Designation: D3763 – 23

Standard Test Method for High Speed Puncture Properties of Plastics Using Load and Displacement Sensors[1]

This standard is issued under the fixed designation D3763; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the determination of puncture properties of rigid plastics over a range of test velocities.

1.2 Test data obtained by this test method are relevant and appropriate for use in engineering design.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—This standard and ISO 6603-2 address the same subject matter, but differ in technical content. The technical content and results shall not be compared between the two test methods.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D618 Practice for Conditioning Plastics for Testing

D883 Terminology Relating to Plastics

D4000 Classification System for Specifying Plastic Materials

E456 Terminology Relating to Quality and Statistics

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E2935 Practice for Evaluating Equivalence of Two Testing Processes

2.2 *ISO Standard:*[3]

ISO 6603-2 Plastics—Determination of Multi-axial Impact Behavior of Rigid Plastics Part 2: Instrumented Puncture Test

3. Terminology

3.1 *Definitions*—Terms used in this standard are defined in accordance with Terminology D883, unless otherwise specified. For terms relating to precision and bias and associated issues, the terms used in this standard are defined in accordance with Terminology E456.

4. Significance and Use

4.1 This test method is designed to provide load versus deformation response of plastics under essentially multi-axial deformation conditions at impact velocities. This test method further provides a measure of the rate sensitivity of the material to impact.

4.2 Multi-axial impact response, while partly dependent on thickness, does not necessarily have a linear correlation with specimen thickness. Therefore, results must be compared only for specimens of essentially the same thickness, unless specific responses versus thickness formulae have been established for the material.

4.3 For many materials, there are cases where a specification that requires the use of this test method, but with some procedural modifications that take precedence when adhering to the specification. Therefore, it is advisable to refer to that material specification before using this test method. Table 1 of Classification System D4000 lists the ASTM materials standards that currently exist.

5. Interferences

5.1 *Inertial Effects*—A loading function encountered when performing an instrumented impact test that will, in some

[1] This test method is under the jurisdiction of ASTM Committee D20 on Plastics and is the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

*A Summary of Changes section appears at the end of this standard

cases, confuse the interpretation of the test data. For further definition and examples of inertial effects, refer to Appendix X1.

6. Apparatus

6.1 The testing machine shall consist of two assemblies, one fixed and the other driven by a suitable method to achieve the required impact velocity (that is, hydraulic, pneumatic, mechanical, or gravity):

6.1.1 *Clamp Assembly,* consisting of two parallel rigid plates with a 76.0 ± 3.0 mm diameter hole in the center of each. The hole edges shall be rounded to a radius of 0.8 ± 0.4 mm. Sufficient force must be applied (mechanically, pneumatically, or hydraulically) to prevent slippage of the specimen in the clamp during impact.

6.1.2 *Plunger Assembly,* consisting of a 12.70 ± 0.13 mm diameter steel rod with a hemispherical end of the same diameter positioned perpendicular to, and centered on, the clamp hole.

6.1.3 *Other Geometries*—The dimensions given in 6.1.1 and 6.1.2 shall be the standard geometry. If other plunger or hole sizes are used they shall be highlighted in the report. Correlations between various geometries have not been established.

6.1.4 *Load Sensing System*—A load cell of sufficiently high natural resonance frequency, as described in A1.1, used together with a calibrating network for adjusting load sensitivity.

6.1.5 *Plunger Displacement Measurement System*—A means of monitoring the displacement of the moving assembly during the loading and complete penetration of the specimen. Acceptable methods and devices for measuring displacement include a suitable transducer or potentiometer attached directly to the system, photographic or optical systems.

6.1.5.1 Alternatively, it is possible to calculate displacements as a function of velocity and total available energy at initial impact, along with increments of load versus time, using a microprocessor.

6.1.5.2 Some machines use an accelerometer, whose output is used to calculate both load and displacement.

6.1.6 *Display and Recording Instrumentation*—Use any suitable means to display and record the data developed from the load and displacement-sensing systems, provided its response characteristics are capable of presenting the data sensed, with minimal distortion. The recording apparatus shall record load and displacement simultaneously. For further information, see A1.2.

6.1.6.1 The most rudimentary apparatus is a cathode-ray oscilloscope with a camera. This approach also requires a planimeter or other suitable device, capable of measuring the area under the recorded load-versus-displacement trace of the event with an accuracy of ±5 %.

6.1.6.2 More sophisticated systems are commercially available. Most of them include computerized data reduction and automatic printouts of results.

7. Test Specimen

7.1 Specimens must be large enough to be adequately gripped in the clamp. In general, the minimum lateral dimension shall be at least 13 mm greater than the diameter of the hole in the clamp (see 6.1.1 and 10.9).

7.2 Specimens shall be cut from injection-molded, extruded, or compression molded sheet; or be cast or molded to size.

8. Conditioning

8.1 *Conditioning*—Condition the test specimens in accordance with Procedure A in Practice D618 unless otherwise specified by contract or the relevant ASTM material specification. Temperature and humidity tolerances shall be in accordance with Section 7 of Practice D618, unless otherwise specified by contract or relevant ASTM material specification.

8.2 *Test Conditions*—Conduct tests at the same temperature and humidity used for conditioning with tolerances in accordance with Section 7 of Practice D618, unless otherwise specified by contract or relevant ASTM material specification.

8.2.1 It is possible to determine the temperature at which transition from ductile to brittle failure occurs in most plastics by changing the conditioning and test temperature in a controlled manner for a given test velocity.

NOTE 2—To facilitate high throughput during automated testing at temperatures other than ambient, it is often necessary to stack the specimens in a column with no airflow in between. To assure compliance with Section 10 of Practice D618, the time to equilibrium must be determined for a given material. A thermocouple may be placed at the center of a specimen stack in which its height is equal to its minimum width. Determine the time to reach equilibrium at the desired test temperature. Experiments with materials having low thermal conductivity values have shown that more than 7.5 h of soak time was required before the stack center temperature fell within the tolerances specified in D618 at a setpoint of –40°C. Two and a half additional hours were needed to reach equilibrium. The opposite extreme was seen in a material of higher thermal conductivity that only required 2 h to reach equilibrium at –40°C.

NOTE 3—The impact behavior of some materials (for example, polypropylene, polyethylene), at sub-ambient temperatures, can be affected by the delay or "transit" time[4] after the specimen is removed from a remote environmental conditioning/freezer chamber. The transit time is defined as the total time from the removal of the specimen from the conditioning environment until the specimen is impacted.

9. Speed of Testing

9.1 For recommended testing speeds see 10.4.

10. Procedure

10.1 Test a minimum of five specimens at each specified speed.

10.2 Measure and record the thickness of each specimen to the nearest 0.025 mm at the center of the specimen. In the case of injection molded specimens, it is sufficient to measure and record thickness for one specimen when it has been previously demonstrated that the thickness does not vary by more than 5 %.

10.3 Clamp the specimen between the plates of the specimen holder, taking care to center the specimen for uniform gripping. Tighten the clamping plate in such a way as to provide uniform clamping pressure to prevent slippage during testing.

10.4 Set the test speed to the desired value. The testing speed (movable-member velocity at the instant before contact with the specimen) shall be as follows:

[4] Transit Time: Reference from ISO document 6603-1-clause 7.1.2 and 7.1.3.

10.4.1 For single-speed tests, use a velocity of 200 m/min.

10.4.1.1 It is acceptable to use other speeds, provided they are clearly stated in the report.

10.4.2 To measure the dependence of puncture properties on impact velocity, use a broad range of test speeds. Some suggested speeds are 2.5, 25, 125, 200, and 250 m/min.

10.5 Set the available energy so that the velocity slowdown is no more than 20 % from the beginning of the test to the point of peak load. If the velocity does decrease by more than 20 %, discard the results and make additional tests on new specimens with more available energy.

NOTE 4—It is observed that when the available energy is at least three times the absorbed energy at the peak load velocity slow-down is less than 20 %.

10.6 Place a safety shield around the specimen holder.

10.7 Make the necessary adjustments to data collection apparatus as required by the manufacturer's instructions or consult literature such as STP 936[5] for further information regarding setting up data acquisition systems.

10.8 Conduct the test, following the manufacturer's instructions for the specific equipment used.

10.9 Remove the specimen and inspect the gripped portion for striations or other evidence of slippage. If there is evidence of slippage, modify the clamping conditions or increase the specimen size and repeat test procedures.

11. Calculation

11.1 Using the load-versus-displacement trace and appropriate scaling factors, calculate the following:

11.1.1 Peak load, in newtons.

11.1.2 Deflection, in millimetres, to the point where peak load first occurred.

11.1.3 From the area within the trace, calculate:

11.1.3.1 Energy, in joules, to the point where load first occurred.

11.1.3.2 Puncture energy absorbed. Calculated at a corresponding point equal to a 50 % drop from the maximum load. Therefore, the point used for each test must be stated in the report.

11.1.4 Load, deflection, energy, or combination thereof, at any other specific point of interest (see Appendix X1).

11.2 For each series of tests, calculate the arithmetic mean for each of the above, to three significant figures.

11.3 Calculate the estimated standard deviations as follows:

$$S = \left(\frac{\Sigma X^2 - n\bar{X}^2}{n-1} \right)^{1/2} \quad (1)$$

where:

S = estimated standard deviation,
X = value of a single determination,
n = number of determinations, and
$\bar{X}$ = arithmetic mean of the set of determinations.

12. Report

12.1 Report the following information:

12.1.1 Complete identification of the material tested, including type, source, manufacturer's code number, form and previous history,

12.1.2 Specimen size and thickness,

12.1.3 Method of preparing test specimens (compression molding, casting, etc.),

12.1.4 Geometry of clamp and plunger, if different from 6.1.1 and 6.1.2,

12.1.5 Source and types of equipment,

12.1.6 Speed of testing (see 10.4),

12.1.7 The point on the curve at which puncture energy was calculated (see 11.1.3.2),

12.1.8 Average value and standard deviation for each of the properties listed in 11.1,

12.1.9 Whether or not any slippage of the specimens was detected, and

12.1.10 If the effect of testing speeds was studied (see 10.4.2).

13. Precision and Bias[6]

13.1 The precision of this test method is based on an interlaboratory study of D3763 High Speed Puncture Properties of Plastics Using Load and Displacement Sensors7conducted in 1996. Eleven (11) laboratories tested seven (7) different materials. Every "test result" represents an average of five (5) individual determination. Each laboratory was asked to submit two (2) replicate test results, from a single operator, for each material. Practice E691 was followed for the design and analysis of the data; the details are given in ASTM Research Report No. D20-1234. (**Warning—**The data in Tables 1-3 shall not be rigorously applied to acceptance or rejection of material, as those data are specific to the interlaboratory study and are not necessarily representative of other lots, conditions, materials, or laboratories. Users of this test method shall apply the principles outlined in Practice E691 to generate data specific to their laboratory and materials, or between specific laboratories.)

13.2 *Bias*—There are no recognized standards by which to estimate bias of this test method.

14. Keywords

14.1 falling weight; impact testing; plastics; puncture properties

[5] *Instrumented Impact Testing of Plastics and Composite Materials, ASTM STP 936,* ASTM, 1986.

[6] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D20-1234.

TABLE 1 Maximum Load

NOTE 1—MU = microcellular urethane, CP = cellulose propionate.

NOTE 2—Thicknesses were: aluminum, 0.031 in.; all others, 0.12 in.

NOTE 3—1982 round robin data, including precision and bias statements, may be found in Appendix X4.

Material	Mean, N	S_r,[A] N	S_R,[B] N	r,[C] N	R,[D] N
(A) Aluminum	4094	75.38	349.0	211	977
(B) ABS	3783	200.22	295.2	561	827
(C) MU	1704	110.53	149.6	309	419
(D) PC	6368	380.58	455.1	1066	1274
(E) Polyester	4244	154.57	278.7	433	780
(F) CP	4889	377.24	424.6	1056	1189
(G) PP	2703	164.89	246.5	462	690

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations from the test results from all of the participating laboratories as follows:

$$S_r = [[(S_1)^2 + (S_2)^2 \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation, as follows:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.

[C] r = within-laboratory critical interval between two test results = 2.8 × S_r.

[D] R = between-laboratories critical interval between two test results = 2.8 × S_R.

TABLE 2 Deflection to Maximum Load Point

NOTE 1—MU = microcellular urethane, CP = cellulose propionate.

NOTE 2—Thicknesses were: aluminum, 0.031 in.; all others, 0.12 in.

NOTE 3—1982 round robin data, including precision and bias statements may be found in Appendix X4.

Material	Mean, mm	S_r,[A] mm	S_R,[B] mm	r,[C] mm	R,[D] mm
(A) Aluminum	8.74	0.2227	0.619	0.62	1.73
(B) ABS	15.75	0.7009	0.811	1.96	2.27
(C) MU	19.33	0.9923	1.238	2.78	3.47
(D) PC	22.21	0.8567	0.897	2.40	2.51
(E) Polyester	19.03	0.9144	0.940	2.56	2.63
(F) CP	16.21	1.0858	1.122	3.04	3.14
(G) PP	15.81	0.7763	0.920	2.17	2.58

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations from the test results from all of the participating laboratories as follows:

$$S_r = [[(S_1)^2 + (S_2)^2 \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation, as follows:

$$S_R = [S_{r2} + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.

[C] r = within-laboratory critical interval between two test results = 2.8 × S_r.

[D] R = between-laboratories critical interval between two test results = 2.8 × S_R.

TABLE 3 Energy to Maximum Load Point

NOTE 1—MU = microcellular urethane, CP = cellulose propionate.

NOTE 2—Thicknesses were: aluminum, 0.031 in.; all others, 0.12 in.

NOTE 3—1982 round robin data, including precision and bias statements, may be found in Appendix X4.

Material	Mean, J	S_r,[A] J	S_R,[B] J	r,[C] J	R,[D] J
(A) Aluminum	14.78	0.506	2.03	1.42	5.67
(B) ABS	30.05	2.083	2.93	5.83	8.21
(C) MU	14.69	1.212	1.71	3.39	4.78
(D) PC	71.23	2.324	3.77	6.51	10.56
(E) Polyester	43.16	1.642	3.12	4.60	8.75
(F) CP	35.31	3.359	3.75	9.41	10.49
(G) PP	21.21	1.357	2.86	3.80	8.01

[A] S_r = within-laboratory standard deviation for the indicated material. It is obtained by pooling the within-laboratory standard deviations from the test results from all of the participating laboratories as follows:

$$S_r = [[(S_1)^2 + (S_2)^2 \ldots + (S_n)^2]/n]^{1/2}$$

[B] S_R = between-laboratories reproducibility, expressed as standard deviation, as follows:

$$S_R = [S_r^2 + S_L^2]^{1/2}$$

where S_L = standard deviation of laboratory means.

[C] r = within-laboratory critical interval between two test results = 2.8 × S_r.

[D] R = between-laboratories critical interval between two test results = 2.8 × S_R.

ANNEX

(Mandatory Information)

A1. MINIMUM INSTRUMENTATION REQUIREMENTS

A1.1 *Force Measurement*—Any transducer that meets the performance requirements for dynamic force measurement may be used. This includes, but is not limited to, strain gage force transducers, piezo-electric force transducers and accelerometers.

A1.1.1 *Performance Requirements*—The natural frequency (f_{dev}) of the transducer plus striker shall be sufficient to avoid distortion of the force-time or acceleration-time data. The time failure (t_f), in seconds, of a given test specimen regulates the minimum natural frequency for a transducer/striker assembly by the following relationship:

$$t_f = 3/f_{dev} \quad \text{(A1.1)}$$

Since time to failure is generally greater than 0.5 msec for plastics, a transducer assembly with a natural frequency greater than 6 kHz is recommended (0.0005 >= 3⁄6000). In addition, the transducer must have the durability to survive repeated impact tests without change in output from its initial calibrated state.

NOTE A1.1—Failure has been shown to be difficult to universally define. One application might define failure as the point on a load versus time curve where the load returns to zero. Another might define failure as a sharp drop in load, followed by a change in load slope, indicating formation of a crack.

A1.1.2 *Natural Frequency*—The mass of the striker assembly between transducer and specimen is directly related to the natural frequency (f_{dev}) of that transducer and will possibly influence the force or acceleration data. Appendix X1, (X1.9.3) describes a method for approximating f_{dev} for any given transducer assembly.

A1.1.3 *Transducer Location*—The transducer shall be located as close as possible to the impact point of the transducer/striker assembly to minimize the mass effect as described in A1.1.2. For testing involving extremely tough materials, it may be necessary to locate the transducer further from the impact point to prevent damage. Generally, this class of materials will produce a high loading impact event with a long t_f. Under these conditions, a transducer/striker assembly with a f_{dev} lower than 6 kHz will not adversely affect the test data. This is due to the damping effect of the test specimen itself as well as the large magnitude of the loading event in comparison to the initial oscillation produced by the transducer assembly.

A1.2 *Recording Apparatus*—Any recording device that meets the performance requirements of dynamic data acquisition may be used. This includes, but is not limited to, oscilloscopes, data loggers, and computer based data acquisition systems.

A1.2.1 *Performance Requirements*—The recording device used to capture a dynamic signal must have the capability to accurately represent that signal with minimal alteration. The following are system recommendations:

A1.2.1.1 8-bit or larger analog to digital converter,

A1.2.1.2 100 kHz minimum sampling rate,

A1.2.1.3 Minimum 1000 data point storage capacity,

A1.2.1.4 Adjustable test times to optimize data resolution, and

A1.2.1.5 Adjustable signal amplification to optimize load readings.

A1.2.2 For materials with a short t_f (0.1 to 2 mSec) or complex loading/failure mechanisms, the sampling rate and number of data points captured shall be increased to properly represent the impact event.

APPENDIXES

(Nonmandatory Information)

X1. ADDITIONAL RESULTS AND DATA INTERPRETATION

X1.1 This test method produces a record of load versus displacement for a penetration impact-type test. These recordings may have useful or important characteristics beyond those required in Section 11. These additional parameters may be reported when identified by controlled penetration, photographic, or other means. It must be emphasized that the load-displacement recordings are dependent on specimen geometry, size, thickness and testing speed. The load-displacement recordings may also display signals or artifacts that are the result of physical or electrical contributions from the test device. If the source of these contributions can be verified, they should be disregarded or filtered. Comparisons should only be made between equivalent specimens and test conditions. The following are examples of some characteristics that have been found useful or may affect the interpretation of the test data.

NOTE X1.1—While this test method discusses the interpretation of load-displacement curve data, an impact event is time-based. Therefore, if a "referee" situation arises when data are in question, a load-time curve should be used to determine characteristics of a given impact event.

X1.2 *Inertial Effect*—A loading function encountered when performing an instrumented impact test that may often be recognized as a "bump," a series of "peaks" or an "initial discontinuity" near the beginning of the load-displacement curve (Fig. X1.1). At this point, it is important to list the three main load contributions affecting a load transducer/probe assembly during an impact test: (*1*) Inertial acceleration loads (probe mass and specimen mass), (*2*) Mechanical bending loads (test specimen), and (*3*) Test system "ringing" (test device + transducer/probe + specimen).

X1.2.1 The level of contribution of each of these factors depends upon the portion of the test being studied along with the toughness and stiffness of the test specimen. Generally, when a material has a high toughness and a low to medium stiffness, the inertial effects will occur early in the test and not affect the data required in Section 11. However, some brittle materials, possessing high stiffness and low toughness, will often show inertial effects or system ringing, or both, persisting to the point of first crack (Fig. X1.2). For related information, see X1.9.

X1.3 *First Crack or Damage*—When there is a sharp loss of load with increasing displacement followed by a noticeable change in the slope of the curve, the loss in load can indicate the first crack or damage in the part (Fig. X1.3). This crack or damage can often be proven by use of controlled penetration or controlled energy input. This is of value where the crack or damage in the part constitutes failure. It is also valuable in composite materials where it signifies first failure of the matrix material.

X1.4 *Relative Stiffness*—Where a distinct linear portion can be identified within the proportional limit, the slope of the initial load-displacement curve is often useful as a relative measure of the elastic response of the specimen (Fig. X1.4). Precautions must be taken to compare only data from specimens of the same thickness and test conditions.

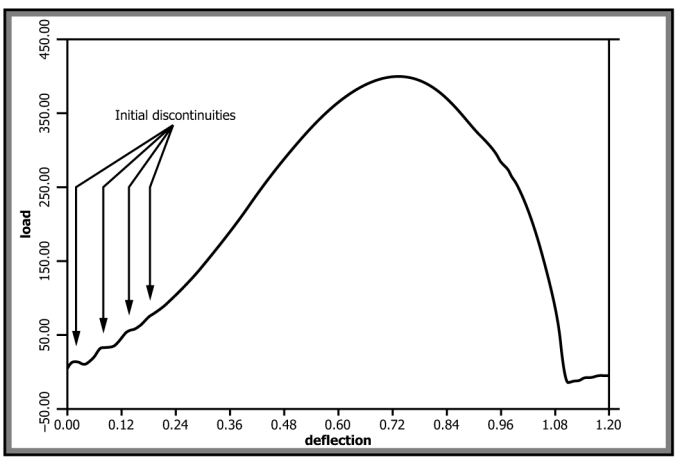

FIG. X1.1 Inertial Effect

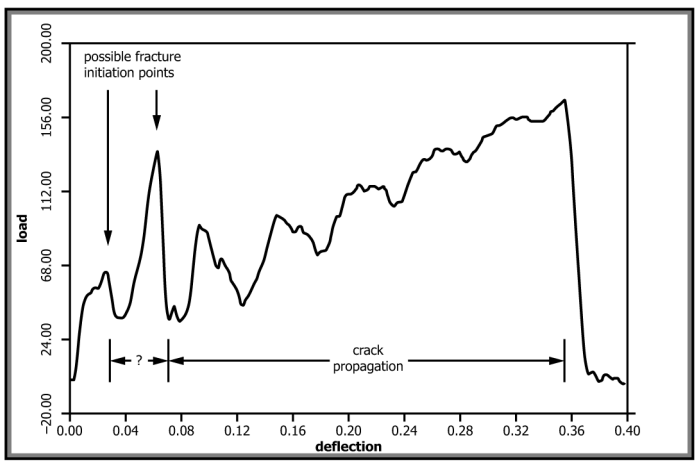

FIG. X1.2 Inertial Effect Interference