INTERNATIONAL STANDARD

ISO 15024

Second edition

Fibre-reinforced plastic composites — Determination of mode I interlaminar fracture toughness, GIC, for unidirectionally reinforced materials

Composites plastiques renforcés de fibres — Détermination de la ténacité à la rupture interlaminaire en mode I, GIC, de matériaux composites à matrice polymère renforcés de fibres unidirectionnelles

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Foreword

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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 of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, Plastics, Subcommittee SC 13, *Composites and reinforcement fibres*.

This second edition cancels and replaces the first edition (ISO 15024:2001), which has been technically revised.

The main changes are as follows:

— a new double cantilever beam (DCB) is added [Figure 1 c)].

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Fibre-reinforced plastic composites — Determination of mode I interlaminar fracture toughness, GIC, for unidirectionally reinforced materials

1 Scope

This document specifies a method for the determination of mode I interlaminar fracture toughness (critical energy release rate), GIC, of unidirectional fibre-reinforced plastic composites using a double cantilever beam (DCB) specimen.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

ISO 1268 (all parts), *Fibre-reinforced plastics — Methods of producing test plates*

ISO 7500-1, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

ISO 9513, *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
mode I interlaminar fracture toughness
critical energy release rate
G_{IC}
resistance to the initiation and propagation of a delamination crack in unidirectional fibre-reinforced polymer matrix composite laminates under mode I opening load

Note 1 to entry: It is measured in joules per square metre.

3.2
mode I crack opening
crack-opening mode due to a load applied perpendicular to the plane of delamination using the double cantilever beam specimen

Note 1 to entry: The double cantilever beam specimen shown in Figure 1 is shown in Figure 1.

3.3
NL point
point of deviation from linearity on the load versus displacement trace

Note 1 to entry: As shown in Figure 2.

3.4
VIS point
point of the onset of delamination, as determined by visual observation, at the edge of the specimen, marked on the load-displacement trace

Note 1 to entry: As shown in Figure 2.

3.5
5 % / MAX point
point which occurs first on loading the specimen between:

a) the point of 5 % increase in compliance ($C_{5\ \%}$) from its initial value (C_0); and

b) the maximum load point.

Note 1 to entry: See Figure 2.

3.6
PROP points
points of discrete delamination length increments beyond the tip of the insert or starter crack tip marked on the load-displacement trace, points where the crack has been arrested being excluded

Note 1 to entry: See Figure 2.

3.7
delamination-resistance curve
R curve
cross-plot of GIC for initiation and subsequent propagation values for *mode I crack opening* (3.2) as a function of delamination length

Note 1 to entry: See Clause 10.

4 Principle

A mode I double cantilever beam (DCB) specimen, as shown in Figure 1, is used to determine G_{IC}, the critical energy release rate, or interlaminar fracture toughness, of fibre-reinforced plastic composites. Figure 1 represents three different loading arrangement for the specimen as following, a) Specimen loading using load blocks, b) Specimen loading using piano hinges, c) Specimen loading using insert hinges (see Annex D). The test method is limited to zero-degree unidirectional lay-ups only (see Annex B.1). Data reduction yields initiation and subsequent propagation values of G_{IC} for mode I opening fracture toughness. A delamination-resistance curve, or R curve, is generated by plotting G_{IC} on the ordinate as a function of delamination length plotted on the abscissa.

The aim of the test method is to determine initiation values for the composite material tested. Fibre bridging is observed in a DCB test and it might not be representative of the composite material tested. Fibre bridging is considered to be the main cause for the observed shape of the R curve, which typically rises before reaching a roughly constant value of G_{IC} for long delamination lengths. A crack-opening load is applied to the DCB specimen, perpendicular to the plane of delamination, through load blocks or piano hinges under displacement control at a constant rate. The DCB specimen contains a thin, non-adhesive starter film embedded at the midplane as shown in Figure 3, which is used to simulate an initial delamination. The specimen is precracked by unloading the DCB specimen immediately after the first increment of delamination growth from the insert, followed by re-loading. The onset of stable delamination growth is monitored, and the delamination initiation and propagation readings are recorded. The R curve is plotted with the initiation values from both the insert and the mode I precrack,

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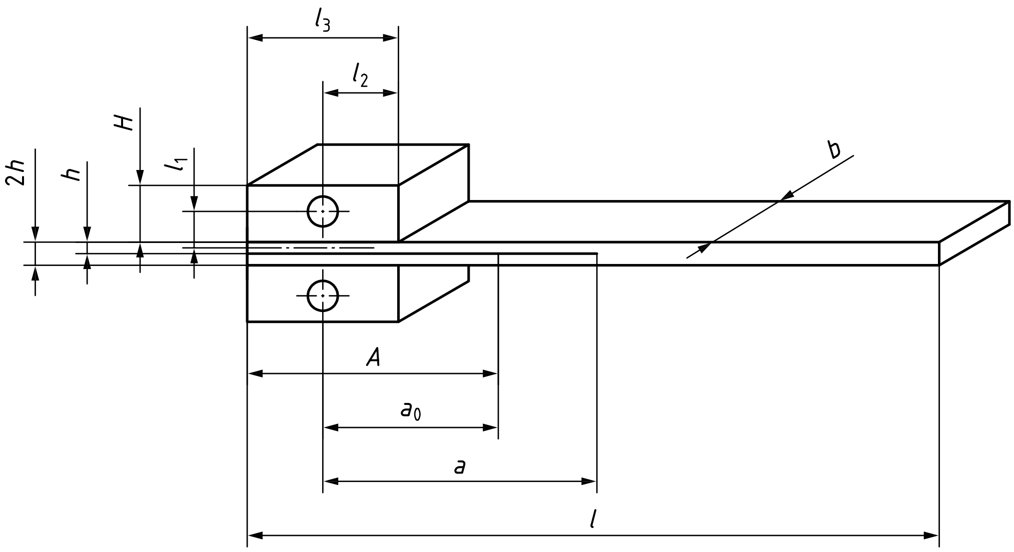
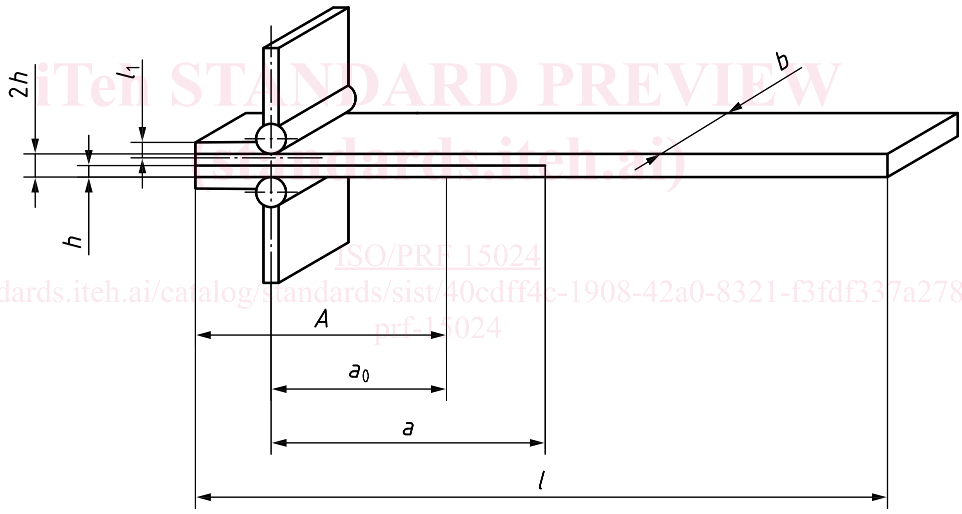
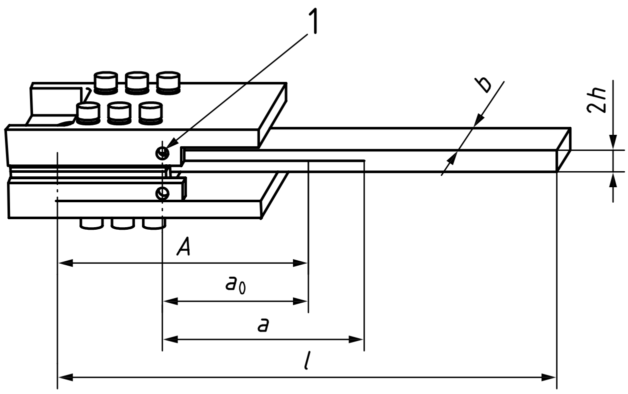
and with the propagation from the precrack. Under certain prescribed circumstances (see 9.2.7), an alternative wedge precracking procedure can be used but is not recommended.



a) Specimen loading using load blocks



b) Specimen loading using piano hinges



c) Specimen loading using insert hinges

Key

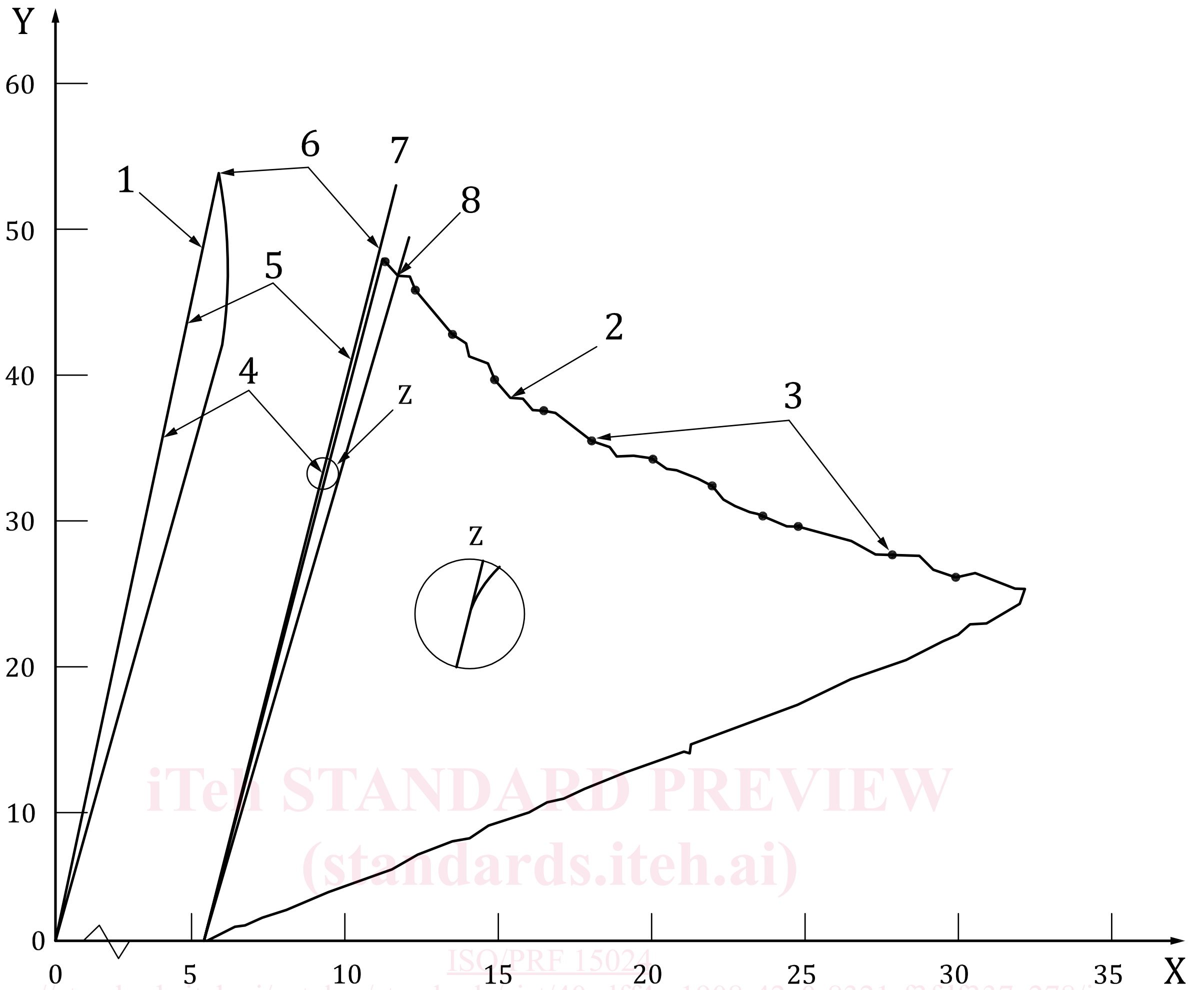
b	specimen width	l_1	distance from centre of loading pin (or piano hinge axis) to midplane of the half-beam to which the load block (or piano hinge) is attached
2*h*	specimen thickness	l_2	distance from centre of loading pin (or piano hinge axis) to edge of load block (or piano hinge)
a_0	initial delamination length	l_3	block length
a	total delamination length	*H*	block thickness
A	insert length	1	centres of hinge axis
l	specimen length		

NOTE 1 Alternative loading arrangements are (a) load blocks and (b) piano hinges.

NOTE 2 The fibre orientation is parallel to the length *l*.

NOTE 3 Details of DCB test with insert hinges is described in Annex D.

Figure 1 — Geometry for the double cantilever beam (DCB) specimen with a starter delamination



Key

X displacement, in millimetres

Y load, in newtons

1 crack initiation followed by unloading

2 crack propagation by re-initiation from the resulting mode I precrack

3 crack propagation markers

4 NL point

5 VIS point

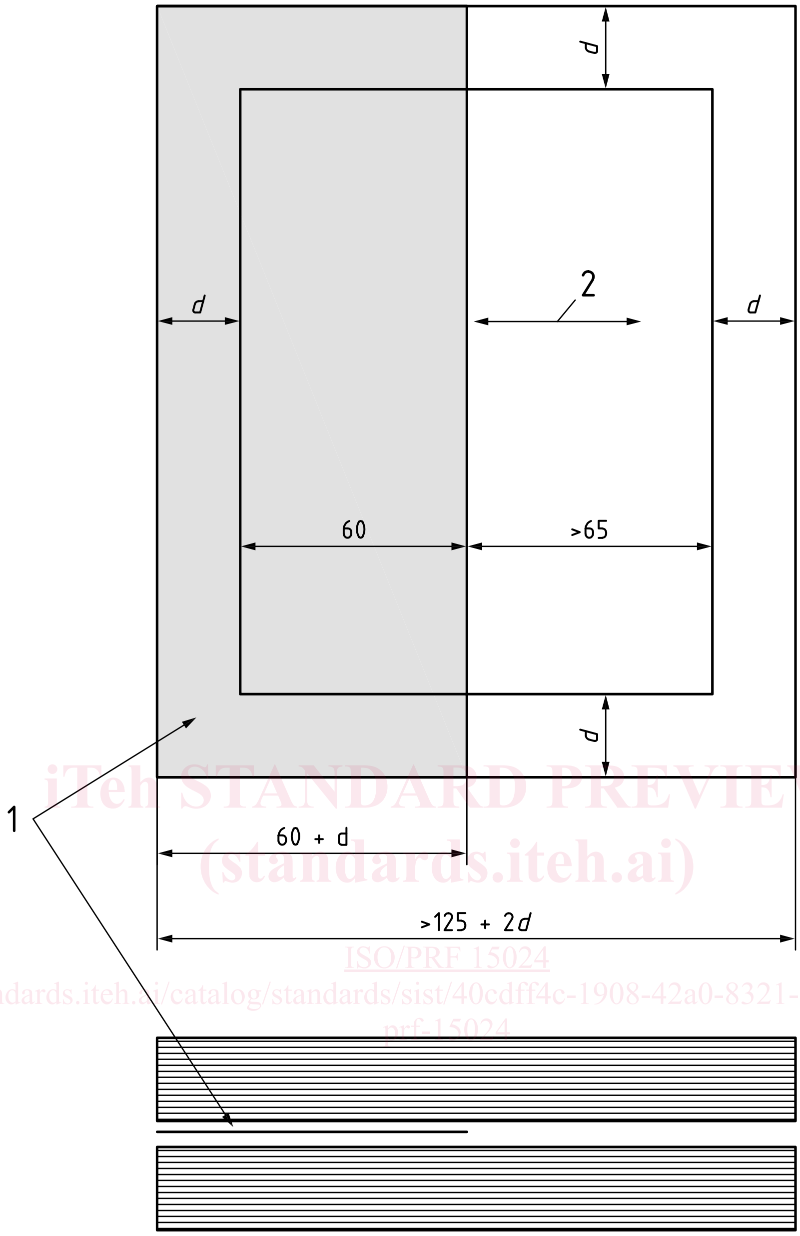
6 MAX point

7 C_0

8 $C_{5\ \%}$

NOTE Figure shows case where 5 % values follow maximum load, and reload curve has been offset 5 mm for clarity

Figure 2 — Load-displacement curve for a DCB test



Key

1 film insert

2 fibre direction

d margin to allow for initial trimming

Figure 3 — Example of test plate preparation showing the laminate structure, the dimensions and the position of the film insert

5 Apparatus

5.1 Test machine

5.1.1 General

The testing machine shall be in accordance with the following requirements.

5.1.2 Speed of testing

The testing machine shall be capable of maintaining the constant displacement rate required in 9.2.1 and 9.3.1 within a tolerance of ±20 %, as specified in ISO 527-1.

5.1.3 Fixture

The test machine shall be equipped with a fixture to introduce the load to the pins inserted into the load blocks or with grips to hold the piano hinges. In each case, rotation of the specimen end shall be allowed. The axis of the load-introduction fixtures shall be aligned with the loading axis of the test machine.

5.1.4 Load and displacement measurements

The force measurement system shall be in accordance with class 1 as defined in ISO 7500-1. The displacement measurement shall be in accordance with class 2 of ISO 9513 within the relevant range used for results determination. Apply machine compliance compensation if the crosshead monitor is used, to ensure that the required accuracy level is as well achieved under loading conditions.

5.1.5 Recorder

The test machine shall allow the displacement and corresponding load to be measured and recorded, preferably on a continuous basis.

5.2 Load blocks or piano hinges

Load blocks or piano hinges, as shown in Figure 1, may be used for introducing the load into the specimen. They shall be at least as wide as the specimen. For the load blocks in Figure 1 a), the maximum value of l_3 shall be 15 mm. The hole to inset the loading pin shall be at the centre of l_3.

5.3 Measuring apparatus

5.3.1 Micrometer, or equivalent, capable of reading to 0,02 mm or less, suitable for measuring the thickness of the specimen. The micrometer shall have contact faces appropriate to the surface being measured (i.e. flat faces for flat, polished surfaces and hemispherical faces for irregular surfaces).

5.3.2 Vernier calipers, or equivalent, capable of reading to 0,05 mm or less, for measuring the width of the specimen.

5.3.3 Linear scale (ruler), with 1 mm divisions, for measuring the specimen length and marking the edges of the specimen to monitor the delamination crack growth.

5.4 Travelling microscope (optional)

A travelling microscope may be used to measure the delamination length. If used, it shall have a travel range of 0 mm to 200 mm, have a magnification no greater than × 70 and be readable to 0,05 mm.

5.5 Non-adhesive insert film

A polymer film of thickness not exceeding 13 µm shall be used as a non-adhesive insert. For epoxy resin matrix composites cured at temperatures below 180 °C, a film of polytetrafluoroethylene (PTFE) is recommended. For composites cured at temperatures above 180 °C (for example those including polyimide or bismaleimide thermoplastics), a film of polyimide is recommended (see B.2).

5.6 Ancillary equipment

5.6.1 Desiccator, for storing the test specimens after conditioning, including a suitable desiccant such as silica gel or anhydrous calcium chloride.

5.6.2 Mould release agent. When a polyimide film is used as the non-adhesive insert film, a mould release agent of the polytetrafluoroethylene (PTFE) type is recommended (see B.2).

5.6.3 Adhesive. A cyanoacrylate adhesive or epoxy adhesive of the two-component room-temperature-cure type to bond the load blocks or piano hinges to the test specimen (see Annex A).

5.6.4 Solvent. Organic solvent such as acetone or ethanol (see Annex A).

5.6.5 Sandpaper (abrasive paper), with 500 grade grit or finer (see Annex A).

5.6.6 White ink. Water-soluble typewriter correction fluid.

6 Test specimen

6.1 Test plate preparation

A test plate shall first be prepared in accordance with the part of ISO 1268 appropriate to the production process used. The recommended plate thickness is 3 mm for 60 % by volume carbon-fibre-reinforced composites and 5 mm for 60 % by volume glass-fibre-reinforced composites.

An even number of unidirectionally aligned layers shall be used (seeB.1). The non-adhesive film insert shall be placed at laminate mid-thickness during lay-up. The insert shall not exceed 13 µm, in order to simulate a sharp crack and cause minimum disturbance of the individual plies of the laminate. Guidelines for the insert material and its preparation are given in B.2.

If a polyimide film is used, the film shall be painted or sprayed with a mould release agent before insertion into the laminate. The film shall be cut to the proper size for insertion into the laminate before applying the mould release agent. Mould release agents containing silicone may contaminate the laminate by migration through the individual layers. Baking of the film will help to prevent silicone migration within the composite. The film shall be coated and baked twice for 30 min at 130 °C. Care shall be exercised in handling the film so that the coated layer of release agent is not damaged or removed from the film.

Figure 3 shows an example of how the test plate can be configured. The positioning of the insert shall allow for the initial trimming of the test plate.

6.2 Specimen preparation

6.2.1 Preferred specimens

Machine the test specimens from the trimmed test plate, with their longitudinal axes parallel to the fibre direction in the test plate. Specimens shall be identified to indicate their original position in the test plate. The specimen configuration and dimensions are illustrated in Figure 1. The dimensions and tolerances for the preferred specimens are shown in Table 1. Specimen surfaces shall not be machined to meet the thickness requirement.

The thickness and width of individual specimens shall not vary by more than ±1 % of the mean value for that type of specimen.

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