
**Plastics — Determination of fracture
toughness of films and thin sheets
— Essential work of fracture (EWF)
method**

*Plastiques — Détermination de la ténacité à la rupture des films et
feuilles minces — Méthode du travail essentiel de rupture (EWF)*





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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.

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Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Fracture occurs under plane stress displaying gross ductility in many practical applications of polymeric materials in which they are used as thin sheets or films (e.g. packaging and coatings). It is inappropriate to adopt thicker test specimens, which are generally used in fracture tests, to measure the fracture toughness in such cases. Thicker test specimens suppress crack tip ductility and bring about a change in stress state which does not occur in practice. The essential work of fracture (EWF) method, described in this document, provides toughness measurement under plane stress. The method which is relatively simple is based on a suggestion by Broberg^[1], further developed first by Cotterell, Reddel and Mai for metals^{[2],[3]} and then by a series of workers^{[4]-[9]} for ductile polymers. More recent reviews on this method are given in References ^[10], ^[11], ^[12].

The method assumes that the overall energy associated with fracture can be partitioned into two components: the essential work necessary to create new surfaces in the so-called fracture process zone, and the non-essential work dissipated for the plastic deformation in the surrounding volume, the process zone.

The essential work of fracture has been shown to be a material property, i.e. independent of the specimen geometry, for a given sheet thickness^{[13],[14]}, when the condition of full yielding of the specimen ligament before the onset of crack propagation is fulfilled. In this case, the essential work of fracture is a parameter that gives an intrinsic material property dependent only on thickness and therefore useful in product design. However, the condition of full yielding of the ligament is usually difficult to verify without specific instrumentation, not commonly available in every laboratory.

Even if this condition is not fulfilled, the EWF test method can still be applied to determine the essential work and non-essential work of the fracture energy, which are repeatable and reproducible parameters useful in the development of new materials, in quality control and interlaboratory comparisons.

This document describes the EWF method independently of the verification of the full ligament yielding condition.

Plastics — Determination of fracture toughness of films and thin sheets — Essential work of fracture (EWF) method

1 Scope

1.1 This document specifies the principles and the method for determining the fracture toughness of polymeric films and thin sheets in the crack opening mode (mode I) under plane stress conditions. The essential work of fracture (EWF) method is based on the use of double edge notched tensile (DENT) specimens.

1.2 The method is suitable for use with films or thin sheets, of thickness not greater than 1 mm, made of ductile polymeric materials, in which fracture propagation is stable (crack growth is always driven by the external applied force). If, at any time during the test, brittle fracture occurs, with fast crack propagation driven by the elastic energy stored in the specimen, the sample is not suitable for the application of the present test method.

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 dates 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 2818, *Plastics — Preparation of test specimens by machining*

ISO 4593, *Plastics — Film and sheeting — Determination of thickness by mechanical scanning*

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*

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

3 Terms, definitions and symbols

3.1 Terms and definitions

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

ISO and IEC maintain terminological 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/>

3.1.1

initial distance between the grips

L_g

distance between the grips before the beginning of the test

Note 1 to entry: It is expressed in millimetres (mm).

Note 2 to entry: See [Figure 1](#).

3.1.2

gauge length

L_0

initial distance between the grips L_g ([3.1.1](#)) when the displacement is measured by the change in the distance between the grips during the test

Note 1 to entry: It is expressed in millimetres (mm).

3.1.3

extensometer gauge length

L_{0e}

gauge length ([3.1.2](#)), set equal to the ligament length b , when the displacement is measured by an extensometer

Note 1 to entry: It is expressed in millimetres (mm).

3.1.4

displacement

x

increase in the *gauge length* L_0 ([3.1.2](#)), or in the *extensometer gauge length* L_{0e} ([3.1.3](#)), occurring from the beginning of the test

Note 1 to entry: It is expressed in millimetres (mm).

3.1.5

test speed

v

rate of separation of the gripping jaws

Note 1 to entry: It is expressed in millimetres per minute (mm/min).

3.1.6

overall fracture energy

W_f

energy measured by the area under the force-displacement curves

Note 1 to entry: It is expressed in millijoules (mJ).

3.1.7

specific fracture energy

w_{sf}

ratio of the *overall fracture energy*, W_f ([3.1.6](#)) to the minimum cross-section area of the specimen

Note 1 to entry: The minimum cross-section area of the specimen is given by the ligament length, b , times the thickness, h .

$$w_{sf} = W_f / hb$$

Note 2 to entry: It is expressed in kilojoules per square metre (kJ/m²).

3.1.8**shape factor** β

dimensionless geometrical factor accounting for the shape of the plastically deformed zone around the fracture zone, the volume of which is proportional to hb^2

3.1.9**essential work of fracture** w_e

specific energy to create new surface

Note 1 to entry: It is expressed in kilojoules per square metre (kJ/m²).

3.1.10**non-essential work of fracture** w_p

energy per unit volume dissipated for plastic deformation in the volume around the fracture zone

Note 1 to entry: It is expressed in megajoules per cubic metre (MJ/m³).

3.1.11**maximum stress** $\sigma_{\max}$

maximum force, $F_{\max}$ divided by the minimum cross-section area of the specimen given by the ligament length, b , times the thickness, h

$$\sigma_{\max} = F_{\max}/hb$$

Note 1 to entry: It is expressed in megapascals (MPa).

3.1.12**average maximum stress** σ_m

average of the maximum stress, $\sigma_{\max}$ (3.1.11) values obtained on the 25 specimens used for the essential work of fracture, w_e (3.1.9) determination

Note 1 to entry: It is expressed in megapascals (MPa).

3.2 Symbols

h	specimen thickness, expressed in millimetres (mm)	See Figure 1 .
B	specimen width, expressed in millimetres (mm)	See Figure 1 .
b	un-cracked ligament length, expressed in millimetres (mm)	See Figure 1 .
L	specimen length, expressed in millimetres (mm)	See Figure 1 .
W_s	energy necessary to create new surfaces, expressed in millijoules (mJ)	
W_{pl}	energy dissipated for plastic deformation in the volume around the fracture zone, expressed in millijoules (mJ)	
F	force	
$F_{\max}$	maximum force, expressed in Newton (N)	
$x_{F\max}$	displacement at maximum force, expressed in millimetres (mm)	

4 Principle

The principle of the experimental technique is to prepare a series of double edge-notched tensile specimens (see [Figure 1](#)) having the same thickness (h), width (B) and length (L) and varying ligament