INTERNATIONAL STANDARD

ISO 6603-2

Second edition
2000-10-01

Plastics — Determination of puncture impact behaviour of rigid plastics —

Part 2: Instrumented impact testing

Plastiques — Détermination du comportement des plastiques rigides perforés sous l'effet d'un choc —

Partie 2: Essais de choc instrumentés

Reference number
ISO 6603-2:2000(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 part of ISO 6603 may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 6603-2 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

This second edition cancels and replaces the first edition (ISO 6603-2:1989), which has been technically revised.

ISO 6603 consists of the following parts, under the general title *Plastics — Determination of puncture impact behaviour of rigid plastics*:

— *Part 1: Non-instrumented impact testing*

— *Part 2: Instrumented impact testing*

Annexes A to E of this part of ISO 6603 are for information only.

Plastics — Determination of puncture impact behaviour of rigid plastics —

Part 2: **Instrumented impact testing**

1 Scope

This part of ISO 6603 specifies a test method for the determination of puncture impact properties of rigid plastics, in the form of flat specimens, using instruments for measuring force and deflection. It is applicable if a force-deflection or force-time diagram, recorded at nominally constant striker velocity, is necessary for detailed characterization of the impact behaviour.

ISO 6603-1 can be used if it is sufficient to characterize the impact behaviour of plastics by a threshold value of impact-failure energy based on many test specimens.

It is not the purpose of this part of ISO 6603 to give an interpretation of the mechanism occurring on every particular point of the force-deflection diagram. These interpretations are a task for scientific research.

NOTE See also clause 1 of ISO 6603-1:2000.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 6603. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 6603 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2602:1980, *Statistical interpretation of test results — Estimation of the mean — Confidence interval.*

ISO 6603-1:2000, *Plastics — Determination of puncture impact behaviour of rigid plastics — Part 1: Non-instrumented impact testing*.

3 Terms and definitions

For the purposes of this part of ISO 6603, the following terms and definitions apply.

3.1
impact velocity
v_0
velocity of the striker relative to the support at the moment of impact

NOTE Impact velocity is expressed in metres per second (m/s).

3.2
force
F
force exerted by the striker on the test specimen in the direction of impact

NOTE Force is expressed in newtons (N).

3.3
deflection
l
relative displacement between the striker and the specimen support, starting from the first contact between the striker and the test specimen

NOTE Deflection is expressed in millimetres (mm).

3.4
energy
E
energy expended in deforming and penetrating the test specimen up to a deflection l

NOTE 1 Energy is expressed in joules (J).

NOTE 2 Energy is measured as the integral of the force-deflection curve starting from the point of impact up to a deflection l.

3.5
maximum force
F_M
maximum force occurring during the test

See Figures 1 to 4.

NOTE Maximum force is expressed in newtons (N).

3.6
deflection at maximum force
l_M
deflection that occurs at maximum force F_M

See Figures 1 to 4.

NOTE Deflection at maximum force is expressed in millimetres (mm).

3.7
energy to maximum force
E_M
energy expended up to the deflection l_M at maximum force

See Figures 1 to 4.

NOTE Energy to maximum force is expressed in joules (J).

3.8
puncture deflection
l_P
deflection at which the force has dropped to half the maximum force F_M

See Figures 1 to 4 and note to 3.9.

NOTE Puncture deflection is expressed in millimetres (mm).

3.9
puncture energy
E_P
energy expended up to the puncture deflection l_P

See Figures 1 to 4 and note 2.

NOTE 1 Puncture energy is expressed in joules (J).

NOTE 2 When testing tough materials, a transducer mounted at some distance from the impacting tip may record frictional force acting between the cylindrical part of the striker and the punctured material. The corresponding frictional energy shall not be included in the puncture energy, which, therefore, is restricted to that deflection, at which the force drops to half the maximum force F_M.

3.10
impact failure
mechanical behaviour of the material under test which may be either one of the following types (see note):

a) **YD** **y**ielding (zero slope at maximum force) followed by **d**eep drawing

b) **YS** **y**ielding (zero slope at maximum force) followed by (at least partially) **s**table cracking

c) **YU** **y**ielding (zero slope at maximum force) followed by **u**nstable cracking

d) **NY** **n**o **y**ielding

See Figures 1 to 4.

NOTE Comparison of Figures 2 and 3 shows puncture deflection l_P and puncture energy E_P are identical for the failure types YS and YU. As shown in Figure 4, identical values at maximum and at puncture are found for the deflection as well as the energy in the case of failure type YU. For complex behaviour see annex A.

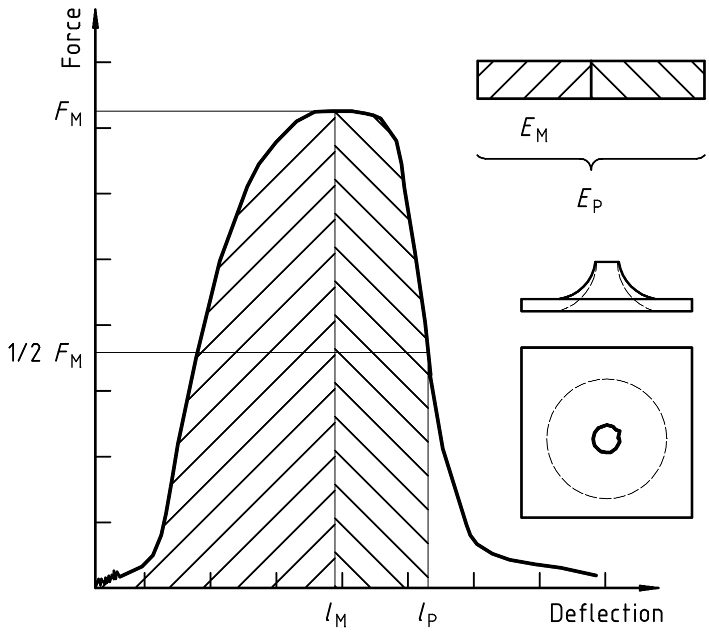


Figure 1 — Example of force-deflection diagram for failure by yielding (zero slope at maximum force) followed by deep drawing, and typical appearance of specimens after testing (with lubrication)

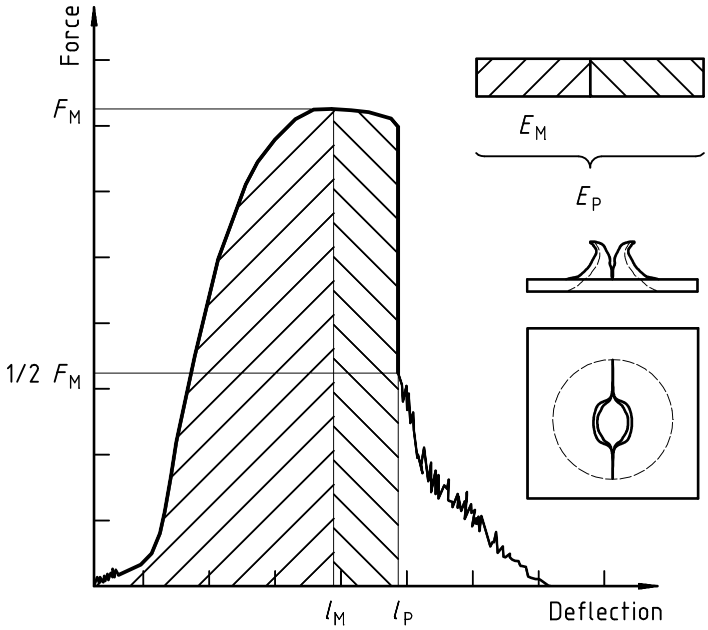
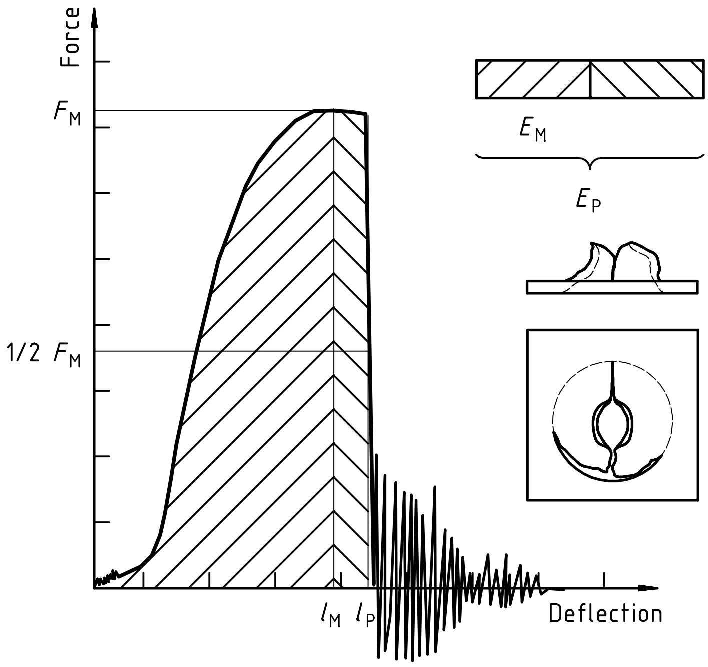


Figure 2 — Example of force-deflection diagram for failure by yielding (zero slope at maximum force) followed by stable crack growth, and typical appearance of specimens after testing (with lubrication)



NOTE Natural vibration of the force detector can be seen after unstable cracking (striker and load cell).

Figure 3 — Example of force-deflection diagram for failure by yielding (zero slope at maximum force) followed by unstable crack growth, and typical appearance of specimens after testing (with lubrication)

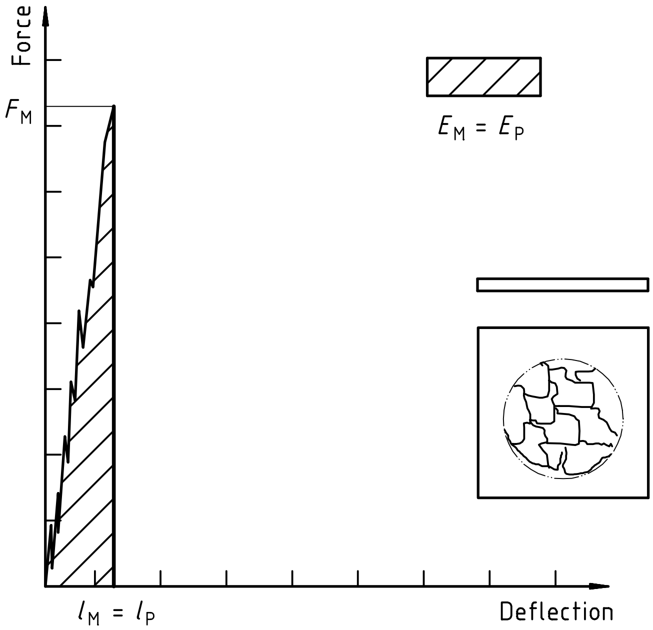


Figure 4 — Example of force-deflection diagram for failure without yielding followed by unstable crack growth, and typical appearance of specimens after testing (with lubrication)

4 Principle

The test specimen is punctured at its centre using a lubricated striker, perpendicularly to the test-specimen surface and at a nominally uniform velocity. The resulting force-deflection or force-time diagram is recorded electronically. The test specimen may be clamped in position during the test.

The force-deflection diagram obtained in these tests records the impact behaviour of the specimen from which several features of the behaviour of the material may be inferred.

5 Apparatus

5.1 Testing device, consisting of the following essential components:

— energy carrier, which may be inertial-mass type or hydraulic type (see 5.1.1);

— striker, which shall be lubricated;

— specimen support with a recommended clamping device.

The test device shall permit the test specimen to be punctured at its centre, perpendicular to its surface at a nominally constant velocity. The force exerted on the test specimen in the direction of impact and the deflection from the centre of the test specimen in the direction of impact shall be derivable or measurable (see Figure 5).

5.1.1 Energy carrier, with a preferred impact velocity v_0 of (4,4 ± 0,2) m/s (see 3.1 and note to 3.1). To avoid results, which cannot be compared due to the viscoelastic behaviour of the material under impact, the decrease of velocity during the test shall not be greater than 20 %.

NOTE For brittle materials, an impact velocity of 1 m/s may be found to be more appropriate because it reduces the level of vibration and noise and improves the quality of the force-deflection diagram (see annex A).

5.1.1.1 Hydraulic type, consisting of a high-speed testing machine with suitable attachments.

Any deviation of the velocity of the striker relative to the support during impact shall be controlled, for example by recording deflection-time curves and checking the slope.

5.1.1.2 Inertial-mass type, which may be accelerated gravitationally, spring- or pneumatically-assisted. Suitable devices are falling-dart machines.

In the case of a gravitationally accelerated mass and neglecting frictional losses; the impact velocity v_0 corresponds to a drop height H_0 of the energy carrier of (1,0 ± 0,1) m.

For all inertial-mass-type energy carriers the impact velocity shall be measured by velocity-measuring sensors placed close to the point of impact. The maximum decrease of velocity during test results in the minimum mass, m_C, of the carrier according to equations (1) and (2) (see note).

$$m_C \geqslant 6\, E^*/v_0^2 \tag{1}$$

$$m_C \geqslant 0{,}31\, E^* \quad \text{for } v_0 = 4{,}4 \text{ m/s} \tag{2}$$

where

m_C is the mass of the energy carrier, expressed in kilograms;

E^* is the highest puncture energy to be measured, expressed in joules (see 3.9);

v_0 is the impact velocity (4,4 m/s, see 3.1).

NOTE In many cases, a weighted energy carrier with a total mass m_C of 20 kg has been found to be sufficient for the larger striker and of 5 kg for the smaller striker (see 5.1.2).

5.1.2 Striker, preferably having a polished hemispherical striking surface of diameter (20,0 ± 0,2) mm. Alternatively, a (10 ± 0,1) mm diameter striking surface may be used.

NOTE 1 The size and dimensions of the striker and condition of the surface will affect the impact results.

The striker shall be made of any material with sufficient resistance to wear and of sufficiently high strength to prevent plastic deformation. In practice, hardened steel or materials with lower density (i.e. titanium) have been found acceptable.

The hemispherical surface of the striker shall be lubricated to reduce any friction between the striker and the test specimen (see note 2 and annex B).

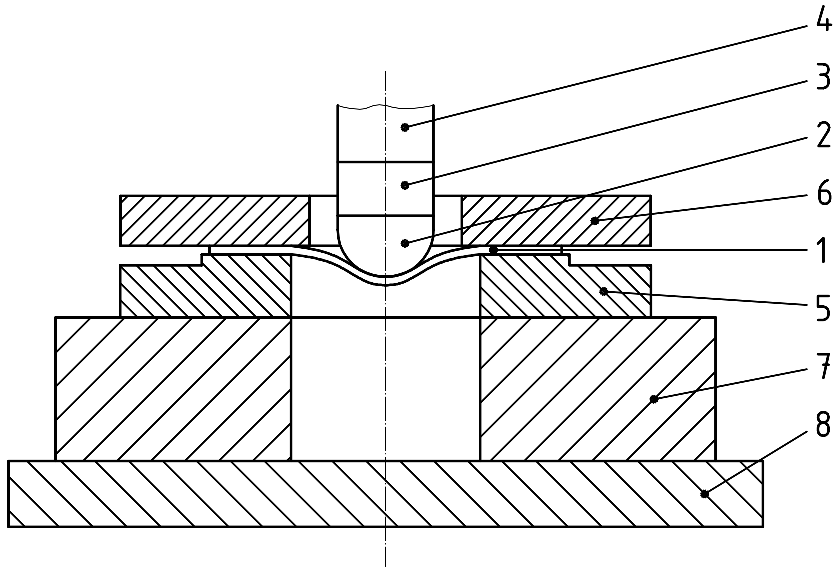
NOTE 2 Test results obtained with a lubricated or dry striker are likely to be different. Below ambient temperatures, condensation can act as a lubricant.

The load cell shall be located within one striker diameter from the tip of the striker, i.e. mounted as closely as possible to the tip to minimize all extraneous forces and sufficiently near to fulfil the frequency-response requirement (see 5.2). An example is shown in Figure 5.

5.1.3 Support ring (see Figures 5 and 6)**,** placed on a rigid base and designed such that air can not be trapped under the test specimen, thus avoiding a possible spring effect. Below the support ring, there shall be sufficient space for the striker to travel after total penetration of the test specimen. The recommended inside diameter of the support ring is (40 ± 2) mm, or alternatively (100 ± 5) mm, with a minimum height of 12 mm.

5.1.4 Base for test device, firmly mounted to a rigid structure so that the mass of the base (see Figure 5) is of sufficient stiffness to minimize deflection of the specimen support.

When calculating the deflection from the kinetics of the accelerated mass, a minimum mass ratio m_B/m_C of 10 between base (m_B) and energy carrier (m_C) shall be used. This prevents the base from being accelerated by more than 1 % of the impact speed up to the end of the test. For directly measured deflections, this minimum ratio is a recommendation only. For the principles of this specification see annex B of ISO 179-2:1997 [5].



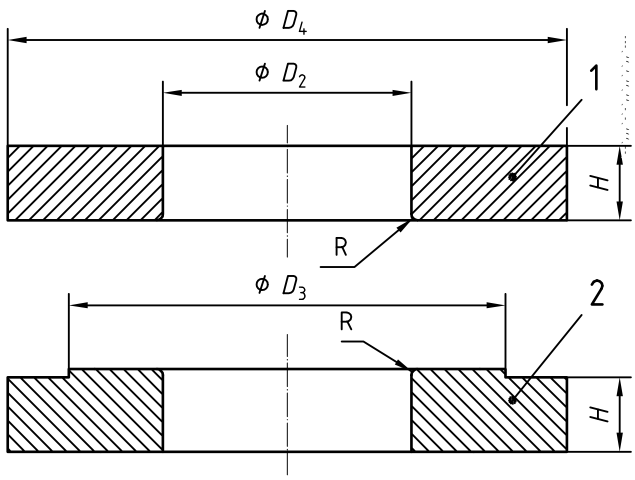
Key

1 Test specimen
2 Hemispherical striker tip
3 Load cell (preferred position)
4 Shaft
5 Test specimen support
6 Clamping ring (optional)
7 Base
8 Acoustical isolation (optional)

Figure 5 — Example of test device

Dimensions in millimetres

Specimen type	Side of square or diameter of disc	
	60	**140**
D_2	40 ± 2	100 ± 5
D_3	60	140
D_4	⩾ 90	⩾ 200
H	12	12
R	1	1



Key

1 Clamping ring (optional)
2 Test specimen support

Figure 6 — Clamping device (schematic)

5.1.5 Clamping device (optional), consisting of two parts, a supporting ring and a clamping ring (see Figure 6), for annular test specimens. The recommended inside diameter of the clamping device is (40 ± 2) mm, alternatively (100 ± 5) mm. The clamp may work by shape or by application of force to the specimen. A clamping force of 3 kN is recommended for the latter (see note).

NOTE Pneumatically and screw-operated clamps have been successfully employed. The results obtained for clamped and unclamped specimens are likely different (see annex C).

5.2 Instruments for measuring force and deflection:

5.2.1 Force measurement system, for measuring the force exerted on the test specimen. The striker may be equipped with strain gauges or a piezoelectric load transducer which shall be placed close to the striker tip. Any other suitable method of force measurement is also acceptable. The measuring system shall be able to record forces with an accuracy equal to or within 1 % of the relevant peak force.

The force measurement system shall be calibrated as set-up ready for measurement. Calibration may be performed statically (for example, by imposing known loads on the striker) or dynamically (see for example reference [4]). Errors in force measurement after calibration shall be less than ± 0,5 % of the forces used for calibration.

As the duration of the test is very short, only electronic load cells with a high natural frequency shall be used (see note 1). The natural frequency f_n of the test device (striker and load cell) shall conform to the following condition:

$$f_n \geqslant 6 \text{ kHz}$$

For interpretation of complex force-deflection curves, even higher values of the natural frequency f_n may be necessary (see annex A). For detecting the first damage depicted in Figure A.2, the natural frequency shall comply with the following condition (see note 2):

$$f_n \geqslant 5/\Delta t_E$$

where

f_n is the natural frequency, expressed in kilohertz;

Δt_E is the event time of the relevant detail of the force-deflection curve, expressed in milliseconds (see Figure A.2).

The natural frequency can be checked by studying the oscillations following brittle or splintering failure (see Figure 3).

For the bandwidth of the amplifier train (direct current or carrier frequency amplifier) the lower bandwidth limit is 0 Hz, and the upper bandwidth limit shall be at least 100 kHz, combined with a sampling frequency of at least 100 kHz (see notes 3 and 4).

NOTE 1 An example of such a measurement train is a piezoelectric load cell, mounted between the striker and the shaft (see Figure 5) and connected to a charge amplifier.

NOTE 2 If, for example, the increase in deflection $\Delta t_E \cdot v_0$ during the event (see Figure A.1) is only 1 mm (10^{-3} m), at an impact velocity v_0 of 4,4 m s^{-1}, then the corresponding event time is $\Delta t_E = [(10^{-3} \text{ m})/(4{,}4 \text{ m s}^{-1})] = 2 \times 10^{-4}$ s, resulting in the minimum natural frequency of $f_n \geqslant [5/(2 \times 10^{-4} \text{ s})] = 25$ kHz.

NOTE 3 In the testing of very brittle products, elastic impact may cause resonant oscillations, thus making it difficult to interpret the force-deflection curve (see annex A). In this case, it can be useful to carry out low-pass filtering on the recorded force-time diagram or parts of it, although the accuracy of the measurements is thereby reduced.

If post-test filtering is used, the type of filter and its essential characteristics are reported in the test report [see 10 i)].

NOTE 4 Vibration of the test specimen (see Figure A.3) and of the test device as well as uniform noise on the trace generates uncertainties of the measured maximum force (see 3.5) but has virtually no effect on the puncture energy (see 3.9).

5.2.2 Deflection measurement system, consisting of an electronic transducer for the determination of the deflection of the test specimen to yield a force-deflection diagram.

In most cases the testing devices for force and deflection show a difference of their transit times generating a time offset in the force-deflection curve, which increases proportionally to the impact velocity. The time traces are to be synchronized by a time shift corresponding to this transit-time difference.

With inertial-mass type machines, it is possible to measure a force-time diagram only and to calculate the deflection in accordance with 8.2.1.

5.3 Thickness gauge, as specified in 5.2 of ISO 6603-1:2000.

6 Test specimens

6.1 Shape and dimensions

See 6.1 in ISO 6603-1:2000.

6.2 Preparation of test specimens

See 6.2 in ISO 6603-1:2000.

6.3 Non-homogeneous test specimens

See 6.3 in ISO 6603-1:2000.

6.4 Checking the test specimens

See 6.4 in ISO 6603-1:2000.

6.5 Number of test specimens

If the test is conducted under constant conditions, at least five or, in cases of arbitration, 10 test specimens are required. If the measurements are to be made as a function of temperature, relative humidity or some other parameter, the number of test specimens may be reduced depending on the statistical scattering of the test results.

If a large number of test specimens is required, for example to determine the temperature dependence of the measured quantities, the test specimens shall be selected in accordance with statistical principles.

6.6 Conditioning of test specimens

See 6.6 in ISO 6603-1:2000.

7 Procedure

7.1 Test atmosphere

See 7.1 in ISO 6603-1:2000.

7.2 Measurement of thickness

See 7.2 in ISO 6603-1:2000.

7.3 Clamping the test specimen (optional)

See 7.3 in ISO 6603-1:2000.

7.4 Lubrication

See 7.4 in ISO 6603-1:2000

7.5 Puncture test procedure

Place the test specimen on the specimen supporting ring (5.1.4) and clamping device (5.1.6) as appropriate.

Conduct the puncture test with the impact velocity specified in 5.1.2. Ensure that the velocity does not change during the puncture process by more than 20 % by checking the deflection-time trace or by using equations (1) and (2) with the energy E^* equal to E_P.

8 Calculations

8.1 Expression of results

Take the force-time curve or, where directly measured, the force-deflection curve as the test result. Other results shall be calculated employing these data.

For the purposes of routine characterization and in the absence of other conditions described in the International Standard for the material concerned, the values of the following properties shall be taken as results of the test:

e) l_M is the deflection at maximum force (see 3.6), expressed in millimetres;

f) E_M is the energy to maximum force (see 3.7), expressed in joules;

g) F_M is the maximum force (see 3.5), expressed in newtons;

h) l_P is the puncture deflection (see 3.8), expressed in millimetres;

i) E_P is the puncture energy (see 3.9), expressed in joules.

Additionally, the type of failure as defined in 3.10 and by Figures 1 to 4 should be reported. For failure types YS and YU, ensure that frictional forces do not affect the force-deflection diagram at large deflections (see note in 3.10). For complex behaviour see annex A.

8.2 Calculation of deflection

If the test results are in the form of a force-deflection curve, the maximum force F_M, the deflection at maximum force l_M and the puncture deflection l_P can be read directly from the graph. The energy to maximum force E_M and the puncture energy E_P (see Figures 1 to 4) can be determined by measuring the area under the force-deflection curve, using a planimeter, computer analysis or other suitable means.

For inertial-mass type energy carriers (see 5.1.2) that show nominally no frictional loss during impact, the deflection of the test specimen may not directly be measured by a displacement measuring system. In this case, it shall be calculated from the force-time trace using equation (3).

$$l(t) = v_0 t - \frac{1}{m_C} \cdot \int_0^t \left[\int_0^{t_1} F(t) \mathrm{d}t_1 \right] \mathrm{d}t + \frac{1}{2} g t^2 \qquad (3)$$

where

v_0 is the impact velocity (see 3.1), expressed in metres per second;

t is the time after impact at which the deflection is to be calculated, expressed in seconds;

$F(t)$ is the force measured at any time after the impact, expressed in newtons;

$l(t)$ is the deflection (see 3.3), expressed in metres;

m_C is the falling mass of the energy carrier, expressed in kilograms;

g is the local acceleration due to gravity, expressed in metres per second squared.

Since the last term of equation (3) is only valid for an energy carrier moving vertically, its relative contribution increases with decreasing impact velocity (drop height of the striker).

8.3 Calculation of energy

Once the force and deflection are known for identical times during impact, the energy expended up to specific times t_j shall be calculated by determining the area under the force-deflection curve according to equation (4) (see note 1).

$$E_j = \int_0^{l_j} F(l)\mathrm{d}l \tag{4}$$

where

$F(l)$ is the force at the deflection l, expressed in newtons;

l is the deflection, expressed in metres;

j is a subscript denoting one of the following points:

M = maximum

P = puncture;

E is the energy, expressed in joules.

NOTE 1 In place of a graph, or in conjunction with it, the values of forces and resultant deflections may be recorded electronically. Utilising electronic integration, the energy to maximum force and the puncture energy can be determined.

In the case of frictionless energy carriers, impacting horizontally, the energy can also be calculated without developing the deflection/time trace, using the equations (5) and (6) (see note 2).

$$E_j = E_{j\mathrm{a}} \cdot \left(1 - \frac{E_{j\mathrm{a}}}{4E_\mathrm{c}}\right) \tag{5}$$

$$E_{j\mathrm{a}} = v_0 \int_0^{t_j} F(t_1)\mathrm{d}t_1 \tag{6}$$

where

$E_{j\mathrm{a}}$ is the approximate value of the energy, calculated assuming a constant velocity v_0, expressed in joules;

E_c is the energy of the energy carrier just before the impact, expressed in joules;

$F(t_1)$ is the force at the time t_1, expressed in newtons.

NOTE 2 Equation (5) is based on the conservation of energy and momentum, omitting the influence of gravity. The second term within brackets is less than 5 % if the ratio E^*/E_c of the maximum energy to be measured to the capacity of the energy carrier is less than 0,2.

8.4 Statistical parameters

Calculate the arithmetic mean, the standard deviation and the coefficient of variation of the properties named in 8.1 for each test series (see ISO 2602).

8.5 Significant figures

Report all calculated mean values to two significant figures.

9 Precision

The precision of this test method is not known because interlaboratory data are not available. When interlaboratory data are obtained, a precision statement will be added with the next revision.

10 Test report

The test report shall include the following information:

a) a reference to this part of ISO 6603

b) the test parameters, identified as follows:

   — the support ring diameter 40 mm (or 100 mm),

   — the striker diameter 20 mm (or 10 mm),

   — whether the specimen was clamped C (or unclamped U),

   — the impact velocity 4,4 m/s (or other),

   e.g. "Instrumented puncture test ISO 6603-2/40/20/C/4,4";

c) the type, identification mark, origin, date of receipt and other pertinent data concerning the test material, such as coated, textured and orientation of texture;

d) the shape and dimensions of the test specimens;

e) the method of preparation of the test specimens;

f) the average thickness of the test specimens, measured in accordance with 7.2;

g) the test conditions and, if applicable, the conditioning procedure;

h) the number of test specimens tested;

i) the appearance of the test specimens after the test (optional);

j) the impact-failure criterion that was agreed upon, if different from that given in 3.8;

k) the natural frequency of the force-measuring device;

l) the type and essential characteristics of post-test filtering, if used;

m) the individual test results, arithmetic mean, standard deviation or coefficient of variation and the 95 % confidence intervals of these mean values of the following properties, if required:

— the maximum force F_M, expressed in newtons;

— the deflection at maximum force l_M , expressed in millimetres;

— the energy to maximum force E_M, expressed in joules;

— the puncture energy E_P, expressed in joules;

— the puncture deflection l_P, expressed in millimetres;

n) the type of failure (see 3.10);

o) the force-deflection or force-time curves;

p) the date of the test.

Annex A
(informative)

Interpretation of complex force-deflection curves

In many impact experiments, the force-deflection diagram is more complicated than those shown in Figures 1 to 4. In such cases, a point of damage D cannot be derived in any simple way from the force-deflection diagram using a standard procedure.

However, by means of an accurate comparison of the force-deflection diagram with the specimen tested, in many cases a reliable statement about the agreed point of damage can be made.

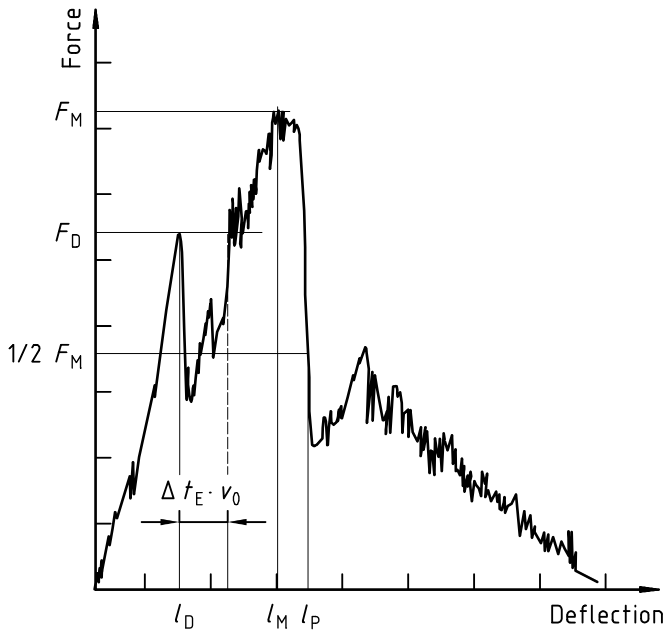
Practically, an impact experiment can be conducted with a lower energy (falling height) using inertial mass systems, respectively lower testing speed using hydraulically driven systems. In the first case, the available energy shall be selected slightly larger than the assumed puncture energy.

This method is especially recommended for the testing of brittle or textile-reinforced materials. In these cases, a dip in the rising part of the force-deflection diagram is found indicating first damage, D (see Figure A.1).

Although for brittle and fibre-filled materials the maximum force usually corresponds to the force of crack initiation, very often a second peak occurs due to the formation of the crack necessary for the penetration of the striker (see Figures A.1 and A.2).

Many peaks in the force-deflection diagram can appear due to resonance (see Figure A.3). The interpretation of such a diagram is very difficult, even when the condition given in 5.2.1 on the natural frequency of the test device is met.

A visual assessment of the broken specimen is then the only way of describing the fracture behaviour under impact.



First damage (D) followed by puncture (P), where Δt_E is the event time of the first damage in the force-time trace and v_0 the impact velocity.

Figure A.1 —Schematic force-deflection diagram for brittle or textile-fibre reinforced material indicating first damage followed by puncture

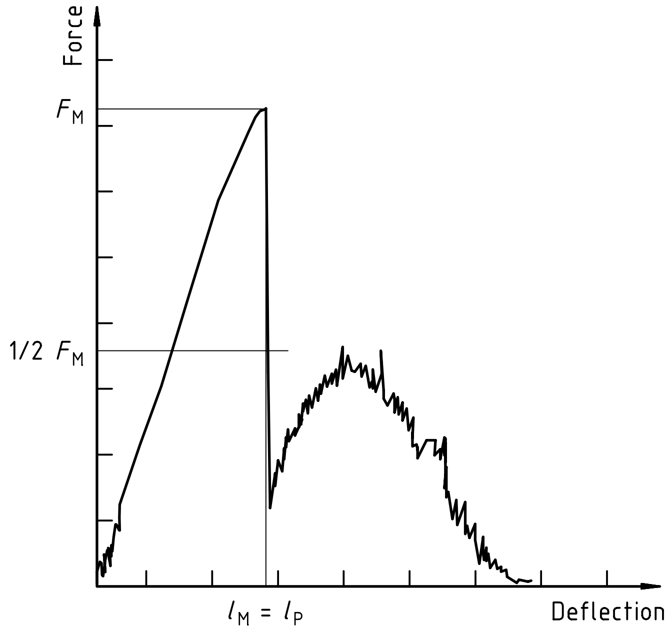


Figure A.2 — Schematic force-deflection diagram for a brittle or textile-fibre reinforced material

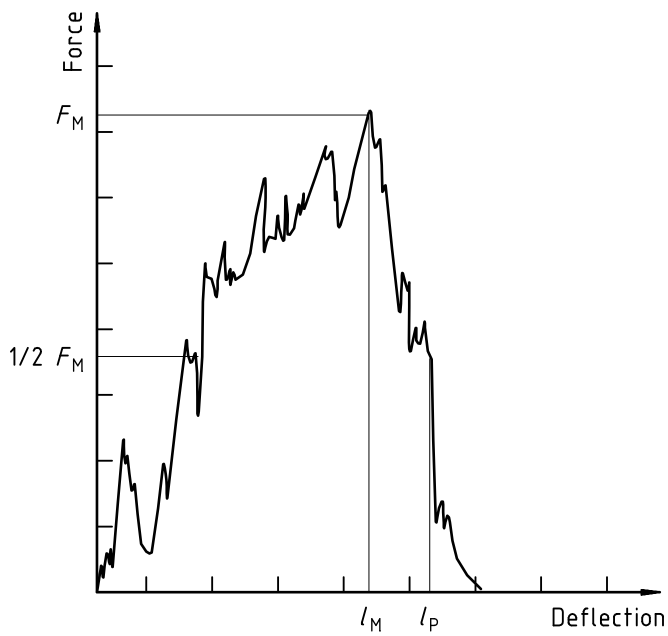


Figure A.3 — Schematic force-deflection diagram for splintering material, superposed by strong resonance of the test specimen

Annex B
(informative)

Friction between striker and specimen

As a result of biaxial symmetric stress, the failure of the specimen in a puncture test is expected to occur at the point of maximum theoretical stress, i.e. at the centre of the specimen. However, a frequent observation is a circular crack and a subsequent punching out of a round cap. Evidently, this effect results from a drop in the amount of stress at the top point due to friction. The maximum stress and consequently the locus of failure shifts to the circle of contact between the striker and the specimen (see Figure B.1). The part of the specimen volume, therefore, which stores and absorbs energy during the test, strongly depends on friction. Additionally, other disadvantages may occur due to friction.

- Due to the action of an unknown amount of friction, the forces appearing in a puncture test are increased in an uncontrolled way.
- For some materials a friction-caused abrasion of the polymer can be observed. The abraded material clings onto the striker tip together with other deposits resulting, for example, from additives like demoulding agents and external lubricants. As a result of this deposit, a distinct increase in scatter occurs which can only be reduced by cleaning the tip carefully before each test (see Figure B.1).
- The type of cooling has a strong influence on puncture ductility. When cold specimens are tested at room temperature, a thin film of water or ice from the atmospheric humidity condenses on the specimen surface and acts as a lubricant. Therefore, an apparent step in the temperature-dependent ductility occurs at about 0 °C (see Figure B.2).
- The results of puncture may be influenced by the striker material, its surface roughness and that of the specimen tested.

Lubricating or greasing the striker overcomes these disadvantages. The failure of the specimens occurs at its centre, as expected. By concentrating the plastic deformation at the centre of the specimen instead of spreading it over a large, undefined portion of the specimen volume, scattering is reduced and comparable data can be obtained. The values obtained with a lubricated striker are unequivocal lower limits of the tested mechanical properties of the material.

Tests at a high standard test speed of 4,4 m/s using lubricants in the viscosity range of 0,01 Pa·s < η < 10 Pa·s have shown that the type of lubricant is not relevant. At test speeds lower than 1 m/s, however, low-viscosity lubricants may be squeezed out of the contact area and can result in diverging values. At test speeds lower than 10^{-2} m/s, results tend to be similar to those of specimens tested without lubrication. Sufficient lubrication, however, generally can be controlled by checking the locus of failure (see Figure B.1).

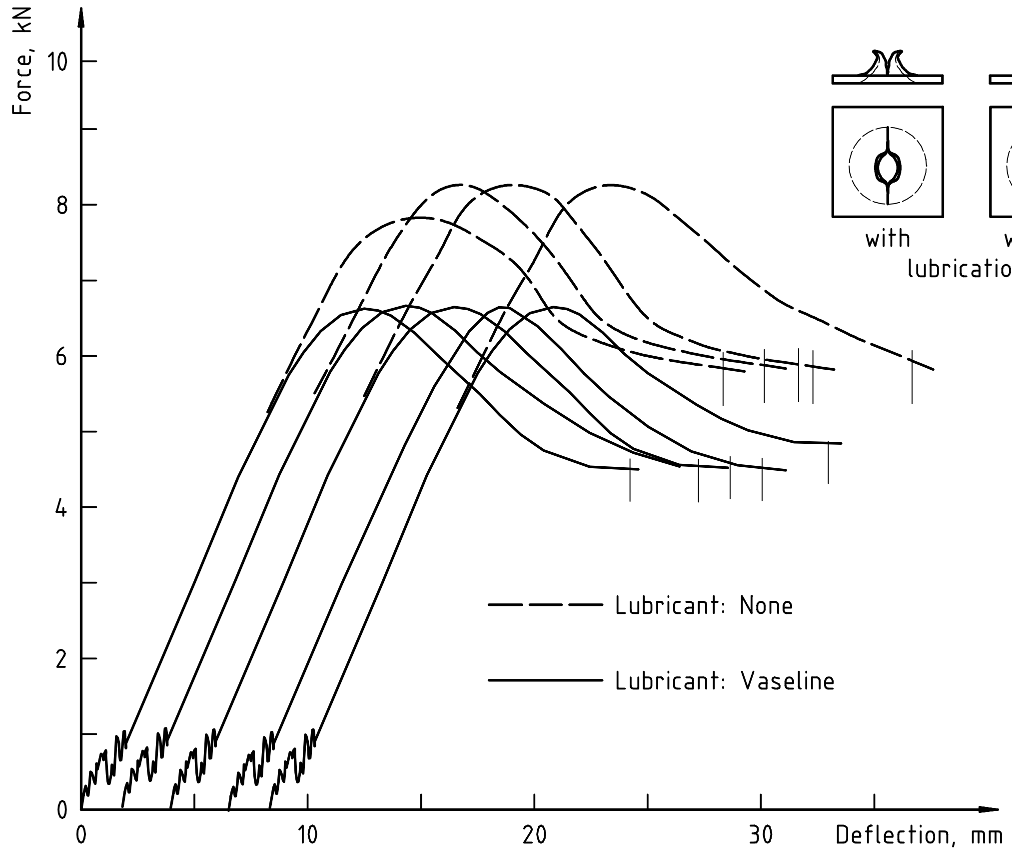


Figure B.1 — Force-deformation curves and the appearance of test specimens with tough failing, tested with and without lubrication of the striker, for example using Vaseline

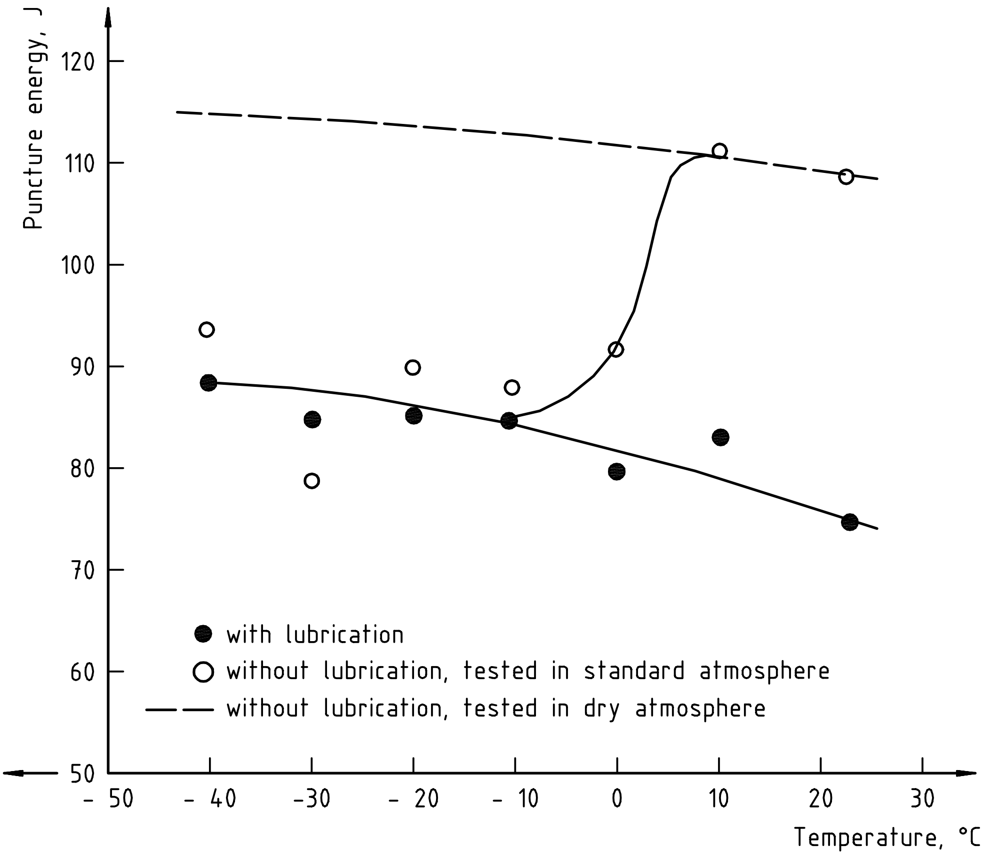


Figure B.2 — Puncture energy as a function of temperature with and without specimen lubrication

Annex C
(informative)

Clamping of specimens

The method of supporting and holding the specimen may have some influence on the puncture behaviour of the given material. Testing unclamped specimens in the case of an unlubricated striker may lead to deformations of the supported outer region of the specimens, making the test specimen change from an initially planar shape to a conical, wavy shape. This additional deformation energy may cause the puncture toughness to be apparently higher than that of clamped specimens which have been prevented from buckling. Until now, however, only minor effects have been found which have been reduced by lubricating the striker. Furthermore, higher vibration amplitudes can be shown for unclamped test specimens.

A clamping device cannot fully prevent the test specimen from radial slippage as claimed in the first edition of this part of ISO 6603 (ISO 6603-2:1989) and is not necessary. It is more important to prevent the supported part of the test specimen from buckling. This can be achieved by clamping the test specimen with sufficient force or by clamping by shape (small clamping force, but rigid construction). Clamping by shape and by friction have not shown significant differences in the puncture behaviour.

Annex D
(informative)

Tough/brittle transitions

Tough/brittle transitions are often encountered in a series of tests carried out at decreasing temperature. At such transitions, the puncture energy, for example, decreases and/or the type of failure changes. The cause of these transitions are molecular relaxation processes which become effective only above a certain temperature and which increase the absorption of the impact energy.

Test time plays a role similar to that of temperature, i.e. if the test time is shortened by increasing the impact velocity, the transition temperature is shifted to higher values. The relationship between time and temperature is determined by the temperature dependence of molecular relaxation times, which is approximated by the Arrhenius equation:

$$t = t_0 \exp (E^*/\mathrm{k}T)$$

where

t is the relaxation time or test time;

T is the absolute temperature of the tough/brittle transition;

E^* is the apparent activation energy.

Within a transition region, a wide scatter of results often is observed, for example the failure of the test specimens being brittle or tough at the same temperature. In high-density polyethylene, for example, such a transition region is found in the temperature range between −140 °C and −105 °C, depending on the relative molecular mass and degree of crystallinity.

Tough/brittle transitions can be recognized by means of the force-deflection diagram or from the appearance of the damaged specimens (see Figures 1 to 4).

For plastics exhibiting a tough/brittle transition, the performance and evaluation of impact tests are subject to certain limitations, since the specimens of a single test series are to be assigned to two different parent populations, namely one exhibiting tough behaviour and one exhibiting brittle behaviour. In such cases, the means and variances are not statistically defined over the entire range of measurements. Nevertheless, it is helpful to employ the mean and standard deviation calculated from the individual measurements to characterize the behaviour of the material.

Where there is a sufficient number of measurements for both parent populations, the characteristic quantities can be calculated separately for the brittle and the tough test specimens. If necessary, the choice of assigning measurements to one of the two parent populations should be decided by use of the statistical procedure normally employed for this purpose.

Annex E
(informative)

Influence of specimen thickness

The forces obtained in a puncture test depend on the thickness of the test specimen. By increasing the thickness of the test specimen the resulting forces are greater than proportional. This is due to the different deformation processes occurring in a puncture test, i.e. small deflections cause biaxial flexural loads to turn into biaxial tension with increasing deflection.

In the region of linear elastic material behaviour, the relationship between the thickness and the resulting force can be described as $F(l) \sim w^n$. The exponent n changes during the test from $n = 1$ (flexural deformation) to $n = 3$ (tension) in a way depending on the material and the test conditions [2], [3]. Therefore, the normalisation of a complete force-deflection curve to a given thickness is impossible. For selected properties, however, the thickness dependence can be fitted [see equations (E.1) and (E.2)]. As an example, for polycarbonate sheets the maximum force and the puncture energy depending on the thickness w are shown in Figure E.1 in a double-logarithmic plot.

$$F_\mathrm{M} \sim w^n$$

$$E_\mathrm{P} \sim w^m$$

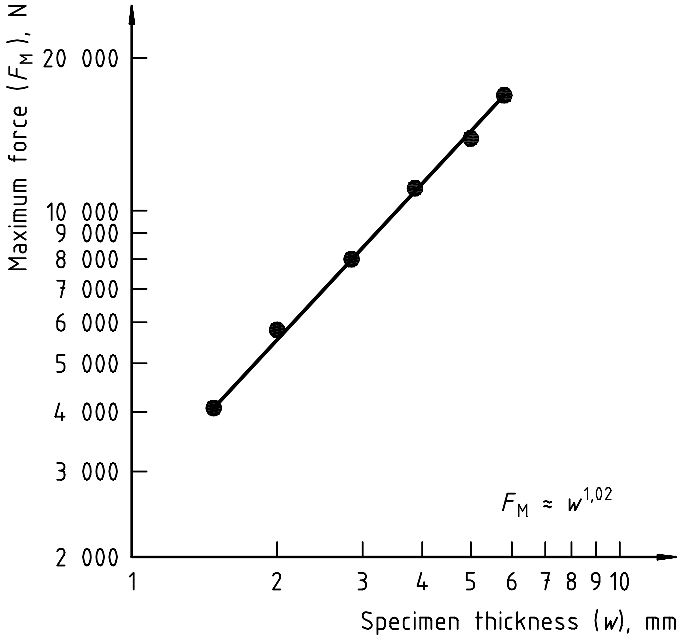
Table E.1 shows the typical range of the exponents n and m for the maximum force and the puncture energy found for a series of thermoplastics and the relative deviations caused by a relative scatter of the thickness of 5 %.

Table E.1 — Exponents, n or m, for fitting the thickness dependence of maximum force F_M and puncture energy E_P and the effect of the scatter of thickness on that of the properties

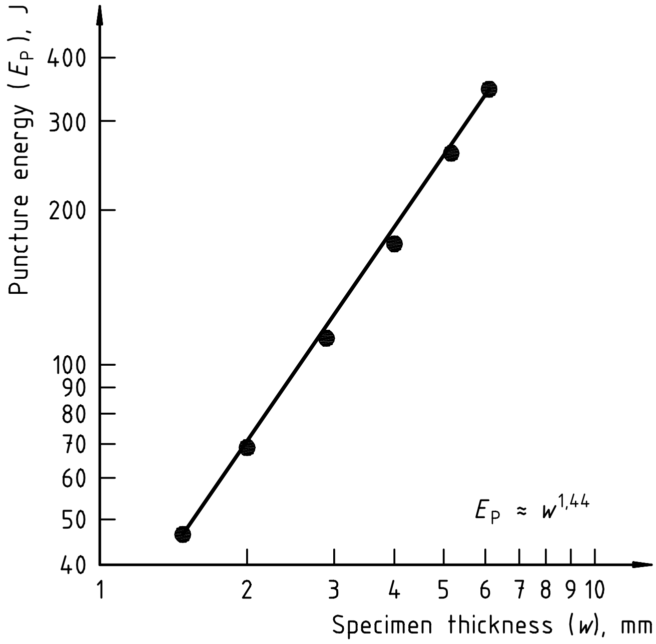
Property	**Exponent** n or m	Effect of the scatter of thickness $\Delta w/w$ of ± 5 % on that of the property
F_M	1,0 to 1,4	± 5 % to ± 7 %
E_P	1,2 to 1,8	± 6,5 % to ± 9 %

As can be seen, even small changes in thickness of 5 %, which are admissible according to this part of ISO 6603, result in distinct deviations of maximum force and puncture energy.

Plotting the test results according to the equations (E.1) and (E.2) (see for example Figure E.1) may give interpolation facilities and may show the source of scatter of data. The consequence is an increased comparability of results obtained at specimens with varying thickness, particularly testing specimens taken from compression-moulded plates or from parts.



a)



b)

Figure E.1 — Maximum force a) and puncture energy b) of a polycarbonate with respect to specimen thickness *w*

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