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AMENDMENT 1
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Plastics — Determination of fracture toughness (G_{IC} and K_{IC}) — Linear elastic fracture mechanics (LEFM) approach

AMENDMENT 1: Guidelines for the testing of injection-moulded plastics containing discontinuous reinforcing fibres

Plastiques — Détermination de la ténacité à la rupture (G_{IC} et K_{IC}) — Application de la mécanique linéaire élastique de la rupture (LEFM)

AMENDEMENT 1: Lignes directrices relatives à l'essai des matériaux plastiques moulés par injection contenant des fibres de renfort discontinues

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

Amendment 1 to ISO 13586:2000 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*. It is based on guidelines originally developed by Technical Committee TC 4 of the European Structural Integrity Society (ESIS).

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

AMENDMENT 1: Guidelines for the testing of injection-moulded plastics containing discontinuous reinforcing fibres

Page 1

Update Clause 2 (normative references) as follows:

Replace ISO 604:1993 by ISO 604:2002 (same title).

Replace ISO 5893:1993 by ISO 5893:2002, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Specification*.

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Add the following references to the Bibliography:

[8] Folkes, M. *Short fibre reinforced thermoplastics*, Research Studies Press, J. Wiley (1992)

[9] Lowe, A.C., Moore, D.R., Rutter, P.M. *Impact and dynamic fracture of polymers and composites*, ESIS Publication 19, edited by J.G. Williams and A. Pavan, p. 383, MEP Ltd (London) (1995)

[10] Moore, D.R., *Experimental Methods in the Application of Fracture Mechanics Principles to the Testing of Polymers and Composites*, Chapter 1, p. 59, *The Measurement of K_{C} and G_{C} at Slow Speeds for Discontinuous Fibre Composites*, edited by B.R.K. Blackman, D.R. Moore, A. Pavan and J.G. Williams, ISBN 008 043689 7, Elsevier Science (2001)

[11] Davis, M., Moore, D.R. *Composites Science & Technology*, **40**, p. 131 (1991)

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Add the following annex before the Bibliography.

Annex B
(informative)

Guidelines for the testing of injection-moulded plastics containing discontinuous reinforcing fibres

B.1 General

ISO 13586 was developed for non-reinforced plastics. However, with the proliferation of injection-moulded products made from fibre-reinforced plastics, it was considered appropriate that some guidelines be given to users who want to apply this International Standard to measure the toughness of reinforced composite materials. Whilst the theoretical basis which underpins the standard cannot be rigorously applied to reinforced plastics, informative results can be obtained.

When applying this International Standard to injection-moulded plastics containing discontinuous reinforcing fibres, three issues arise. The first of these relates to sample morphology stemming from the injection-moulding manufacturing method. The second relates to a feature involved in crack initiation and the third concerns the application of LEFM to this class of anisotropic, heterogeneous material and the validity of the toughness values.

B.2 Effect of injection moulding on fibre alignment

During the injection moulding of plastics containing discontinuous reinforcing fibres, the melt is delivered into a mould tool under a shear stress field. This causes the fibres to be aligned in the direction of mould fill. However, the melt strikes a cold mould surface and quickly solidifies. Therefore, the fibres aligned in the direction of mould fill are generally near to the mould surface. The melt that enters the central or core region of the mould is then subjected to a stress field where the deformations are extensional, i.e. a diverging stress field [8]. This aligns the fibres in this core region at approximately right angles to the direction of mould fill. In simplistic terms, a skin-core-skin structure is established through the thickness of the moulding. Of course, in reality this is an over-simplification of a much more complex fibre orientation, but an adequate approximation for an assessment of toughness. The mould thickness will then determine which layer will be dominant, with thin mouldings being skin-dominated and thicker mouldings being core-dominated.

B.3 Guidelines for the preparation of samples

These guidelines require that the direction of mould fill from the injection-moulding process be known for the material to be tested. An injection moulding will have in-plane anisotropy and through-thickness heterogeneity. The moulding will have three mutually perpendicular directions, as follows:

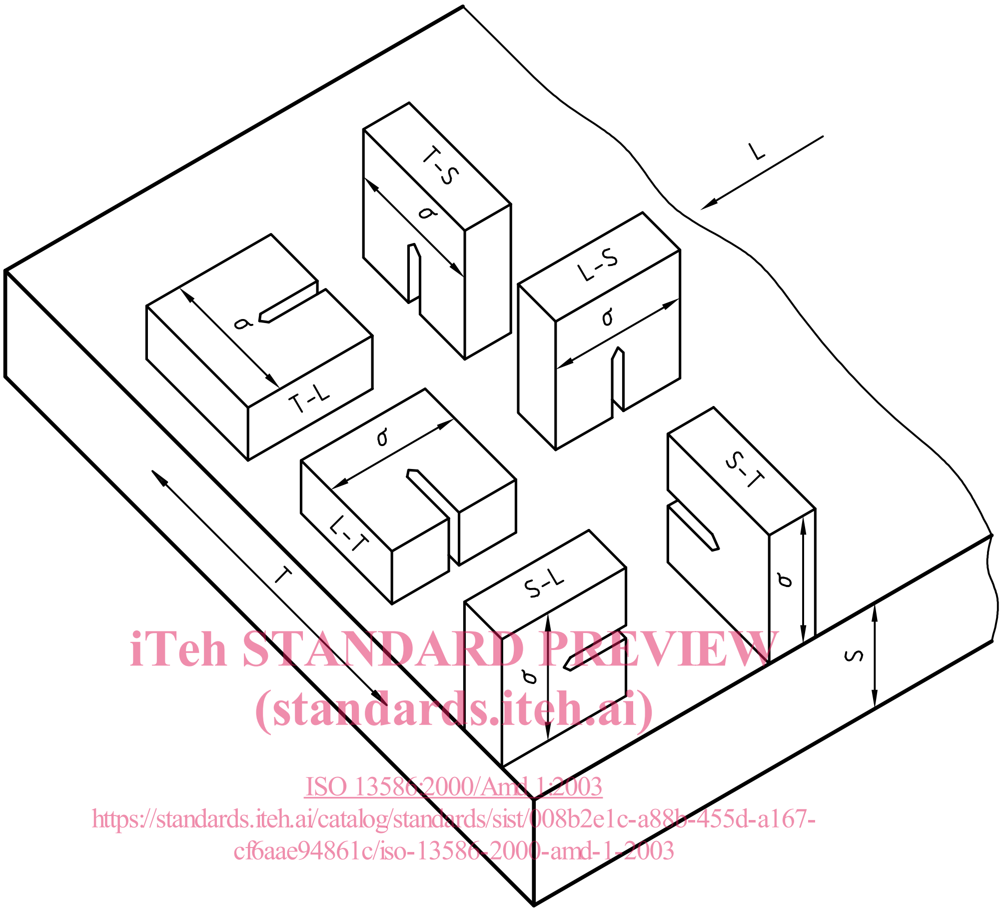
L Longitudinal, i.e. in the processing direction;

T Transverse, i.e. in the mould width direction;

S Short transverse, i.e. in the through-thickness direction.

The anisotropic sheet shown in Figure B.1 will have six different directions of toughness for which six specimens designated T-S, L-S, S-T, T-L, L-T and S-L can be used for measurement purposes. The first letter designates the direction normal to the crack plane, i.e. the direction of the stress applied to generate a colinear crack. The second letter is the expected direction of crack propagation. However, in practice the specimens have to be cut with a thickness equal to the thickness of the moulding, so only the T-L and L-T specimens can be used and it is recommended that both T-L and L-T specimens be prepared. Thus both the

T-L and L-T specimens will have a thickness h equal to the mould thickness. Either SENB or CT specimens may be used. Specimens should not be cut from close to the edge of the moulding. The notch tip radius should be sharp and it is recommended that it should be less than 50 µm.



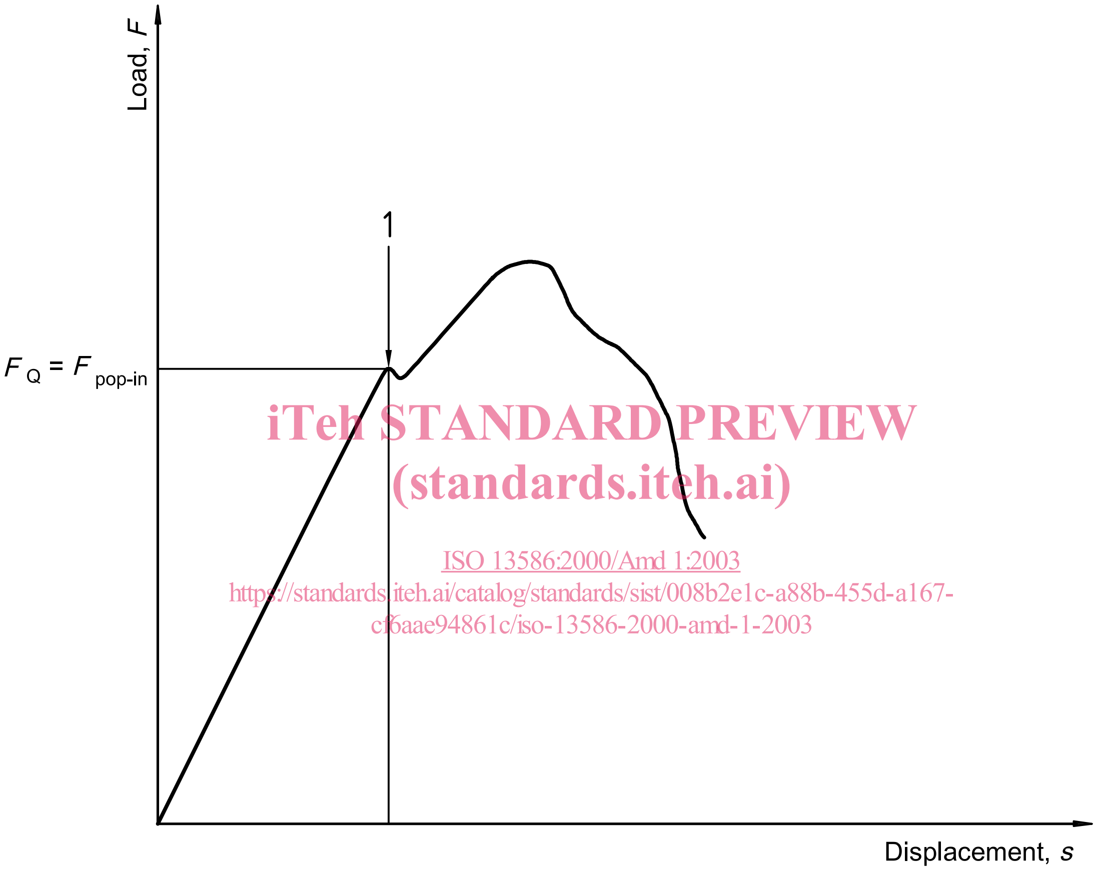
Key

L	longitudinal direction (direction of mould fill)
T	long transverse direction (mould width direction)
S	short transverse direction (through-thickness direction)
σ	direction of stress

Figure B.1 — Specimen configuration for an anisotropic sheet (illustrated for a CT specimen)

B.4 Guidelines for the interpretation of the load-displacement curve when "pop-in" occurs

When testing injection-moulded plastics containing discontinuous reinforcing fibres, a force decrease (termed "pop-in") is sometimes observed [9] on the load-displacement curve prior to the main peak as shown in Figure B.2. This initial peak force is followed by a drop which can then be followed by a further, often significant, rise. If the stiffness, i.e. the slope of the force-displacement curve, reduces after the drop in the force, then it is likely that the crack has initiated. When this is observed, the value of the force at which the "pop-in" occurs should be taken as F_Q. When "pop-in" does not occur, the trace should be interpreted as described in Clause 6 and shown in Figure 7.



Key

1 "pop-in"

Figure B.2 — Load-displacement curve for a notched test specimen made from injection-moulded plastic containing discontinuous reinforcing fibres when "pop-in" occurs

B.5 Guidelines for assessing the colinearity of the crack growth

The crack growth in homogeneous polymeric materials should be colinear and grow in the direction at right angles to the direction of the applied stress. However, for a discontinuous-fibre-reinforced composite the crack growth will usually not be colinear. It is informative to assess the extent of non-colinearity of each specimen after the test. It is recommended that this be done by firstly observing the fractured surface side-on to the crack growth and then by examination of the plane of the crack. A visual observation of the side-on view will provide information on the degree of colinearity at the edge of the specimen, i.e. in the "skin" layer. Then, by microscopic examination of the plane of the crack, an estimation can be made of the skin thickness t_S and of the core thickness t_C. These regions can be identified due to the preferential alignment of the fibres during injection moulding as described in Clause B.2. When the crack grows through a region of the moulding where the fibres are aligned parallel to the crack, a smooth fracture surface is observed. However, when the crack grows through a region of the moulding where the fibres are aligned perpendicular to the crack, then a rough fracture surface is observed. It follows therefore that the fracture surface of the L-T specimen will have a smooth core layer and rough skin layers. However, the fracture surface of the T-L specimens will have a rough core layer and smooth skin layers.

B.6 Estimation of the smooth fraction for L-T and T-L specimens

If the thickness of the skin layer t_S and the thickness of the core layer t_C are measured optically, then the amount of smooth fracture, termed the smooth fraction, can be estimated. In T-L specimens, the smooth fraction is the value of $2t_S/h$ and for the L-T specimens it is the value of t_C/h, where h is the thickness of the specimen as defined in Figure 1 for the SENB specimen and Figure 3 for the CT specimen.

A smooth fraction of unity implies a completely smooth fracture surface (as would typically be obtained when fracturing an unreinforced polymer) and a smooth fraction of zero implies a completely rough fracture surface. Round-robin results [10] obtained by ESIS TC 4 on a 50 % by mass glass polyamide composite are shown in Figure B.3. Reference [4] discusses in detail the nature of the results, the interpretation of the fracture surface and the shape of the curve in Figure B.3. Further discussion is beyond the scope of this test method. The results show that, as the smooth fraction tends towards unity, then the K_C value should tend towards the plane strain value for the resin. From these data, an anticipated resin K_C value of around 3,5 MPa·m$^{1/2}$ would be suggested, which does seem reasonable. When the smooth fraction tends towards zero, the fracture process is dominated by fibre pull-out and breaking fibres, so a large K_C would be expected, as was indeed observed.

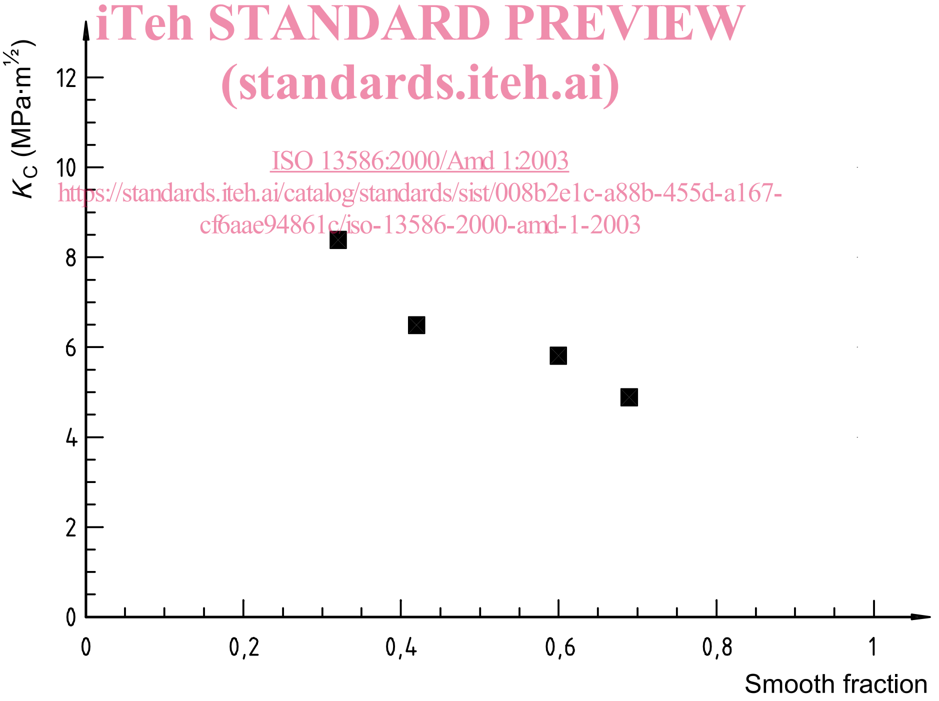


Figure B.3 — K_C plotted against the smooth fraction of the fracture surface for 50 % by mass glass-fibre-reinforced polyarylamide injection mouldings of thickness 2 mm and 5 mm

B.7 Guidelines for comparing the toughness of two different reinforced materials

When comparing toughness values measured for different discontinuous-fibre-reinforced composites, it is recommended that values of K_C versus smooth fraction be plotted for each composite. The values of K_C at a common smooth fraction can then be compared. The larger K_C value will infer the higher toughness. The