INTERNATIONAL STANDARD

ISO 6603-2

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Plastics — Determination of multiaxial impact behaviour of rigid plastics —

Part 2 :
Instrumented puncture test

Plastiques — Détermination du comportement des plastiques rigides sous un choc multiaxial —

Partie 2 : Essai par perforation instrumentée

Reference number
ISO 6603-2:1989(E)

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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

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

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

— *Part 1: Falling dart method*

— *Part 2: Instrumented puncture test*

Annexes A and B and C and D of this part of ISO 6603 are for information only.

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Plastics — Determination of multiaxial impact behaviour of rigid plastics —

Part 2 :
Instrumented puncture test

1 Scope

1.1 This part of ISO 6603 specifies a method for the determination of the multiaxial impact behaviour of rigid plastics in the form of flat test specimens, such as discs and squares, moulded directly or cut from sheets.

This test is used for the characterization of plastic sheeting or mouldings under the impact of a striker applied at a right angle to the plane of the sheet.

Different test parameters are specified depending on the geometry of the striker.

1.2 ISO 6603-1[1)] can be used if it is sufficient to characterize the impact behaviour of plastics by an impact-failure energy. This part of ISO 6603 is for use if a force-deformation or force-time diagram recorded at practically constant striker velocity is necessary for characterization of the impact behaviour.

This applies if:

— measured quantities derivable only from this diagram are required;

— only a small number of test specimens is available.

1.3 The test method is applicable to test specimens with a thickness between 1 mm and 4 mm.

NOTE 1 For thicknesses less than 1 mm, ISO 7765-2 should be used. Thicknesses greater than 4 mm may be tested if the equipment is suitable, but the test then falls outside the scope of this part of ISO 6603.

1.4 The test results are comparable only if the conditions of the preparation of the specimens, their dimensions and surfaces as well as the testing conditions are the same. In particular, results determined on test specimens of different thicknesses cannot be compared with one another. Comprehensive evaluation of the reaction to impact stress requires that determinations be made as a function of deformation rate and temperature for different materials variables, such as crystallinity and moisture content. The impact behaviour of finished products cannot be predicted directly from this test, but specimens may be taken from finished products for tests by this method.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this part of ISO 6603. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this part of ISO 6603 are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 291:1977, *Plastics — Standard atmospheres for conditioning and testing.*

ISO 293:1986, *Plastics — Compression moulding test specimens of thermoplastic materials.*

1) ISO 6603-1:1985, *Plastics — Determination of multiaxial impact behaviour of rigid plastics — Part 1: Falling dart method.*

ISO 294:1975, *Plastics — Injection moulding test specimens of thermoplastic materials.*

ISO 2557-2:1986, *Plastics — Amorphous thermoplastics — Preparation of test specimens with a specified reversion — Part 2: Plates.*

ISO 7765-2:—[2)], *Plastics — Film and sheeting — Determination of impact resistance by the free-falling-dart method — Part 2: Instrumented puncture test.*

3 Definitions

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

3.1 peak force, F_p: The maximum force exerted by the striker in the direction of impact during the test (see figures 1, 2 and 3).

3.2 deformation at peak force, l_p: The deformation at the centre of the test specimen corresponding to the peak force. For materials exhibiting a peak force plateau, the deformation is taken at the centre of the plateau (see figures 1 and 2).

3.3 energy to peak force, E_p: The area under the force-deformation diagram bounded by the origin, the peak force and the deformation at peak force (see figures 1, 2 and 3).

3.4 total penetration energy, E_{tot}: The total energy expended in penetrating the test specimen (see figures 1, 2 and 3).

4 Principle

The test specimen is penetrated normal to the plane by a striker at a nominally uniform velocity. The resulting force-deformation or force-time diagram is electronically recorded. The test specimen may or may not be clamped in position during the test.

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

For example, the fracture may be "brittle", "ductile", "tough" or characterized by initial damage or by crack initiation and propagation. In addition, dynamic effects may be present such as load cell/indentor resonance, specimen resonance and initial contact/inertia peaks (see annex A).

In all cases, care must be exercised in analysing these features because the operative mechanism and the trains of inference are not yet fully established and are the subject of continuing research.

NOTES

2 Examples of force-deformation diagrams for tough and brittle materials are given in figures 1 to 3, with more complex behaviour being described in annex A.

3 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-deformation diagram. These interpretations are a task for scientific research.

5 Apparatus

The apparatus consists of a mechanical part for applying the test force (test device), the instruments for measuring the force and distance, and a thickness gauge.

5.1 Test device

The essential components of the test device are: the energy carrier (normally a falling mass, but a pneumatically or hydraulically or spring-assisted driven mass or a pendulum-impact test device may also be used), the striker, and the test specimen support (with a clamping ring, where used).

The test device shall permit the test specimen to be punctured at the centre at a nominally constant velocity perpendicular to the specimen surface. The force exerted on the test specimen in the direction of impact and the deformation of the specimen in the direction of impact shall be derivable or measurable (see figure 4). Devices suitable for this test are falling-dart machines, pendulums with an arm long enough for the penetration path to be regarded as approximately linear, and high-speed tensile-testing machines with suitable auxiliary attachments.

5.1.1 Energy carrier

It shall be ensured that the available impact energy (e.g. drop energy) is large in comparison with the absorbed penetration energy, E_{tot}. Because, over the range of velocities used in this test, the striker velocity has a relatively small influence on the viscoelastic behaviour of plastics, a decrease in striker velocity of 20 % is acceptable. This requirement is met by falling-dart machines and pendulums if

$$m \geqslant \frac{3E_{tot}}{g \cdot h_o}$$

where

m is the falling mass, in kilograms;

g is the acceleration due to gravity (9,81 m/s^2);

2) To be published.

h_o is the height of fall, in metres;

E_{tot} is the total penetration energy, in joules.

If a falling-dart system is used, it shall be capable of holding and releasing a weighted striker such that the striker falls constrained by guide(s). The fall shall be largely without friction or losses through windage. Any friction shall be considered in the calculations.

NOTE 4 In many cases, a weighted striker with a total mass 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).

Velocity-measuring sensors shall be placed close to the point of impact to compensate for the effects of friction.

With hydraulically driven high-speed tensile-testing machines, any deviation of the velocity during impact shall be proven, e.g. by recording the distance-time curve and checking its slope.

5.1.2 Striker

The preferred striker has a polished hardened hemispherical striking surface of diameter 20 mm ± 0,2 mm. Alternatively, a 10 mm ± 0,1 mm diameter striking surface may be used. The striker shall be constructed of steel.

The load cell on the striker shall be mounted as close as possible to the tip to minimize all extraneous forces. An example is shown in figure 4.

The resonant frequency of the combination of striker and load cell shall be higher than that specified in 5.2.

5.1.3 Test specimen support

A hollow steel cylinder of internal diameter 40 mm ± 2 mm and minimum height 12 mm shall be used. The support shall be placed on a solid base and shall be designed such that air cannot be trapped under the test specimen, thus avoiding a possible spring effect. Below the support, enough space shall be available as stopping distance for the striker after total penetration of the test specimen.

5.1.4 Clamping device (optional)

A two-piece annular specimen clamp having an inside diameter of 40 mm ± 2 mm is recommended (see figure 5). Pneumatically operated clamps have been successfully employed. If a clamping device is used, ensure that no slippage occurs.

NOTE 5 The results for clamped and unclamped specimens are likely to be different.

5.2 Instruments for measuring force and distance

The electronic devices for measuring force and distance shall be chosen such that the force and distance can be measured to within 5 %.

EXAMPLE — If the resolution of an electronic device is 0,4 % of full-scale deflection (FSD) and the measured value in a test is 20 % of FSD, then the resolution for the test is 2 %.

Because of the very short time to failure (t_f) of the test specimen during the test, only electronic load cells with a high natural frequency shall be used.

The shortest failure time $t_{f,min}$ measurable by the apparatus shall be as given by

$$t_{f,min} \geqslant \frac{5}{f_{dev}}$$

where f_{dev} is the natural frequency of the test device (striker plus load cell).

For the bandwidth b_{tot} of the amplifier train (direct current or carrier frequency amplifier) with a lower bandwidth limit of 0 Hz, the following applies by analogy:

$$b_{tot} \geqslant \frac{16}{t_{f,min}}$$

where

$$b_{tot} = \left(\sum_{j=1}^{n} \frac{1}{b_j^2} \right)^{-\frac{1}{2}}$$

b_j being the bandwidth of the jth component amplifier.

The deformation of the specimen in the direction of penetration can be determined directly with an electronic transducer, thus yielding a force-deformation diagram. It is also possible to use a force-time diagram and calculate the deformation in accordance with clause 8.

NOTES

6 An example of such a measurement train is a piezo-load cell mounted between the striker and the shaft (see figure 4) and connected to a charge amplifier.

7 In the testing of very brittle products, elastic impact may cause resonant oscillations in the load cell and make it difficult to interpret the force-deformation curve. In this case it can be useful to insert a low-pass filter between the force signal amplifier and the recorder, although the accuracy of the measurements is thereby reduced.

If a filter is used, the type of filter and its essential characteristics shall be reported in the test report [see clause 9 e)].

5.3 Thickness gauge

This shall permit the thickness of test specimens to be measured to within ± 0,01 mm.

6 Test specimens

6.1 Preparation of test specimens

The test specimens shall be prepared in accordance with the instructions in the relevant International Standard, or in accordance with the specifications for the material to be tested, or as agreed upon by the interested parties.

If such specifications are not available, the test specimens may be prepared either directly, using one of the methods given in 6.2, or by machining. The test specimens may also be prepared with a cutting or punching device, since no special requirements are placed on the cut edges. However, both surfaces shall be free of damage and flaws so that the effects of notching are avoided. Test specimens taken from larger sheets or sections of sheeting shall be taken from points that are as uniformly distributed over the surface as possible. Non-homogeneous edge zones shall not be used. If a large number of test specimens is required, for example to determine the temperature dependence of the measured quantities, the specimens shall be selected in accordance with statistical principles.

6.2 Preferred test specimen

The preferred test specimen is 60 mm ± 2 mm in diameter or 60 mm ± 2 mm square. For moulding and extrusion materials, the preferred test specimen is 2 mm ± 0,1 mm thick, prepared from sheet moulded under the conditions described in ISO 293, ISO 294 or ISO 2557-2, or as agreed upon between the interested parties. For sheet, the thickness of the test specimen shall be that of the sheet under test.

If the thickness of any test specimen differs by more than 5 % from the average thickness of the test specimens from that sample, that test specimen shall be discarded and replaced by another.

6.3 Number of test specimens

If the test is conducted under constant conditions, at least five or, in cases of arbitration, exactly 10 test specimens are required. If the measurements are to be made as a function of temperature, relative humidity or some other parameter, five specimens per measurement point are sufficient.

6.4 Conditioning of test specimens

The test specimens shall be conditioned as required by the specifications for the material concerned or as agreed upon by the interested parties. Otherwise, select the most appropriate conditions from ISO 291.

7 Procedure

7.1 Test atmosphere

Conduct the test in one of the standard atmospheres specified in ISO 291.

NOTE 8 The test can also be conducted at temperatures other than room temperature. The method of cooling or heating the test specimen may influence the result, but is not covered by this part of ISO 6603.

7.2 Measurement of thickness

For each test specimen, measure the thickness to the nearest 0,02 mm at three points which are equidistant from one another on a circle with a radius of 10 mm centred on the centre of the test specimen. Record the average value of the measured thicknesses.

7.3 Clamping the test specimen (optional)

In clamping the test specimen, take care to ensure that the clamping force does not induce bending or torsional forces in the specimen.

7.4 Puncture test

Conduct the puncture test with an impact velocity of 4,4 m/s ± 0,1 m/s, corresponding to a height of fall of 1 m. The velocity shall not change during the penetration process by more than 20 % of its value at the time of impact on the test specimen (see the conditions for the falling mass in 5.1.1).

If there is reason to believe that the results will depend on which side of the test specimen faces the striker, each side shall be tested separately. In general, the test is conducted on either side, selected at random.

NOTE 9 For brittle materials, an impact velocity of 1 m/s may be found to be more appropriate because it leads to a lower noise level and improves the quality of the force-deformation diagram.

8 Expression of results

For the purposes of routine characterization and in the absence of other conditions described in the International Standard for the material concerned, the peak of the force-deformation diagram shall be taken as the result of the test. The point where the force has fallen to zero shall be used to determine the total penetration energy. When testing tough materials, however, a transducer mounted some distance from the impacting tip can record an approximately constant frictional force between the dart and the punctured material; this force shall not be included in the calculation of the total penetration energy.

If it is clear from the force-deformation curve and/or other information that a crack is forming in the test specimen, the corresponding point of the force-deformation curve shall be used to calculate a damaging force F_d, damaging elongation l_d and damaging energy E_d.

If the test results are in the form of a force-deformation curve, the peak force F_p and deformation at peak force l_p can be read directly from the graph. The energy to peak force E_p and the total penetration energy E_{tot} can be determined by measuring the area under the curve, using a planimeter or other suitable means (see figures 1 to 3).

When the results are in the form of a force-time curve, the deformation at peak force l_p is given, in metres, by the approximation (see annex B):

$$l_p \approx \left(v_o - \frac{A_p}{3m} \right) t_p$$

where

v_o is the impact velocity just before impact, in metres per second;

A_p is the area under the force-time curve up to the peak force, in newton seconds:

$$A_p = \int_0^{t_p} F(t) \mathrm{d}t$$

t_p is the time to peak force, in seconds;

m is the falling mass, in kilograms.

NOTES

10 The exact calculation of l_p requires double integration:

$$l_p = \frac{1}{m} \int_0^{t_p} \int_0^{t_p} F(t) \mathrm{d}t^2 + v_o \cdot t_p$$

The energy to peak force E_p, in joules, is given by the exact relationship (no approximation)

$$E_p = v_o \cdot A_p \left(1 - \frac{v_o \cdot A_p}{4E_o} \right)$$

where E_o is the energy, in joules, of the striker just before impact.

The total penetration energy E_{tot}, in joules, is given by

$$E_{tot} = v_o \cdot A_{tot} \left(1 - \frac{v_o \cdot A_{tot}}{4E_o} \right)$$

where A_{tot} is the total area under the force-time curve, in newton seconds:

$$A_{tot} = \int_0^{\infty} F(t) \mathrm{d}t$$

11 In place of a graph, or concomitant with it, the values of the peak force and the deformation at peak force may be recorded electronically. This also applies to the energy to peak force and the total penetration energy after electronic integration.

The mean, the standard deviation and the coefficient of variation shall be calculated for every test series.

9 Test report

The test report shall include the following information:

a) a reference to this part of ISO 6603;

b) the type, identification mark, origin and date of receipt of the material tested, plus any other pertinent data concerning the material;

c) the method of preparation of the test specimens;

d) the test conditions and conditioning procedures, if applicable;

e) the natural frequency, total band width and type of filter (if used) and its essential characteristics;

f) the test velocity, if not 4,4 m/s;

g) the diameter of the striker used;

h) whether clamping has or has not been used (if so, give details);

i) the agreed point of damage, if not as given in 3.1 to 3.3;

j) the average thickness of each test specimen as measured in 7.2;

k) the number of test specimens used;

l) the arithmetic mean, standard deviation and coefficient of variation of

- the peak force F_p, in newtons,
- the deformation at peak force l_p, in metres,
- the energy to peak force E_p, in joules,
- the total penetration energy E_{tot}, in joules;

m) the force-deformation curve or force-time curve;

n) the appearance of the test specimens after the test (possibly with a representative test specimen as an illustrative example).

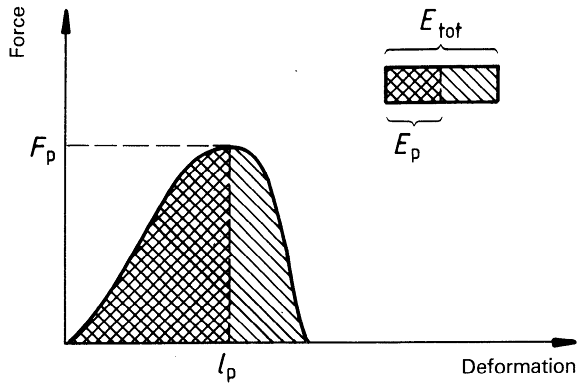


Figure 1 — Force-deformation diagram for tough materials (schematic)

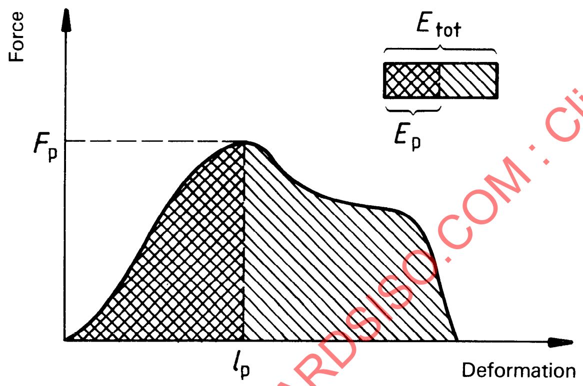


Figure 2 — Force-deformation diagram for very tough materials (schematic)

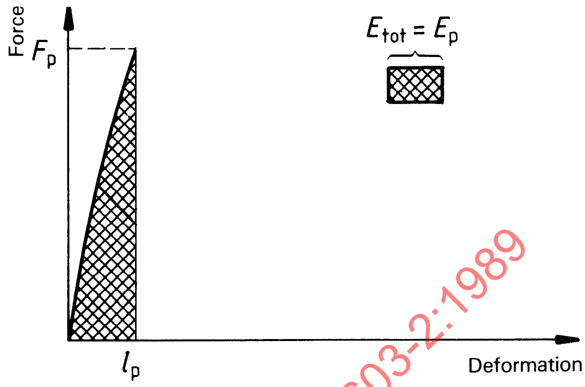
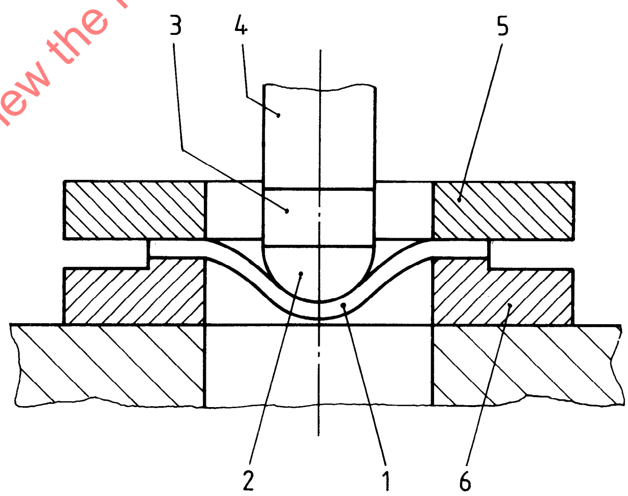


Figure 3 — Force-deformation diagram for brittle materials (schematic)



1 Test specimen
2 Hemispherical striker
3 Load cell (preferred position)
4 Shaft
5 Clamping ring (where used)
6 Test specimen support

Figure 4 — Test device (schematic)

Dimensions in millimetres

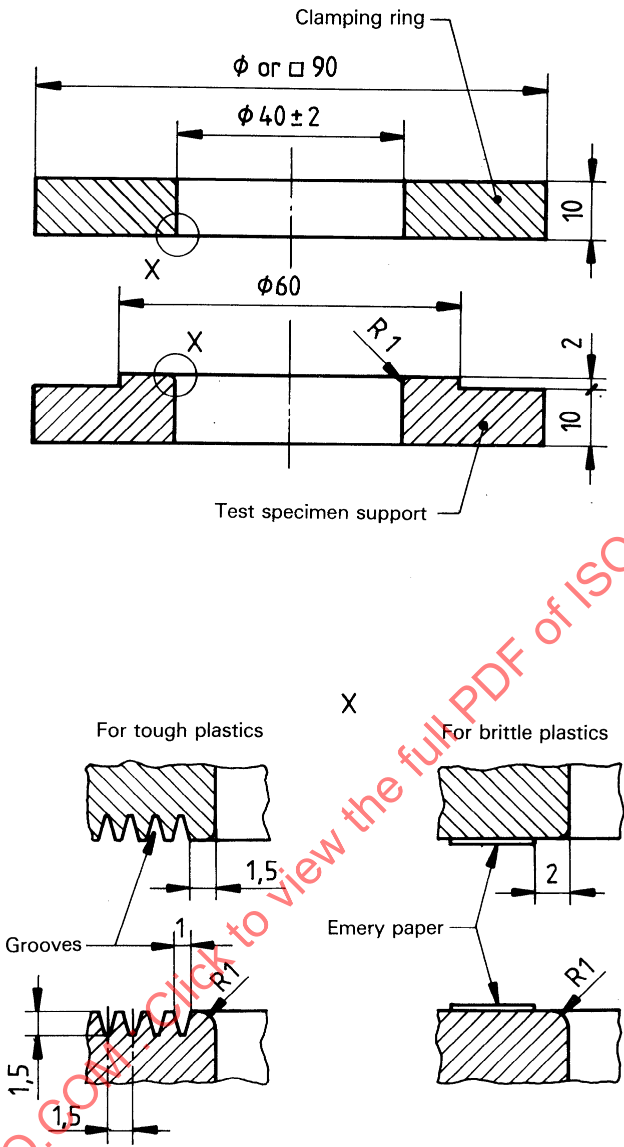


Figure 5 — Clamping device (Example shown with modifications for tough and brittle plastics)

Annex A
(informative)

Interpretation of complex force-deformation curves

In many impact experiments, the force-deformation diagram is more complicated than shown in figures 1 to 3. In such cases, a point of damage cannot be derived in any simple way from the force-deformation diagram using a standard procedure.

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

A practical expedient is to conduct the impact experiment with a lower energy (falling height). In this case, the available energy must be selected slightly larger than the supposed damaging energy.

This working method is especially recommended for the testing of UV-aged or strongly oriented test specimens. In those cases one often finds a dip in the rising part of the force-deformation diagram (see figure A.1).

Although for brittle and fibre-filled materials the peak force usually corresponds to the damaging force, very often a second peak occurs due to the formation of the hole during the penetration of the dart (see figure A.2).

Many peaks in the force-deformation diagram could 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 on the natural frequency of the test device is met.

A visual assessment (in all cases strongly recommended) of the broken test specimen is then the only way of describing the fracture behaviour under impact.

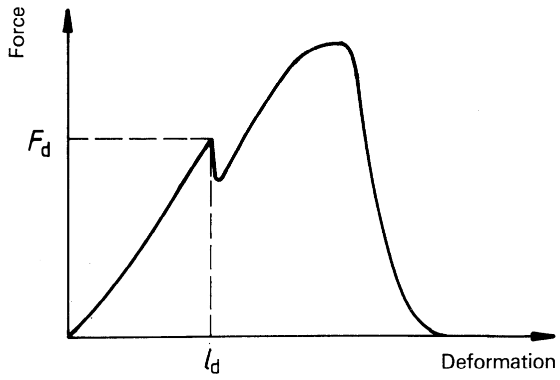


Figure A.1 — Force-deformation diagram for a UV-aged or strongly oriented material (schematic)

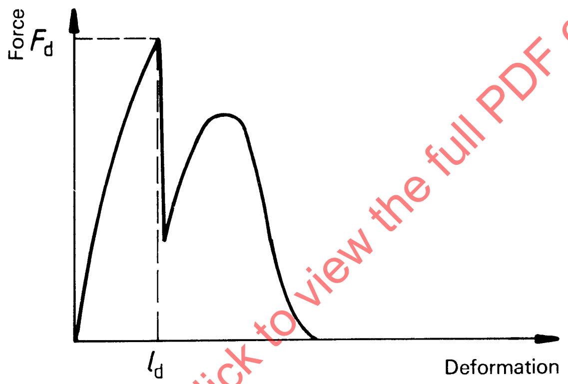


Figure A.2 — Force-deformation diagram for a brittle or fibre-filled material (schematic)

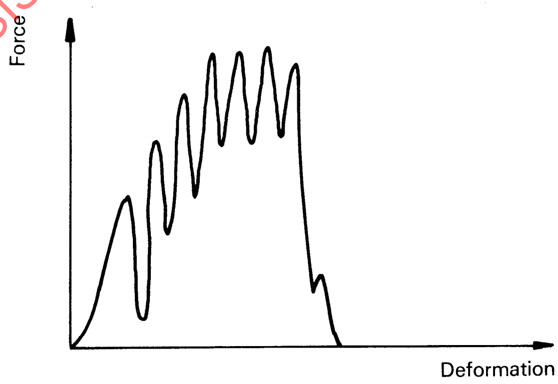


Figure A.3 — Force-deformation diagram in the case of strong resonance (schematic)

Annex B
(informative)

Derivation of the approximation for l_p used in clause 8

Let

- m be the mass of the striker;
- v_o be the velocity of the striker just before impact;
- v_p be the velocity of the striker corresponding to the peak force.

The change in velocity up to the point at which the peak force occurs can be calculated from

$$m \cdot v_o - m \cdot v_p = \int_0^{t_p} F(t) \mathrm{d}t = A_p$$

$$v_p = v_o - \frac{A_p}{m} \qquad \ldots (B.1)$$

l_p can be calculated from

$$l_p = \bar{v} \cdot t_p \qquad \ldots (B.2)$$

where $\bar{v}$ is the mean velocity of the striker between $t = 0$ and $t = t_p$, the time to peak force.

It has been shown [1] (see annex D) that the velocity often decreases in proportion to t^2 (i.e. $\mathrm{d}v/\mathrm{d}t$ is proportional to t):

$$\bar{v} = at^2 + v_o$$

$$v_p = at_p^2 + v_o$$

$$a = \frac{v_p - v_o}{t_p^2} \qquad \ldots (B.3)$$

The average velocity is given by

$$\bar{v} = \frac{1}{t_p} \int_0^{t_p} v \mathrm{d}t = \frac{1}{t_p} \int_0^{t_p} (at^2 + v_o) \mathrm{d}t$$

$$= \frac{1}{t_p} \left[\frac{a}{3} t^3 + v_o \cdot t \right]_0^{t_p}$$

$$= \frac{a}{3} t_p^2 + v_o \qquad \ldots (B.4)$$

Combining equations (B.3) and (B.4) gives

$$\bar{v} = \frac{v_p + 2v_o}{3} \qquad \ldots (B.5)$$

Combining equations (B.5) and (B.1) with equation (B.2) gives

$$l_p = \left(v_o - \frac{A_p}{3m} \right) t_p$$

which is used in clause 8.

If the assumption $v \approx t^2$ is not accepted, l_p can only be calculated by double integration:

$$l_p = -\frac{1}{m} \int_0^{t_p} \int_0^{t_p} F(t) \mathrm{d}t^2 + v_o \cdot t_p$$