Designation: D 3763 – 02

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

This standard is issued under the fixed designation D 3763; 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 plastics, including films, over a range of test velocities.

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

1.3 The values stated in SI units are to be regarded as the 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 and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 1—This specification does not closely conform to ISO 6603.2. The only similarity between the two tests is that they are both instrumented impact tests. The differences in striker, fixture, and specimen geometries and in test velocity can produce significantly different test results.

2. Referenced Documents

2.1 *ASTM Standards:*

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 883 Terminology Relating to Plastics[2]

D 1600 Terminology for Abbreviated Terms Relating to Plastics[2]

D 4000 Classification System for Specifying Plastic Materials[3]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[4]

2.2 *ISO Standard:*[5]

ISO 6603.2 Plastics—Determination of Multiaxial Impact Behavior of Rigid Plastics Part 2: Instrumented Puncture Test

3. Terminology

3.1 *Definitions*—For definitions see Terminology D 883 and for abbreviations see Terminology D 1600.

4. Significance and Use

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

4.2 Multiaxial impact response, while partly dependent on thickness, does not necessarily have a linear correlation with specimen thickness. Therefore, results should 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 may be 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 D 4000 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 may, in some 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

[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] *Annual Book of ASTM Standards,* Vol 08.01.

[3] *Annual Book of ASTM Standards,* Vol 08.02.

[4] *Annual Book of ASTM Standards,* Vol 14.02.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

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

the clamp during impact. If films are tested, some type of gasket may also be required to prevent slippage.

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. This can be accomplished through the use of a suitable transducer or potentiometer attached directly to the system. Photographic or optical systems can also be utilized for measuring displacement.

6.1.5.1 Alternatively, displacement may be calculated 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 should 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 may be cut from injection-molded, extruded, or compression molded sheet; or they may be cast or molded to size.

8. Conditioning

8.1 *Conditioning*— Condition the test specimens in a room or enclosed space maintained 23 ± 2°C, and 50 % relative humidity, in accordance with Procedure A in Practice D 618 unless otherwise specified.

8.2 *Test Conditions*— Conduct tests in the standard laboratory atmosphere of 23 ± 2°C, and 50 ± 5 % relative humidity, unless otherwise specified. In cases of disagreement, the tolerances shall be ±1°C, and ±2 % relative humidity.

8.2.1 By changing the conditioning and test temperature in a controlled manner for a given test velocity, the temperature at which transition from ductile to brittle failure occurs can be determined for most plastics.

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 D 618, 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 D 618 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.

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.

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:

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

10.4.1.1 Other speeds may be used, 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 should decrease by more than 20 %, discard the results and make additional tests on new specimens with more available energy.

NOTE 3—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[6] for further information regarding setting up data acquisition systems.

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

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 Total energy absorbed. The point for determining this has not been standardized. 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:

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

where:

S = estimated standard deviation,
X = value of a single determination,
n = number of determinations, and
$\overline{X}$ = 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 total 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

13.1 Tables 1-3 are based on a round robin conducted in 1996 in accordance with Practice E 691, involving 7 materials tested by 11 laboratories. For each material, all of the specimens were prepared at the laboratory of the company volunteering that material for the round robin. Ten specimens from each material were sent to each participating laboratory. Each test result was the average of 5 individual determinations. Each laboratory obtained 2 test results for each material.

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.

NOTE 4—**Caution:** The explanations of r and R (13.2-13.2.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 1-3 should not be applied to acceptance or rejection of materials, as these data only apply to the materials tested in the round robin and are unlikely to be rigorously representative of other lots, conditions, materials, or laboratories. Users of this test method should apply the principles outlined in Practice E 691 to generate data specific to their materials and laboratory (or between specific laboratories). The principles of 13.2-13.2.3 would then be valid for such data.

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.

13.2 *Concept of r and R in* Tables 1-3—If S_r and S_R have been calculated from a large enough body of data, and for test results that were averages from testing 5 specimens for each test result, then the following applies:

13.2.1 *Repeatability*— Two test results obtained within one laboratory shall be judged not equivalent if they differ by more than the *r* value for that material. *r* is the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment on the same day in the same laboratory.

13.2.2 *Reproducibility*— Two test results obtained by different laboratories shall be judged not equivalent if they differ more than the *R* value for that material. *R* is the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

13.2.3 Any judgment in accordance with 13.2.1 and 13.2.2 would have an approximate 95 % (0.95) probability of being correct.

13.3 *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

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 can 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 should 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 should 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

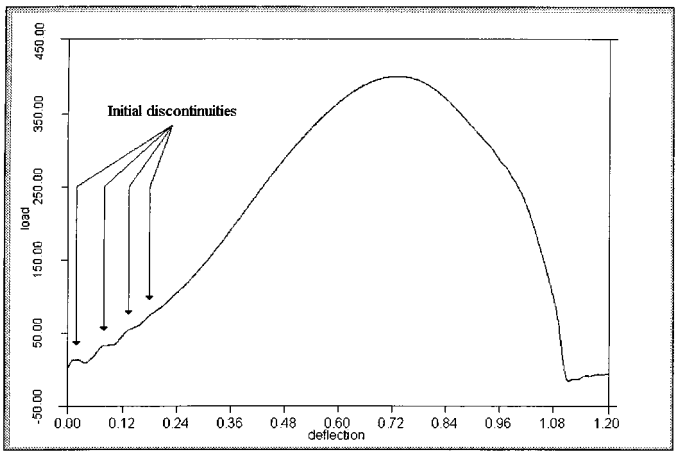

FIG. X1.1 Inertial Effect

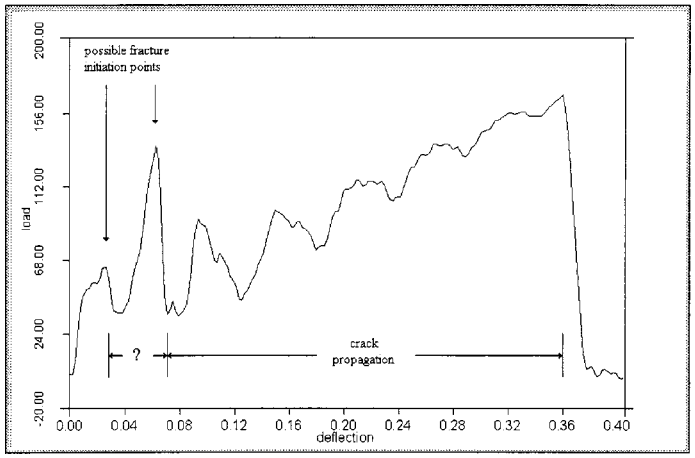

FIG. X1.2 Inertial Effect Interference

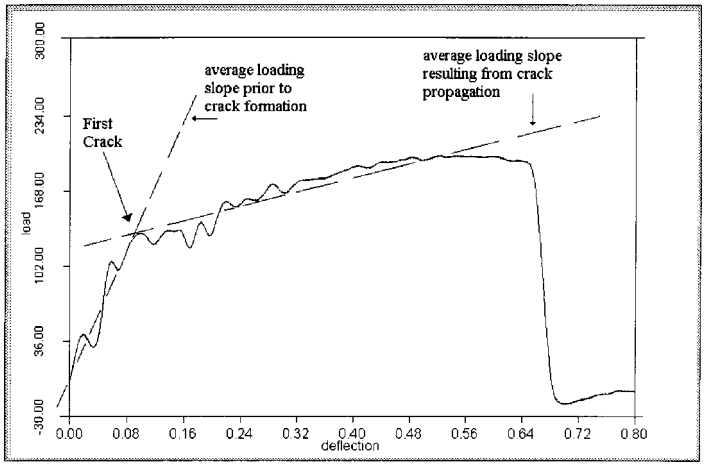

FIG. X1.3 First Crack Determination

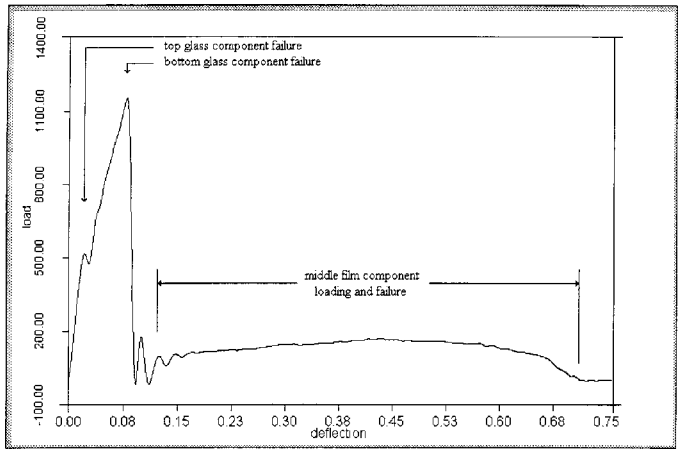

FIG. X1.5 Laminated Glass Data

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.

X1.5 *Proportional Limit*—The proportional limit is the first major deviation from the initial linear portion of the load-displacement curve (Fig. X1.4). It can be used as the point of onset of plastic damage. It is specimen and test condition dependent.

X1.6 *Failure of Composite*—The failure of composite structures in the penetration test may be characterized by a variety of changes in the load-displacement curve after first crack or damage. Some of the most common are multiple peaks when testing a matrix material or multiple slope changes when testing a fiber-reinforced, layered, or filled material (Fig. X1.5 and Fig. X1.6). The inclusion of the area under all of the peaks is often important, especially when the total energy absorbed by the part is significant, such as in automotive or packaging applications.

NOTE X1.2—Fig. X1.5 and Fig. X1.6 represent only two examples from a multitude of possibilities that might be encountered while testing composite materials.

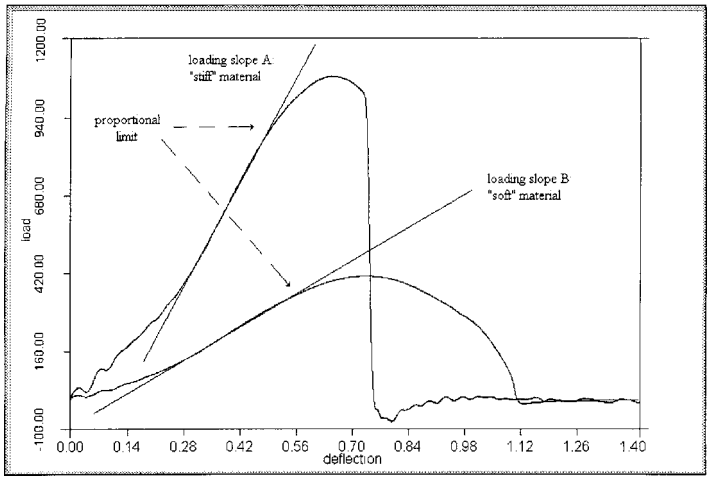

FIG. X1.4 Relative Stiffness Comparison and Proportional Limit

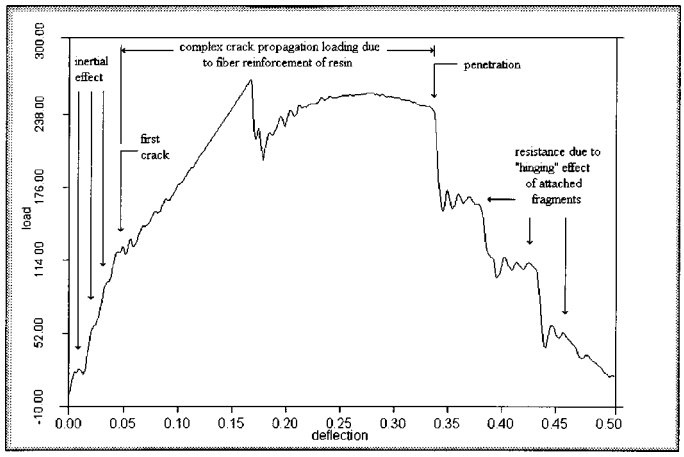

FIG. X1.6 Fiber-Reinforced Resin Data

X1.7 *Ductile or Elastomeric Failure*—There are several means of defining the point of failure of ductile- or elastomeric-type materials. The operator must define the criteria used if reporting this point. The failure may be obvious if the load drops to zero with little or no increase in displacement. A percent drop in load from the peak is one type of criteria used. If the probe is a one-piece design from the load transducer to the impact point, the portion of the load-displacement recording that follows penetration represents the friction effect of the probe sliding through the puncture and has no utility for describing the impact fracture.

X1.8 *Failure Mode*—Information can be submitted on the type of failure of the specimen, by visual inspection, using the following terms:

X1.8.1 *Ductile Failure*—One where the specimen deformed plastically before fracturing. The specimen is in one piece after the penetration and the deformed material exhibits plastic flow.

X1.8.2 *Brittle Failure*—One where the specimen test area is broken into two or more pieces, with sharp edges and shows almost no plastic flow.

NOTE X1.3—The ductile-to-brittle failure modes are a continuum and may be hard to separate. Each contains features of both and should be specific to the material under consideration.

X1.9 *Multiple Zero Slope Points*—Despite "noise" on the load-displacement recording, the recording may exhibit two or more points of zero slope. These may be indicative of cracks, tears, or failure of individual components in a composite. If they are significant to the application of the test data, they should be described and reported. See Fig. X1.5 and Fig. X1.6. Care must be taken to ensure that the zero slope points are not caused by inertial effects. See X1.4.

X1.9.1 *Investigating Noise or Multiple Peaks on the Load-Displacement Curve*—Care should be exercised that the peak or peaks reported are real and not artifacts of the impact test or inertial effects. This is especially true when brittle failures are encountered. The impact can produce inertial effects along with excitation of the natural frequencies of the transducer/probe/test device/specimen combination and since the "ringing" is added to the test data, significant errors can occur. If the multiple peaks of the unfiltered or unsmoothed test curve are approaching the natural frequency of the force measuring system, the validity of the data should be investigated.

X1.9.2 *Validity Determination*—Observe the multiple peaks on the load-displacement curve just after the probe has penetrated the specimen. If the peaks continue and are similar in frequency to the peaks on the data curve, the peaks are probably ringing noise. Another method involves performing additional tests at decreasing impact velocities. If, at slower velocities, the general curve shape and amplitude remain constant but the multiple peaks decrease in amplitude, the peaks are probably artifacts of the test.

X1.9.3 *Natural Frequency Determination*—It is recommended that each laboratory know the approximate natural frequency of its load transducer/probe assembly. The determination can be made by "ringing the system" much like the ringing of a tuning fork. With the transducer/probe assembly attached to the tester, a steel mallet or other hard tool is used to impact the probe in the same direction as the test impact, thereby exciting the natural frequency of the transducer/probe assembly. A recording system such as an analog or digital memory oscilloscope or computer data acquisition can be used to record the" ringing" of the load signal versus time following the impact. From this data, the approximate natural frequency can be characterized. Care should be taken not to overload and damage the transducer.

X1.10 For further information, consult the literature.[6,7]

[7] *Analysis and Control of Inertial Effects During Instrumented Impact Testing, ASTM STP 563*, ASTM, pp. 50–55.

X2. ALGORITHMS FOR INTERPRETATION OF HIGH SPEED TEST DATA

X2.1 This appendix covers algorithms for the interpretation of load-displacement or load-time curves acquired by computer data acquisition systems for transducers in high-speed material testing. In such systems, the curves are represented digitally as numeric arrays of load-displacement of load-time.

X2.1.1 The following information is limited to algorithms for the interpretation of data. It does not cover issues pertaining to the resolution, accuracy, or frequency of data acquisition.

X2.1.2 This appendix defines a set of algorithms to be used for calculating standard material properties of polymers, elastomers and related materials. It does not cover any visual interpretation or non-standard calculations not required in Section 11.

X2.2 *Symbols:*

X2.2.1 m = mass of falling weight including all attachments; that is, load cell, mounting hardware, and strikers,

X2.2.2 g = acceleration of gravity, $g = v$ for horizontal testing equipment,

X2.2.3 v = velocity of the falling weight,

X2.2.4 a = acceleration of the falling weight,

X2.2.5 F = force measured by the load cell,

X2.2.6 r = resultant force applied to specimen,

X2.2.7 t = time,

X2.2.8 E = energy, and

X2.2.9 d = displacement.

X2.3 *Load Cell*—Displacement calculated using load measurements can be achieved using the following method:

$$mg - P(t) = ma(t) \tag{X2.1}$$

where:

$$a(t) = g - \frac{1}{m} P(t)$$

$$V(t) = \int_i^t a(t)dt$$

$$x(t) = \int_i^t V(t)dt$$

where:

i = the point when the specimen is engaged.

NOTE X2.1—This procedure has only been proven for free-fall, drop-weight impact test machines. Mechanically driven systems require monitoring of the crosshead acceleration and have not been experimentally verified.

X2.4 *Velocity*—The three most commonly used methods for measuring velocity are: direct measurement, calculation from deflection-measuring device, and calculation from load-cell output and the determination of output initial velocity.

X2.4.1 *Direct Measurement*—Direct measurement gives a continuous output and requires no calculations.

X2.4.2 *Calculated from Displacement-Measuring Device*—Velocity from this type of measurement is simply:

$$V(t) = \frac{dx^2}{dt} \tag{X2.2}$$

X2.4.3 *Calculation from Load-Cell Output and the Determination of Initial Velocity*—To calculate the initial velocity for drop-weight systems it is common to use a light-beam detector in which a flag passes through. The flag has a known

dimension and using equations of motion the velocity can be determined at some point prior to the testing event:

$$V_i = V_0 + gt \quad \text{(X2.3)}$$

where:

V_0 = measured velocity of falling weight,
V_i = velocity at the point when the specimen is engaged, and
t = the time elapsed between V_0 and V_i.

The following equations are used to determine the velocity versus time:

$$a(t) = g - \frac{P(t)}{m}$$

$$V(t) = V_i + {}_i\int^t a(t)dt \quad \text{(X2.4)}$$

where:

i = the point the specimen is engaged.

X2.5 *Energy*—Energy may be computed by either the integration of the load-displacement curve or an energy balance.

X2.5.1 *Integration of the Load-Displacement Curve*—In systems that utilize a direct-measurement system for displacement the following is a simple method:

$$E(x) = {}_i\int^{14} Fdx \quad \text{(X2.5)}$$

NOTE X2.2—Systems that calculate displacement through multiple calculations can induce large errors using this method.

X2.5.2 *Energy Balance*—For a drop-weight machine the energy at any time can be calculated with the following equation:

$$E(t) = \frac{1}{2} m(v_i^2 - v(t)^2) + mg(\times (t)) \quad \text{(X2.6)}$$

NOTE X2.3—The operator of the test should view each curve to ensure that the algorithm has picked the correct value for the peak load.

NOTE X2.4—The algorithm for peak load must have the capabilities for the operator to select a point for peak load other than the value chosen by the algorithm.

NOTE X2.5—For referee purposes, all integration will be done using the trapezoid method.

X3. CALIBRATION VERIFICATION

X3.1 This appendix is designed to be a guideline for the use of 102 by 102 by 0.8 mm (4 by 4 by 0.032 in.) thick aluminum 6061-T6 as a standard control specimen for load cells used to perform instrumented impact tests.

X3.1.1 This test method is designed only to verify load cell accuracy. It is not designed to be an alternative method of load cell calibration. Any changes or recalibration of a load cell used for instrumented impact testing should be performed on NIST traceable equipment.

X3.1.2 Procure a sheet of standard 6061-T6 aluminum. Cut the aluminum sheet into specimens of size 102 by 102 by 0.8 mm (4 by 4 by 0.032 in.). After the specimens have been cut, randomly order specimens.

X3.1.3 Using a recently calibrated NIST traceable instrumented load cell, perform ten impact tests in accordance with this test method using samples prepared as described in X3.1.

X3.1.4 Record the average and the standard deviation for maximum load. Record the average and standard deviation for absorbed energy at maximum load. The values obtained for average maximum load and average energy to maximum load are the baseline for your control chart.

X3.1.5 To verify the accuracy and repeatability of any instrumented load cell, perform a minimum of five impact tests in accordance with this test method on control specimens prepared as described in X3.1.2. Compare the average values obtained for maximum load and energy absorbed at maximum load with the baseline values obtained in X3.1.3. If either of the values differ significantly from your baseline numbers, recalibration of your load cell using NIST traceable equipment is recommended.

X3.1.6 Every time a new batch of control specimens is procured a new baseline value for average maximum load and average energy absorbed at maximum load must be established. To establish a new baseline, repeat X3.1.2 to X3.1.4.

X4. 1982 ROUND ROBIN DATA INCLUDING PRECISION AND BIAS

X4.1 *Precision and Bias:*[8]

X4.1.1 Tables X4.1-X4.4 are based on a round robin conducted in 1982, involving 3 materials, tested at 2 speeds, by 10 laboratories. Five laboratories used falling weight machines and five used hydraulically driven machines. Each laboratory tested 3 specimens of each material at each speed.

TABLE X4.1 Maximum Load

Material	Speed, in./min	Mean, lbf	S_r, lbf	S_R, lbf	I_r, lbf	I_R, lbf
SMC	5000	432	22.86	40.3	65	114
	15 000	445	24.24	56.2	69	159
PP	5000	528	6.75	29.6	19	84
	15 000	552	7.21	45.7	20	129
GRPP	5000	930	21.73	50.8	61	144
	15 000	861	26.29	116.1	74	329

NOTE 1—Thicknesses were: SMC, 0.11 in.; PP, 0.11 in.; GRPP, 0.15 in.

[8] Supporting data are available from ASTM Headquarters. Request RR:D20-1114.

TABLE X4.2 Deflection to Maximum Load Point

Material	Speed, in./min	Mean, in.	S_r, in.	S_R, in.	I_r, in.	I_R, in.
SMC	5000	0.225	0.01460	0.0455	0.041	0.129
	15 000	0.226	0.00921	0.0448	0.026	0.127
PP	5000	0.602	0.00733	0.0409	0.021	0.116
	15 000	0.603	0.00953	0.0570	0.027	0.161
GRPP	5000	0.308	0.00971	0.0347	0.027	0.098
	15 000	0.295	0.01064	0.0537	0.030	0.152

NOTE 1—Thicknesses were: SMC, 0.11 in.; PP, 0.11 in.; GRPP, 0.15 in.

TABLE X4.3 Energy to Maximum Load Point

Material	Speed, in./min	Mean, ft · lbf	S_r, ft · lbf	S_R, ft · lbf	I_r, ft · lbf	I_R, ft · lbf
SMC	5000	4.28	0.509	1.32	1.44	3.74
	15 000	4.22	0.335	0.79	0.95	2.25
PP	5000	13.12	0.416	1.47	1.18	4.16
	15 000	13.04	0.326	1.86	0.92	5.26
GRPP	5000	13.09	0.631	1.66	1.79	4.68
	15 000	11.16	0.872	0.92	2.47	2.60

NOTE 1—Thicknesses were: SMC, 0.11 in.; PP, 0.11 in.; GRPP, 0.15 in.

X4.1.2 In Tables X4.1-X4.4, for the materials and speeds indicated, and for mean values that are derived from testing five specimens:

X4.1.2.1 S_r is the within-laboratory standard deviation of the mean, and $I_r = 2.83\ S_r$. (See X4.1.2.3 for application of I_r):

X4.1.2.2 S_R is the between-laboratory standard deviation of the mean, and $I_R = 2.83\ S_R$. (See X4.1.2.4 for application of I_R).

X4.1.2.3 *Repeatability*—In comparing two mean values for the same material, obtained by the same operator, using the same equipment on the same day, the means should be judged not equivalent if they differ by more than the I_r value for that material and condition.

TABLE X4.4 Total Energy

Material	Speed, in./min	Mean, t · lbf	S_r, ft · lbf	S_R, ft · lbf	I_r, ft · lbf	I_R, ft · lbf
SMC	5000	9.96	0.631	2.88	1.79	8.15
	15 000	9.11	0.532	2.29	1.51	6.49
PP	5000	24.46	0.367	2.15	1.04	6.09
	15 000	24.91	0.322	3.37	0.91	9.52
GRPP	5000	24.07	0.662	2.51	1.87	7.10
	15 000	20.29	0.747	3.32	2.11	9.38

NOTE 1—Thicknesses were: SMC, 0.11 in.; PP, 0.11 in.; GRPP, 0.15 in.

X4.1.2.4 *Reproducibility*—In comparing two mean values for the same material, obtained by different operators, using different equipment on different days, the means should be judged not equivalent if they differ by more than the I_R value for that material and condition. (This applies between different laboratories or between different equipment within the same laboratory.)

X4.1.2.5 The judgments in X4.1.2.3 and X4.1.2.4 will be correct in approximately 95 % of such comparisons.

X4.1.2.6 Other materials may give somewhat different results.

X4.2 For further information on the methodology used in this section, see Practice E 691.

X4.3 There are no recognized standards on which to base an estimate of bias for this test method.

SUMMARY OF CHANGES

This section identifies the location of selected changes to this test method. For the convenience of the user, Committee D20 has highlighted those changes that may impact the use of this test method. This section may also include descriptions of the changes or reasons for the changes, or both.

D 3763 – 02:
(*1*) Added Note 2 to Section 8 and renumbered subsequent notes.
D 3763 – 00:
(*1*) Deleted old 10.6.
(*2*) Modified 10.9.
(*3*) Changed column headings in Table 1 from "kN" to "N."
(*4*) In X3.1 and X3.1.2, changed aluminum "T-6061–T6511" to "6061–T6."

D 3763 – 97a:
(*1*) New precision and bias data, including Tables 1-3, were added.
(*2*) 1982 round-robin data was included as Appendix X4.
D 3763 – 99:
(*1*) In 5.1.2, changed plunger assembly tolerance from ±0.025 mm to ±0.13 mm.
D 3763 – 97:
(*1*) Added Annex A1.