International Standard ISO 6603/1

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Plastics — Determination of multiaxial impact behaviour of rigid plastics — Part 1: Falling dart method

Plastiques — Détermination du comportement des plastiques rigides sous un choc multiaxial — Partie 1: Essai par chute de projectile

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Foreword

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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 6603/1 was prepared by Technical Committee ISO/TC 61, *Plastics*.

Plastics — Determination of multiaxial impact behaviour of rigid plastics — Part 1: Falling dart method

1 Scope and field of application

This International Standard specifies a method for the determination of impact properties of rigid plastic materials in the form of disks or square pieces of standard dimensions, moulded directly or cut from sheets (see note 1).

This falling dart method is used for the assessment of plastic sheeting or mouldings under an impact stress applied at right angles to the plane of the sheet (see note 2). Part 1 of this International Standard can be used if it is sufficient to characterize the impact behaviour of plastics by an impact-failure energy. If recording of the force-deformation curve is necessary, Part 2 shall be used (see annex B).

Two methods of test are described.

The preferred method is method A, the staircase method. In this technique, a uniform energy increment is employed during testing and the energy is decreased or increased by the uniform increment after testing each test specimen, depending upon the result (fail or not fail) observed for the preceding test specimen.

Method B is the statistical method. In this technique, successive groups of at least ten test specimens each are tested. Impact failure energy is calculated by statistical methods (see note 3).

This method shall be used where both brittle and ductile failures occur within a homogeneous group of test specimens.

NOTES

1 The test results obtained by testing specimens prepared separately from moulding materials cannot be simply related to mouldings of other shapes because the results of these tests depend on the shape of the moulding and the conditions of their production.

2 This International Standard is not suitable for thin films.

3 The variable energy can be realized either by choosing a variable falling mass at constant height or by choosing a variable falling height at constant falling mass. The variable height procedure is velocity dependent and differing results may be observed depending upon the material's strain rate. Therefore, the constant falling height method is preferred.

2 References

ISO 291, *Standard atmospheres for conditioning and testing.*

ISO 293, *Plastics — Recommended practice for compression moulding test specimens of thermoplastic materials.*

ISO 294, *Plastics — Recommended practice for injection moulding test specimens of thermoplastic materials.*

ISO 2557/2, *Plastics — Amorphous thermoplastic moulding materials — Preparation of test specimens with a defined level of shrinkage — Part 2: Test specimens in the form of rectangular plates (Injection moulding).*

3 Definitions

For the purpose of this International Standard, the following definitions apply:

3.1 Failure-criteria terms

The following definitions of failure-criteria terms describe definite alterations of the test specimens caused by the falling mass. The criterion of failure shall be that specified in the International Standard for the material or shall be agreed upon by the interested parties.

3.1.1 crack: Any fissure that can be observed by the unaided eye and that does not penetrate the full thickness of the material (see figure 1).

3.1.2 break: Any fissure through the full thickness of the material (see figure 2).

3.1.3 penetration: Failure in which the indenter wholly penetrates the test specimen (see figure 3).

3.1.4 shattering: Breaking of the test specimen into two or more parts (see figure 3).

3.1.5 indentation: An irreversible deformation without cracking. The amount of indentation is measured by the depth of the dent (d_t) (see figure 4). The value of d_t that constitutes the pass-fail criterion shall be agreed by the interested parties.

NOTE — If other criteria of failure (crazing, stress whitening, etc.) are of importance, these criteria must be defined and included in the test report.

3.2 Impact-failure terms

3.2.1 50 % impact-failure energy, E_{50}: The energy that will cause 50 % of the test specimens to fail according to one of the criteria in 3.1.

3.2.2 50 % impact-failure mass, M_{50}: The mass that will cause 50 % of the test specimens to fail, according to one of the criteria in 3.1, at a given falling height.

3.2.3 50 % impact-failure height, H_{50}: The height that will cause 50 % of the test specimens to fail, according to one of the criteria in 3.1, using a given falling mass.

4 Principle

The impact strength of suitably sized test specimens is determined by striking them with a weight dropped vertically from a known height.

Two methods of adjusting the energy at impact are permitted: altering the mass at constant height (preferred) and altering the height at constant mass.

Two methods of test are also given: staircase (preferred) and statistical.

5 Apparatus

The apparatus shall be constructed (for example, figure 5) using the following components:

5.1 Test specimen support

A hollow steel cylinder of internal diameter 40 ± 2 mm with a minimum height of 12 mm (see figure 6). 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.

5.2 Clamping device (optional)

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

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

5.3 Falling dart system

Device capable of holding and releasing a weighted striker, such that the striker may fall contained by guide(s). The fall shall be substantially without friction or losses through windage, or the amount of friction has to be taken into account in the calculations.

5.4 Weighted striker

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

5.5 Weights (masses)

Appropriate weights that can be firmly attached to the striker. The combined mass of the weights to be attached and the mass of the striker shall be known to within 1 %.

5.6 Appropriate device for catching the dart after drop

To prevent multiple impact and damage of the striker.

6 Test specimens

6.1 Preparation and sampling of test specimens

The test specimens shall be prepared and sampled in accordance with the instructions in the relevant International Standards (see clause 2), or in accordance with the specifications for the material to be tested, or as agreed by the interested parties.

6.2 Standard test specimens

The standard test specimen shall be 60 ± 2 mm in diameter or 60 ± 2 mm square. For moulding and extrusion materials, the test specimen shall preferably be 2 ± 0,1 mm thick, prepared from sheet moulded under the conditions described in ISO 293, ISO 294, or ISO 2557/2. For sheet, the thickness shall be that of the sheet under test, but not less than 1 mm or more than 4 mm.

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

6.3 Number of test specimens

Method A (staircase method): At least 30 test specimens shall be used (10 for the pretest to determine the starting energy).

Method B (statistical method): At least 40 test specimens shall be used (10 for pretest and 30 for the main test).

Each test specimen shall be struck only once.

6.4 Conditioning of test specimens

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

7 Procedure

7.1 Test atmosphere

Carry out the test in one of the standard atmospheres specified in ISO 291.

7.2 General directions

Measure and record the average thickness of the test specimens in the area of impact to the nearest 0,02 mm.

Place the test specimen on the specimen support (5.1) and clamp (5.2) as appropriate.

Firmly secure the necessary weights (5.5) to the striker (5.4).

Put the dart (5.3) into position at a height between 0,3 and 2,0 m, according to the method chosen, and release the dart.

If the dart rebounds from the test specimen surface, catch the dart after it bounces to prevent both multiple impact with the test specimen surface and damage to the hemispherical contact surface of the dart as a result of impact with metal parts of the apparatus.

Examine the test specimen to determine whether it has or has not failed in the sense of one of the definitions given in 3.1.

7.3 Method A: Staircase method (Preferred method)

By this technique, a uniform energy increment is employed during testing and the energy is changed after striking each test specimen. Variation of the energy during testing can be realized by varying the falling mass at constant falling height or by varying the falling height at constant mass.

Preferably, a falling height of 1 m should be chosen if a variable falling mass is used. If a variable height is used, this should be chosen at any range between 0,3 and 2,0 m, but preferably about 1,0 m.

7.3.1 Pretesting

Use 10 test specimens to estimate the 50 % impact-failure energy E_{50}.

NOTE — It is suggested that during the pretesting the increments be not uniform. Begin with relatively large increments to find the energies which will cause with certainty failure or no failure. Finish the pretesting with smaller energy increments in order to roughly estimate the energy that causes 50 % of the test specimens to fail.

7.3.2 Main testing

For a starting point, select an energy near the expected impact failure energy, based on the pretesting.

Select an energy increment ΔE appropriate to the impact strength of the sample; the value chosen for ΔE should be such that three to six energy steps will be employed in the determination. A ΔE value equal to some 5 % to 15 % of the expected impact failure energy E_{50} according to the pretesting is usually appropriate.

Examine the test specimen to determine whether it has or has not failed and record the result on a form such as that shown in figures 7 and 8, using an "o" to denote non-failure and an "x" to denote failure.

If the first test specimen failed, decrease the energy by ΔE. If the first test specimen did not fail, increase the energy by ΔE. Continue testing successive test specimens, decreasing or increasing the energy by ΔE between drops, depending upon whether the preceding test specimen did or did not fail.

7.3.3 Expression of results

7.3.3.1 Calculation

Calculate the 50 % impact-failure energy E_{50}, in joules, as follows:

$E_{50} = H \times g \times M_{50}$ in the case of constant height

$E_{50} = M \times g \times H_{50}$ in the case of constant mass

where

H is the constant falling height, in metres;

M is the constant falling mass, in kilograms;

g is the acceleration of free fall (9,81 m/s^2);

$$M_{50} = M_a + \Delta M \left(\frac{A}{N} \pm 0{,}5 \right)$$

$$H_{50} = H_a + \Delta H \left(\frac{A}{N} \pm 0{,}5 \right)$$

[the + sign is taken if the no-failure ($N = N_o$) blows are considered and the − sign if the failure ($N = N_x$) blows are considered]

where

M_a is the smallest mass among the k mass steps M_i (i = 1 to k) from the main test, in kilograms;

ΔM is the increment of mass, in kilograms;

H_a is the smallest height among the k height steps H_i (i = 1 to k) from the main test, in metres;

ΔH is the increment of height, in metres;

$$N = \sum_{i=1}^{k} n_i$$

[total sum of the failure (N_x) or no-failure (N_o) test specimens, depending on which number is smaller]

n_i is the number of test specimens that have failure or no-failure, respectively, at the height H_i or the mass M_i;

$$A = \sum_{i=1}^{k} n_i z_i$$

z_i is the number of mass increments from M_a or the number of height increments from H_a:

$$z_i = \frac{1}{\Delta M} (M_i - M_a)$$

or

$$z_i = \frac{1}{\Delta H} (H_i - H_a)$$

7.3.3.2 Standard deviation

Calculate the standard deviation s, in joules, as follows:

$$s = 1{,}62\ \Delta E \left[\frac{NB - A^2}{N^2} + 0{,}029\right]$$

where

$$B = \sum_{i=1}^{k} n_i z_i^2$$

This formula is valid only if $\dfrac{NB - A^2}{N^2} > 0{,}3$

Examples of the calculation are given in annex A.

NOTE — If the inequality $0{,}5s \leqslant \Delta E \leqslant 2s$ is not fulfilled, the test should be repeated with another ΔE.

7.4 Method B: Statistical method

By this technique, successive groups of at least 10 test specimens each are tested. For each group one energy is employed and from group to group the energy is varied in increments. Variation of the energy during test can be realized by varying the falling mass at constant falling height or by varying the falling height at constant mass.

Testing is carried to a point where there are at least five results for percentage failure: one 0 % result, one 100 % result and at least three results between 0 % and 100 % results. The three results within the 0 % and 100 % limits shall not all be lower or higher than 50 %.

7.4.1 Pretesting

Test a minimum of 10 test specimens to estimate the approximate limits at which 0 % and 100 % failure occurs.

7.4.2 Main testing

Select the mass (or height) increments such that within the "zero" and "100 % limits", based on the pretesting, a minimum of three points is determined, at each of which at least 10 test specimens are to be tested.

Record the falling mass (or height) and the percentage of failures for each point.

At this stage, if the minimum five results described in 7.4 have been obtained, testing is complete.

7.4.3 Expression of results

7.4.3.1 Calculation

Plot the data on probability graph paper with mass (or height) on the linear scale and per cent failure on the probability scale, omitting the 0 % and 100 % failure points.

Draw the best fitting straight line through the points and read M_{50} (or H_{50}) from the graph at that falling mass (or height) corresponding to the intersection of the straight line with the 50 % probability line.

7.4.3.2 Standard deviation

For evaluation of the standard deviation, s, determine in the same way E_{16} and E_{84} as shown in figure 9 and calculate s as follows:

$$s = \frac{E_{84} - E_{16}}{2}$$

NOTE — The best fitting straight line may be obtained by a suitable technique such as the least-squares method of regression analysis.

An example of the calculation is given in annex A.

8 Test report

The report shall include the following information:

a) reference to this International Standard;

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

c) method of preparation of the test specimens;

d) average value of the measured thickness of the test specimens;

e) test conditions and conditioning procedures, if applicable;

f) whether clamping has or has not been used and the details of clamping;

g) method used, A or B, with the diameter of the striker used (for example A 20, B 10);

h) the constant height (or mass) and the increment used;

j) impact failure criterion that has been agreed upon;

k) 50 % impact-failure energy, in joules, to three significant figures and, if required, the standard deviation and the individual test results in graphic form (see examples in figures 7 to 9).

Annex A

Examples of calculation

(This annex forms an integral part of the standard.)

A.1 Method A: Staircase method

Example 1: Variable falling mass, constant height of fall (figure 7 and table 1):

Table 1

i	Falling mass (kg)	n_i (o)	n_i (x)	n_i	z_i	$n_i z_i$	$n_i z_i^2$
1	1,65	0	1	1	4	4	16
2	1,50	1	4	4	3	12	36
3	1,35	4	4	4	2	8	16
4	1,20	4	1	1	1	1	1
5 (= k)	1,05	1	0	0	0	0	0
	$\sum_{i=1}^{k}$	10 (N_o)	10 (N_x)	10 ($N = N_x$)		25 (A)	69 (B)

Number of specimens: 20

Height of fall: 0,66 m

Falling mass: variable

Mass increment: 0,15 kg

Primary falling mass from the pretesting: 1,35 kg

The number failure blows N_x and no-failure blows N_o are the same, so either can be used in the calculations. Otherwise, the smaller number should be used. In the example in table 1 and the following calculations, the failure blows were used.

$$M_a = 1{,}05 \text{ kg}; \qquad \Delta M = 0{,}15 \text{ kg}; \qquad N = N_x = 10$$

$$A = \sum_{i=1}^{k=5} n_i z_i = 25 \qquad B = \sum_{i=1}^{k=5} n_i z_i^2 = 69$$

$$E_{50} = HgM_{50} = Hg\left[M_a + \Delta M\left(\frac{A}{N} - \frac{1}{2}\right)\right]$$

$$E_{50} = 0{,}66 \times 9{,}81\left[1{,}05 + 0{,}15\left(\frac{25}{10} - \frac{1}{2}\right)\right] = 8{,}74 \text{ J}$$

$$s = 1{,}62\,\Delta E\left(\frac{NB - A^2}{N^2} + 0{,}029\right) = 1{,}62\,(Hg\Delta M)\left(\frac{NB - A^2}{N^2} + 0{,}029\right)$$

$$s = 1{,}62\,(0{,}66 \times 9{,}81 \times 0{,}15)\left(\frac{10 \times 69 - 625}{100} + 0{,}029\right) = 1{,}07 \text{ J}$$

Thus

$E_{50} = 8{,}74$ J

$s \;\; = 1{,}07$ J

Example 2: Variable height of fall, constant mass (figure 8 and table 2):

Table 2

i	**Height of fall** (m)	n_i (o)	n_i (x)	n_i	z_i	$n_i\, z_i$	$n_i\, z_i^2$
1	1,6	0	1	1	3	3	9
2	1,4	2	5	5	2	10	20
3	1,2	6	3	3	1	3	3
4 (= k)	1,0	3	0	0	0	0	0
	$\sum_{i=1}^{k}$	11 (N_o)	9 (N_x)	9 ($N = N_x$)		16 (A)	32 (B)

Number of specimens: 20

Falling mass: 1 kg

Height of fall: variable

Height of fall increment: 0,2 m

Primary height of fall from the pretesting: 1,2 m

Due to $N_x < N_o$ the calculation is conducted on the basis of the $N = N_x$.

$$E_{50} = MgH_{50} = Mg\left[H_a + \Delta H\left(\frac{A}{N} - \frac{1}{2}\right)\right]$$

$$E_{50} = 1{,}0 \times 9{,}81\left[1{,}0 + 0{,}2\left(\frac{16}{9} - \frac{1}{2}\right)\right] = 12{,}3 \text{ J}$$

$$s = 1{,}62\,\Delta E\left(\frac{NB - A^2}{N^2} + 0{,}029\right) = 1{,}62\,(Mg\Delta H)\left(\frac{NB - A^2}{N^2} + 0{,}029\right)$$

$$s = 1{,}62\,(1 \times 9{,}81 \times 0{,}2)\left(\frac{9 \times 32 - 256}{81} + 0{,}029\right) = 1{,}35 \text{ J}$$

Thus

$E_{50} = 12{,}3$ J

$s \;\; = 1{,}35$ J

A.2 Method B: Statistical method

Example (figure 9)

Height of fall: 1 m

Results of pretesting:

0 % failure: 0,090 kg

100 % failure: 0,170 kg

Selected steps for main testing and percentage of failure:

Mass (kg)	**Failure** (%)
0,105	10
0,120	20
0,135	60

We have $E_{50} = M_{50} \times 9{,}81 \times H$

(M_{50} in kilograms, H in metres, E_{50} in joules)

According to figure 9, we obtain:

$$E_{50} = 0{,}132 \times 9{,}81 \times 1 = 1{,}29 \text{ J}$$

$$E_{16} = 0{,}114 \times 9{,}81 \times 1 = 1{,}12 \text{ J}$$

$$E_{84} = 0{,}153 \times 9{,}81 \times 1 = 1{,}50 \text{ J}$$

$$s = \frac{1{,}50 - 1{,}12}{2} = 0{,}19 \text{ J}$$

Thus

$$E_{50} = 1{,}29 \text{ J}$$

$$s = 0{,}19 \text{ J}$$