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Fibre-reinforced plastic composites — Determination of the mode II fracture resistance for unidirectionally reinforced materials using the calibrated end-loaded split (C-ELS) test and an effective crack length approach

Composites plastiques renforcés de fibres — Détermination de la résistance à la rupture en mode II de matériaux renforcés de fibres unidirectionelles en utilisant l'essai de délaminage (C-ELS) et une approche de la longueur de rupture effective

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Foreword

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ISO 15114 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

This second/third/... edition cancels and replaces the first/second/... edition (), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

Introduction

Previous attempts to determine Mode II delamination resistance curves (R-curves) for composites have been hampered by the experimental difficulty of determining crack length in the absence of any applied beam opening displacement and when a complex damage zone develops ahead of the crack front. The effects of friction in the different Mode II test specimens have also been widely debated and have typically been determined to introduce errors of between 1-3 % in G_{IIC} determination for ELS specimens (n.b. friction effects would appear to be more significant in 3 point loaded end notch flexure (3ENF) [to be standardised by ASTM] and, particularly, in the 4 point loaded (4ENF) test specimen. Stabilised ENF was not popular in round-robin trials).

The test protocol presented here uses the end loaded split test apparatus and specifies an experimental procedure to calibrate the clamping fixture and simultaneously determine the flexural modulus of the specimen. This serves two purposes. Firstly, the clamp calibration has been found to significantly reduce scatter in the results between different test labs and secondly, it provides an accurate means by which crack lengths may be calculated and thus their measurement can be avoided. Although this protocol currently still requires an experimental determination of crack length to be attempted, the use of calculated (or effective crack lengths) is intended to make this requirement redundant when sufficient data have been collected in round-robin programmes to validate the newly proposed scheme. The protocol is a development of that published by ESIS (the European Structural Integrity Society), Technical Committee 4, Polymers and Composites,[1] who carried out the preliminary enabling research through a series of round-robin exercises conducted in 2004 and 2007.

Fibre-reinforced plastic composites — Determination of the Mode II fracture resistance for unidirectionally reinforced materials using the calibrated end loaded split (C-ELS) test and an effective crack length approach

1 Scope

1.1 This International Standard specifies a method for the determination of Mode II shear load delamination resistance. G_{IIc}, (critical energy release rate), of unidirectional fibre-reinforced plastic composites using the Calibrated End Loaded Split (C-ELS) test.
1.2 It is applicable to carbon-fibre and glass-fibre reinforced thermosets and thermoplastics.
1.3 The scope is not necessarily limited to these fibres and lay-ups, but for laminates with other types of fibres or lay-ups, no recommendations for specimen dimensions and fibre volume content are currently available.

Annex A is informative.

2 Normative references

The following referenced documents are indispensable for the application 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 4588, *Adhesives; preparation of metal surfaces for adhesive bonding*

ISO 5893, *Rubber and plastics test equipment; tensile, flexural and compression types (constant rate of traverse); description*

ISO 14125, *Fibre-reinforced plastic composites — Determination of flexural properties*

ISO 15024, *Plastics — Determination of the mode I energy release rate for fibre-composites using the double cantilever beam (DCB) test specimen*

3 Symbols and abbreviated terms

For the purpose of this protocol the following symbols and conventions apply

a measured delamination length, distance between the load-line (intersection of the plane through the pin-hole centre of the load-block normal to the specimen width and the plane of delamination) and the tip of the pre-crack or delamination on the edge of the specimen (Figure 1)

A starter delamination (insert) length, distance between end of specimen on which the load-block is mounted and tip of the insert

b width of the specimen

C	compliance δ/P of the specimen
C_0	initial compliance of the specimen neglecting start-up effects, e.g. due to play in the specimen fixture
C_{max}	compliance of the specimen at maximum load
$C_{5\%}$	initial compliance C_0 of the specimen increased by 5 %
δ	displacement of the cross-head of the testing machine
E_1	elastic modulus determined from "three-point bending" flexural test or from the clamp calibration test
G_{IIC}	critical energy release rate for Mode II shear loading
$2h$	total thickness of the specimen (thickness of each specimen arm is h)
H	height of the load-block
l	total length of the specimen
l_1	distance from the centre of the loading pin to the mid-plane of the specimen beam to which the load-block is attached (Figure 5), i.e. equal to (H+h)/2 if the hole is through the centre of the block.
l_2	distance between the centre of the pin-hole of the load-block and its edge, measured towards the tip of the insert (starter film) or the tip of the Mode I or Mode II precrack (Figure 5), i.e. equal to l_3/2 if the hole is through the centre of the block.
l_3	length of the load-block (Figure 5)
L	free length of the specimen between load-line and clamp
m	slope of a plot of C versus a^3
MAX	maximum load on the load-displacement curve (Figure 7)
NL	onset of non-linearity on the load-displacement curve (Figure 7)
P	load measured by the load-cell of the testing machine
PROP	increments of the delamination length during stable delamination growth (propagation) that are marked on the load-displacement curve (Figure 7)
r^2	correlation coefficient of linear fit
VIS	onset of visually recognisable delamination growth on the edge of the specimen that is marked on the load-displacement curve (Figure 7)
5%	point of intersection of a straight line with the load-displacement curve, with the slope of the straight line corresponding to $C_{5\%}$

4 Principle

This procedure specifies a method for the determination of the delamination resistance of unidirectional fibre-reinforced polymer laminates under Mode II shear load using the Calibrated End Loaded Split (C-ELS) test. The resistance to the initiation and propagation of a delamination is determined from a non-adhesive insert and from a Mode **I** (opening) or a Mode **II** (shear) precrack. The critical energy release rate for Mode **II** loading can be calculated and a resistance-curve (R-curve, i.e. a plot of the critical energy release rate versus delamination length) determined.

5 Apparatus

A tensile testing machine in compliance with ISO 5893, capable of producing a constant load-rate between 1 and 5 mm/min in displacement control should be used. The load-cell should be calibrated and accurate within ± 1 % for the chosen load-range (loads are typically expected to be in the range of 100 – 1000 N). The testing machine shall be equipped with a fixture to introduce the load to the pin inserted into the load-block that allows rotation of the specimen end.

The recommended loading jig requires a clamping arrangement to freely slide in bearings in the horizontal direction (side-ways) with a fixed load point. This is shown schematically in Figure 1. Two test fixtures used in the round-robin programmes(see clause 9) are shown in Figure 2.

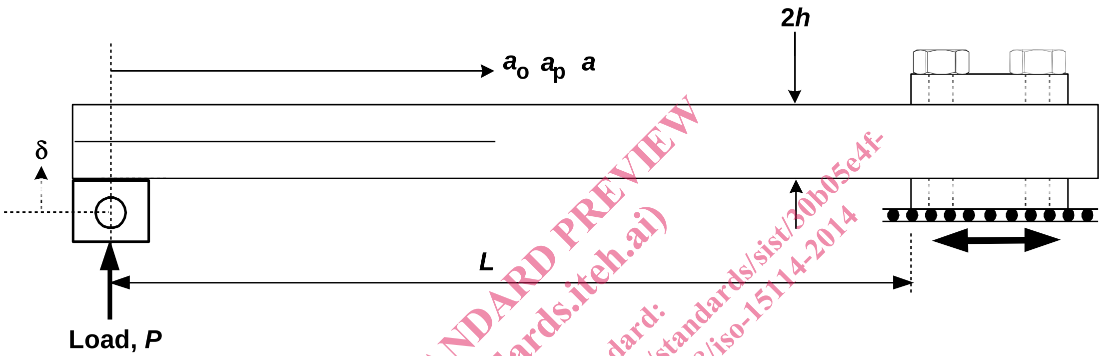

Figure 1 — ELS test specimen showing the clamping fixture and loading

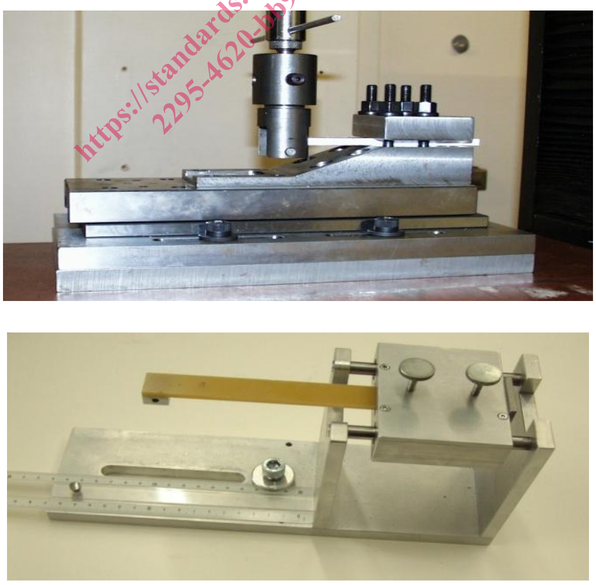

Figure 2 — Two alternative ELS test fixtures

A calibrated lever arm (torque wrench) is required to apply a consistent pressure whilst fixing the specimens into the sliding fixture. During the test, the load shall be applied vertically on the load-block by pulling upward provided the clamp is symmetrical with respect to the specimen. The testing machine shall be equipped with means for recording the complete load-displacement curves (loading and unloading) that allow a determination of the loads and the corresponding displacements with an accuracy of ± 1 %. Vernier callipers or a micrometer should be used to measure the specimen thickness (2*h*) to an accuracy of ± 0.02 mm and the specimen width, *b*, to an accuracy of ± 0.02 mm. A travelling microscope (or video camera) shall be used to monitor the length of the delamination along one edge of the specimen with a magnification of between ×10 and ×25.

6 Specimens

6.1 Preparation of specimens

The recommended specimen width *b* and length *l* are 20 mm and 190 mm, respectively. The specimen length shall not be less than the length of the insert or of the starter delamination plus 110 mm. The free length *L* is typically 100 mm. The recommended specimen thickness (2*h*) is 3 mm for 60 % by volume carbon fibre-reinforced and 5 mm for 60 % by volume glass fibre-reinforced composites.

NOTE Other specimen dimensions may be used, but the specimen width should be between 15 and 30 mm. Increasing the length of the specimen is not critical, shortening will reduce the maximum delamination length that can be investigated and thus yield too few data points for the analysis (see clause 8.4). If specimens are too thin or not sufficiently stiff, delamination growth may not be induced or occur at large displacements only, or permanent deformation of the specimen may occur, invalidating the assumptions of Linear Elastic Fracture Mechanics.

6.2 The initial defect

A crack starter film should be placed at the laminate mid-thickness during the lay-up of the composite panel prior to moulding. The film should be PTFE or other an fluoro-polymer with excellent non-stick properties. The film should be thin (between 10 and 13 microns) to minimise the disturbance of the laminate. The upper service temperature of the film should be greater than the cure temperature of the laminate. When the composite panel is trimmed, the starter film length should be at least 50 mm from the load-line so that the influence of the load-block can be neglected. This initial defect will be extended in mode **I** or mode **II** loading prior to testing (see clause 7.2).

6.3 Attaching the load-block to the specimen

One load-block should be bonded to each specimen for the purposes of load-introduction (Figure 3b). The block should be of the same width as the specimen. Prior to bonding, the load-block and the specimen (in the position where the block will adhere) should firstly be lightly abraded using an abrasive paper or grit blasting. Both the load-block and the specimen should then be cleaned with a solvent.

NOTE A tough, room-temperature cure adhesive (e.g. two part epoxy) is recommended. If bond failure occurs it may be necessary to consult ISO 4588 for a more sophisticated surface treatment procedure. Bonding of the load-block should be done immediately after the surface preparation

The load-block should be well aligned with the specimen and held in position with a clamp while the adhesive sets. Specimen edges should be smoothed prior to determining the dimensions. For the clamp calibration procedure (as described in clause 7.1), one specimen should be prepared with the load-block bonded to the end not containing the insert film as shown in Figure 3a. After the clamp calibration, this load-block may be removed and one may be bonded at the insert end (Figure 3b) to allow the specimen to be tested in mode **II**.

