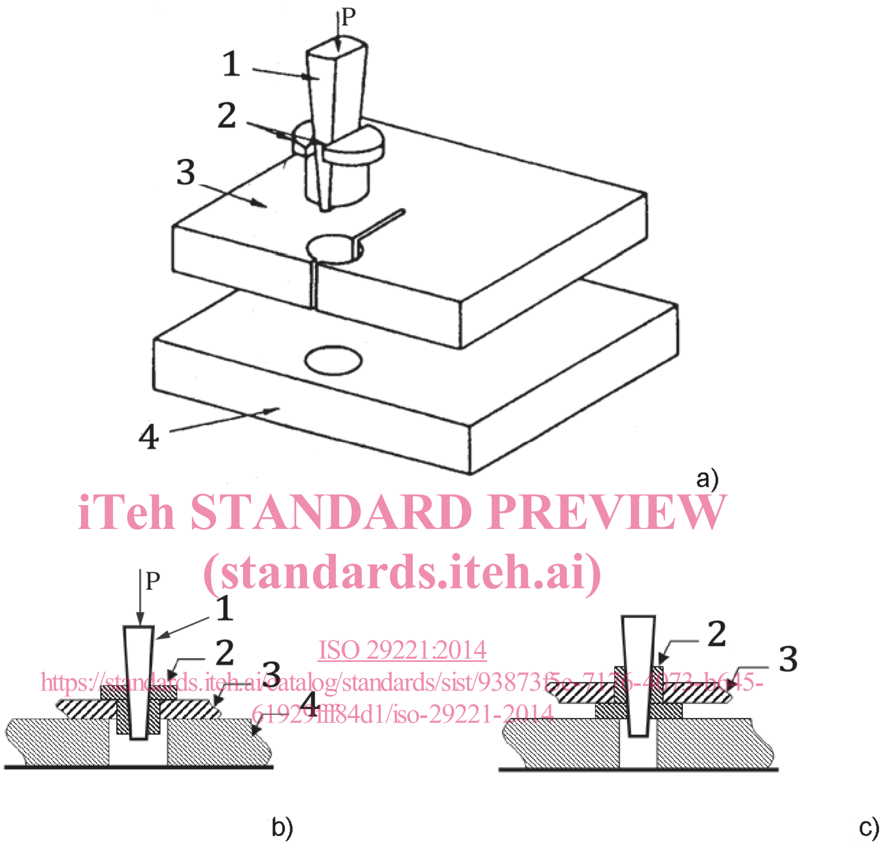
possible galling. A low-taper-angle wedge and split-pin arrangement is used. The split pin shall be long enough to contact the full specimen thickness, and the radius should be large enough to avoid plastic indentations of the test specimen. In all cases, it is recommended that the diameter of the split 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.



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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

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Dimensions in millimetres

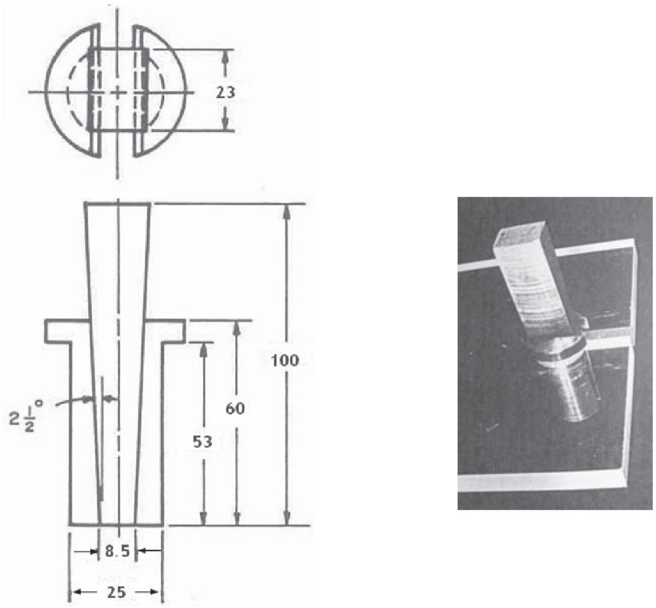

Figure 2 — Suggested geometry and dimensions of wedge and split-pin assembly

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

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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.

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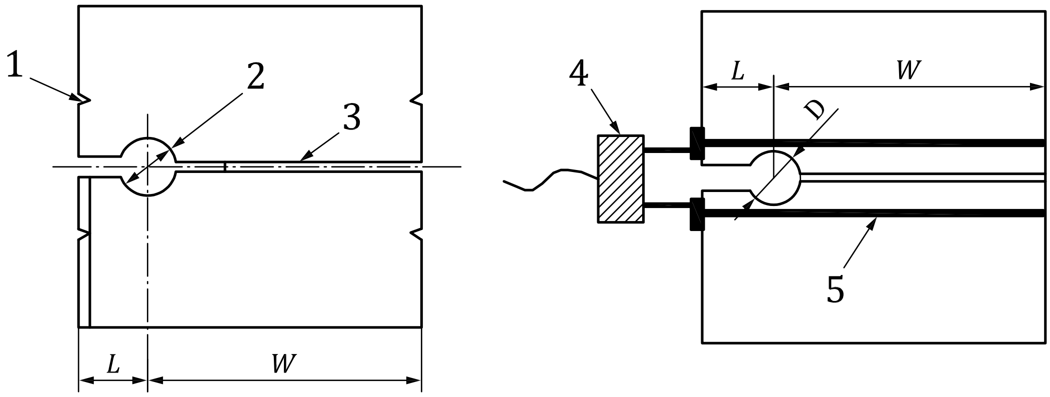

Key

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.

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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.

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