International Standard

ISO 4651

Cellular rubbers and plastics — Determination of dynamic cushioning performance

Caoutchoucs et plastiques alvéolaires — Détermination de la capacité d'amortissement dynamique

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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.

International Standard ISO 4651 was developed by Technical Committee ISO/TC 45, *Rubber and rubber products*, and by Technical Committee ISO/TC 61, *Plastics*, and was circulated to the member bodies in February 1976.

It has been approved by the member bodies of the following countries :

Belgium	India	Sweden
Brazil	Italy	Switzerland
Canada	Mexico	Turkey
Czechoslovakia	Netherlands	United Kingdom
Egypt, Arab Rep. of	Poland	USA
France	Portugal	USSR
Germany, F. R.	Romania	
Hungary	Spain	

The member body of the following country expressed disapproval of the document on technical grounds :

New Zealand

Cellular rubbers and plastics — Determination of dynamic cushioning performance

1 Scope and field of application

This International Standard specifies the procedure for determining the dynamic cushioning performance of cellular rubber materials and rigid and flexible cellular plastics, by measuring the peak deceleration of a mass when it is dropped on a test piece. The test described is intended primarily for quality assurance; in addition, however, since this type of test is also used to obtain design data, notes are given in an annex to assist in the latter respect.

The method is applicable solely to materials used in packaging.

2 References

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

ISO 471, *Rubber — Standard temperatures, humidities and times for the conditioning and testing of test pieces.*

ISO 845, *Cellular rubbers and plastics — Determination of apparent density.*

ISO 1923, *Rigid cellular plastics — Determination of linear dimensions.*[1]

ISO 2231, *Fabric coated with rubber or plastics — Standard atmospheres for conditioning and testing.*

ISO 3205, *Preferred test temperatures.*

3 Definitions

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

3.1 static stress (σ_{ST}) : The force exerted by the drop hammer at rest divided by the original area of the test piece.

3.2 peak deceleration (a) : The maximum deceleration of the drop hammer during the impact on the test piece. In the International System of Units (SI), this is expressed in metres per second per second (m/s^2).

3.3 displacement curve (see annex) : The curve describing the displacement of the impacted surface of the test piece as a function of time during the impact.

3.4 dynamic stress : The decelerating force exerted by the material upon the drop hammer divided by the original area of the test piece.

3.5 deceleration force : The mass of the drop hammer multiplied by its instantaneous deceleration.

3.6 strain : Displacement expressed as a percentage of the original thickness.

3.7 dynamic compression diagram (see annex) : The curve describing the relation between the dynamic stress (decelerating force per unit area) and the strain (displacement/thickness) in the cushioning material during impact. The slope of this curve at a specified strain (dynamic compressibility) may be used as a characteristic constant for the given speed of impact and the thickness of the test piece.

3.8 cushioning diagram (see annex) : The diagram indicating both the peak deceleration, a, and the maximum value $\triangle L_{max}$ of the displacement of the impact surface as a function of the static stress σ_{ST} for the test pieces of the concerned materials having given thickness L_o.

3.9 corrected value of peak deceleration (a_c) : The value of the peak deceleration after correction for any small deviation of the test piece original thickness from the standard reference thickness of 50 mm. This is obtained by multiplying the measured peak deceleration by the original thickness divided by the standard reference thickness.

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[1] At present at the stage of draft. (Revision of ISO 1923-1972 and ISO/R 1794-1971.)

3.10 **equivalent drop height** (h) : That drop height which, in conditions of free fall in vacuo under standard gravitational acceleration, would result in the same impact velocity of the hammer as was obtained during the test.

The equivalent drop height, in metres, is given by the formula :

$$h = \frac{v^2}{2g_n}$$

where

v is the impact velocity, in metres per second, of the hammer;

g_n is the standard acceleration of free fall, i.e. 9,806 65 m/s².

4 Test pieces

The test piece shall be a right parallelepiped with the following dimensions :

— length   150 ± 5 mm

— width   150 ± 5 mm

— thickness   50 ± 5 mm

The test piece shall be cut by any suitable means which does not alter the dynamic characteristics, for example a band-saw or a sharp knife. Hot wire shall not be used for cutting test pieces.

The difference in the mean thickness between the test pieces in a set of ten shall not be greater than 2 mm. The dimensions shall be measured in accordance with ISO 1923. The thickness of the test piece may be achieved by plying up not more than two sheets not less than 20 mm thick and of the same orientation with respect to any known direction of anisotropy.

NOTES

1 Uniformity of test pieces : the density of each test piece shall not vary by more than ± 10 % from the average density of a set of 10 test pieces.

2 Test pieces cut from finished articles should be tested so that the direction of dynamic stress corresponds with that of the dynamic stress to which the material is subjected in the finished article. If this is not possible, the relation of the direction of the principal dynamic stress in the finished article to that of the test direction should be stated in the report.

5 Number of test pieces

A total of at least ten test pieces is required for the tests described.

6 Pre-conditioning and test conditions

Samples shall be tested not less than 72 h after manufacture. Prior to testing, the test pieces shall be conditioned for at least 16 h in accordance with ISO 291, ISO 471 or ISO 2231, as ap-propriate. In cases of dispute, one set of conditions shall be agreed upon, preferably 23 ± 2 °C and 50 ± 5 % relative humidity.

The conditioning period may form the latter part of the 72 h following manufacture. The tests shall be carried out under the same conditions unless otherwise agreed between supplier and purchaser.

7 Apparatus

7.1 General

The apparatus shall consist of a flat-based drop hammer having a surface larger than the test piece and an anvil of mass at least 100 times that of the drop hammer and whose face is parallel to the base of the drop hammer. Two basic types of dynamic testing equipment are in use (see figures 1 and 2). They are the guided vertical drop tester, in which the hammer drops between vertical guides onto the test piece which rests on the anvil, and the pendulum tester.

The guided vertical drop tester is preferred for high deceleration tests and/or high static stresses. The pendulum test is suitable for relatively low deceleration or low static stresses.

The hammer shall be fitted with a means of recording the peak value of deceleration on impact, with an accuracy of ± 5 %, preferably by means of recording the deceleration time pulse on impact. Means shall also be available for measuring the velocity of the hammer, with an accuracy of ± 5 %, immediately prior to impact. The velocity shall be measured within the last 50 mm of travel of the hammer, for example by using a digital timer to record the transit time over 25 mm.

The mass of the hammer shall be adjustable in the range of static stress required; alternatively, several hammers may be used.

It is important that both hammer and anvil be sufficiently rigid so that undesirable vibrations are not recorded in the deceleration-time curve. The natural frequency of vibration of the hammer shall be as high as practicable, preferably above 1 000 Hz.

CAUTION — It is essential that the drop hammer mechanism is such that the safety of the operator is assured when test pieces are placed on the anvil, and some form of safety interlock is recommended.

7.2 Recording equipment

The means of recording the deceleration-time pulses shall consist of a transducer, means of amplification, and recorder. Transducers generally are either piezoelectric or strain gauge types. The selection of specific recording equipment is optional. However, all recording equipment (including both transducer and recorders) shall have a frequency response adequate to measure the peak deceleration to an accuracy of ± 5 %. The deceleration-time pulse obtained is usually a transient pulse approximating, on flexible foams, to a sinusoidal

half-wavelength (half-sine) at low cushion displacements and becoming triangular or even spire-like, as illustrated in figure 3, for impacts producing high cushion displacements. On rigid foams, which crush on compression, the acceleration-time pulse may approximate to a steeply rising initial section, followed by a constant (or approximately constant) level before decreasing. The range of frequency response needed to measure these transient pulses is wider than might be anticipated. It is important, therefore, that the following requirements should be borne in mind in respect of the main elements of the recording equipment.

7.2.1 Transducers

Generally, these are either the piezoelectric or of the strain gauge type. Piezoelectric decelerometers have little inherent damping and, if the frequency of resonance is too low, they can be caused to resonate by the decelerating pulse, so producing overshoot errors.

In general, these may be avoided by ensuring that the natural period of vibration of the transducer is less than 1/20 of the duration of the deceleration pulse, T. However, for half-sine pulses or for pulses with a rapid initial rise, it is sufficient that the natural period of vibration is less than 1/10 of the pulse duration or 1/6 of the rise time of the pulse respectively.

Strain gauge or inductive decelerometers have higher inherent damping (between 0,4 and 0,7 of critical). To obtain an accuracy of better than 5 % in the measurement of peak deceleration, the decelerometer shall have a natural period of vibration of less than 1/3 of the pulse duration for half-sine or triangular pulses. For pulses with a rapid initial rise, the natural period shall be less than 1/6 of the rise time.

Piezoelectric decelerometers do not respond to sustained signals and the low frequency response depends on the succeeding part of the amplifier system. If the next stage is a cathode follower, the time-constant of the input circuit of the cathode follower, combined with that of the transducer, controls low frequency response. To record peak decelerations to within 5 % on half-sine pulses, the time-constant shall be at least seven times the pulse duration (T). For square-type pulses, the corresponding value shall be 20 T.

If the following stage is a charge amplifier, then the response to continuous sine-waves shall not be reduced by more than 5 % at a frequency of $1/22\ T$ for 5 % errors on half-sine pulses. The corresponding frequency for square pulses is $1/50\ T$.

These figures, for the frequency at which the response to continuous sine-waves is reduced by 5 %, can be used also for any amplifying system where a.c. coupling is employed.

7.2.2 Recorders

The high frequency response of cathode ray oscilloscopes is usually adequate. For galvanometer oscillographs, high frequency response may be limited, and, as these devices are usually damped to 0,4 to 0,7 of critical, the galvanometer oscillograph should have a natural period of vibration of less than 1/3 of the pulse duration for half-sine or triangular pulses. Oscilloscopes, and other recorders using a.c. amplifiers, can have inadequate low frequency response, and the considera-

tions outlined above concerning charge amplifiers shall be followed. It is possible for direct pen recorders to have inadequate response due to the inertia of the recording pen.

Pulse durations and rise times depend on the type of material being tested and the conditions of test. For 50 mm thick test pieces, pulse durations on flexible foam in the range of 10 to 25 ms have been reported. For rigid materials, pulses may be short with rise times of the order of 2 to 5 ms. Peak reading meters can be used to obtain more accurate measurements of the deceleration on impact.

8 Procedure

8.1 General

Record the original thickness of the test pieces, determined as indicated in clause 6. Measure the density of each test piece in accordance with ISO 845. Ensure that the drop hammer is in a safe position.

Place the test piece on the anvil of the apparatus, and prepare the drop hammer to impact on the test piece.

Impact the test piece three times at intervals of 60 ± 15 s, using a fixed predetermined velocity and static stress as specified in 8.2 and 8.3 respectively. Measure the peak deceleration of the drop hammer on the first and third impacts. Each test piece shall be used for only one particular combination of static stress and impact velocity.

After the test piece has been subjected to the three impacts, allow it to recover for 5 min and remeasure its thickness.

8.2 Impact velocity

Use two velocities, corresponding to free fall under gravity from heights of 250 mm and 750 mm; a drop height of 1 250 mm may also be used.

8.3 Static stress

At each impact velocity, five different static stresses shall be chosen by agreement between purchaser and supplier, such that one static stress gives approximately the minimum peak deceleration on impact, and the remaining four static stresses are distributed above and below this value, corresponding to approximately 10 and 20 % increases in peak deceleration.

For particular materials, the number of static stress values chosen may be reduced to two, corresponding to the + 10 % value. This may be agreed between purchaser and supplier if previous testing shows that significant changes in the performance of the cushion will be detected by this reduced testing.

9 Expression of results

9.1 Residual set

The residual set after impact of the test piece, expressed as a percentage, is given by the formula

$$\left(\frac{L_o - L_v}{L_o} \right) \times 100$$

where

L_o is the original thickness, in millimetres, of the test piece;

L_v is the thickness, in millimetres, of the test piece after impact.

9.2 Peak deceleration

The corrected value, a_c, of the peak deceleration, in units of standard acceleration of free fall, is given by the formula

$$a_c = \frac{a_m L_o}{L_s}$$

where

a_m is the measured value of peak deceleration, in units of standard acceleration of free fall;

L_o is the original thickness, in millimetres, of the test piece;

L_s is the standard reference thickness, in millimetres, for test pieces (50 mm).

10 Test report

The test report shall include the following particulars :

a) a reference to this International Standard;

b) a description of the material;

c) the direction of testing with respect to any known anisotropy of the original material;

d) the test conditions, with a brief indication of the drop testing machine used;

e) the static stress used, test piece thickness and the corresponding corrected deceleration values;

f) the residual set after impact;

g) whether the test pieces were plied or not;

h) number of drops, and drop height.

Annex

Use of dynamic cushioning performance to obtain design data

(This annex does not form part of the standard.)

The following notes provide guidance on the use of this method of test to obtain data suitable for design purposes.

A.1 Presentation of data

Data obtained according to this method of test and intended for design purposes may be presented in any of the following manners.

A.1.1 Deceleration-static stress diagram, in which the peak deceleration a (m/s^2) is plotted against the static stress σ_{ST} (kPa) :

— for a specified number of consecutive drops in accordance with 8.1 or A.2.5 on a test piece of given thickness according to A.2.1 and an *impact velocity or equivalent drop height according to 8.2 or A.2.2;*

— for a number of test pieces of varying thickness selected in accordance with A.2.1 and an impact velocity or equivalent drop height according to 8.2 or A.2.2;

— for a test piece of given thickness in accordance with A.2.1 and a series of selected impact velocities or equivalent drop heights according to 8.2 or A.2.2.

A.1.2 Cushioning diagram, which is similar to the deceleration-static stress diagram (see A.1.1), with the addition that for each set of measurements the maximum displacement $\triangle L_{max.}$ (mm) is also plotted in the same diagram as a function of the static stress σ_{ST}. An example of a cushioning diagram is shown in figure 4.

A.1.3 Dynamic compression diagram, in which the dynamic stress σ_{DYN} (kPa) is shown as a function of the relative compression $\triangle L_{max.}/L_o$ of the test piece expressed as such or as a percentage. The caption of the diagram shall state the original thickness L_o (mm) of the test piece and the selected impact velocity or equivalent drop height respectively.

A.2 Testing requirements for design data acquisition

A.2.1 Significance of test piece size

The size (and shape) of the test piece is known to influence the values of peak deceleration, particularly with partially or dominantly open-cell foams. The correction procedure shall not be applied to specimens lying outside the standard tolerance on thickness.

The dimensions for test pieces chosen for this method are believed to reduce variation due to size to acceptable values.

For design purposes, the thickness, if the information is available, should be chosen to represent the finished article. In other cases and for the acquisition of comprehensive design data for a particular cellular material, in addition to, or in place of, the stipulated standard thickness of 50 ± 5 mm, one or more of the following thicknesses should be chosen :

10 — 25 — 50 — 75 — 100 — 125 mm

NOTE — The dynamic cushioning performance of a free cushion may not be comparable with that of a restricted cushion. In a packaging application, *the peak deceleration may be affected by indentation of the cushion, friction against the side cushions and distortion of the outer container.*

A.2.2 Impact velocity or equivalent drop height

The two velocities chosen for this method are intended to cover the majority of applications and *to show the differences in performance of a cellular material under low and high initial strain rates.*

For design data acquisition, and depending on the final application, other velocities or equivalent drop heights may be necessary. For velocities outside the range covered by the two stated in this method, it is necessary that at least the same testing machine performance be achieved.

A.2.3   Static stress σ_{ST}

The most likely range of static stresses for design purposes would be from 0,5 kPa to about 15 kPa, thus covering most cellular materials representing potential cushioning materials. It is recommended that, for this range, at least six static stresses be employed.

A.2.4   Displacement measurement

For the presentation of design data in accordance with A.1.2 and A.1.3, a device to record the displacement of the hammer as a function of time or of deceleration of the hammer is required.

A.2.5   Number of drops

For most practical applications, first and third drop performances are adequate. The change of peak deceleration with five impacts may, however, be needed to give sufficient protection in distribution systems undergoing repeated transport. In such cases, it is recommended that the first and fifth drop performances be measured and reported or, alternatively, that comprehensive data be presented in the form of the deceleration-static stress diagram according to A.1.1, showing the first drop performance and the average of the four succeeding drop performances.

A.2.6   Temperature

For design purposes, performance over a temperature range from − 40 to + 55 °C may be required. The appropriate test temperature shall be chosen from those given in ISO 3205. Parts of the testing apparatus which contact the test piece shall be capable of functioning unimpaired at these temperatures.

A.2.7   Humidity

Where data on the performance of a particular cellular material under tropical conditions are required, or where exposure of a finished article to such conditions is envisaged, the recommended test conditions are 40 ± 2 °C and 90 ± 5 % relative humidity.

NOTE — In certain cases, extended conditioning to ensure uniform distribution of moisture throughout the test piece may be necessary.
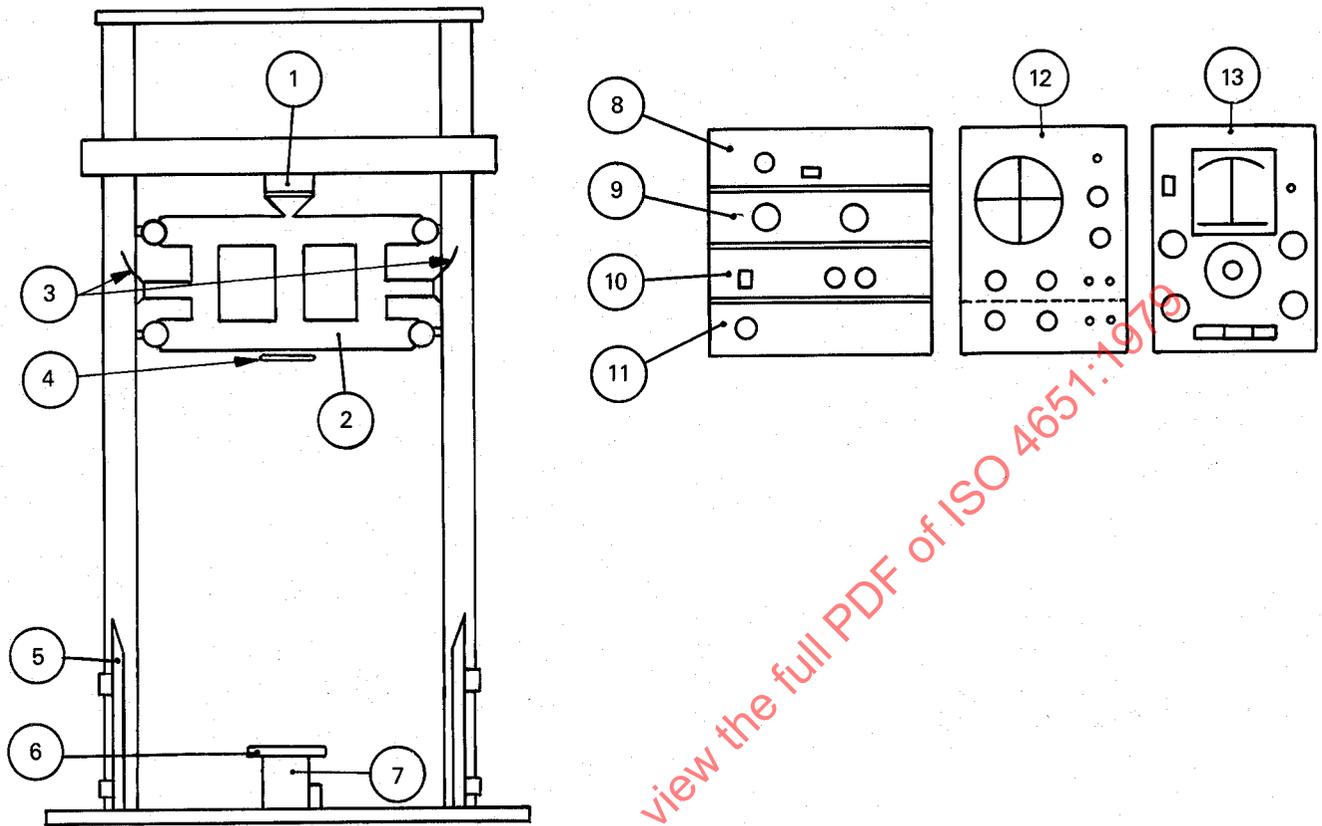
1 Electromagnet

2 Carriage

3 Sliding contacts for displacement potentiometer

4 Hammer

5 Displacement potentiometer

6 Test piece mount (anvil), 950 g

7 Pressure cell, 0 to 50 kN

8 Overload warning device for pressure cell

9 Automatic supply for photographic illumination

10 Electromagnet supply and supply for displacement potentiometer

11 a.c. stablizer for all equipment

12 Double-beam oscilloscope, 0 to 300 kHz with automatic camera

13 Carrier-frequency linear amplifier, 50 kHz

Figure 1 — Typical arrangement of drop hammer apparatus for determination of dynamic cushioning performance