Designation: D 3029 – 94

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St. Philadelphia, Pa 19103
Reprinted from the Annual Book of ASTM Standards. Copyright ASTM
If not listed in the current combined index, will appear in the next edition.

An American National Standard

Standard Test Methods for Impact Resistance of Flat, Rigid Plastic Specimens by Means of a Tup (Falling Weight)[1]

This standard is issued under the fixed designation D 3029; 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.

This standard has been approved for use by agencies of the Department of Defense. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

1. Scope

1.1 These test methods cover the determination of the relative ranking of materials according to the energy required to crack or break flat, rigid plastic specimens under various specified conditions of impact of a free-falling tup or weight.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 *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.* Specific hazards statements are given in Section 8.

2. Referenced Documents

2.1 *ASTM Standards:*

D 374 Test Methods for Thickness of Solid Electrical Insulation[2]

D 618 Practice for Conditioning Plastics and Electrical Insulating Materials for Testing[3]

D 883 Terminology Relating to Plastics[3]

D 1600 Terminology for Abbreviated Terms Relating to Plastics[3]

D 1709 Test Methods for Impact Resistance of Plastic Film by the Free-Falling Dart Method[3]

D 1898 Practice for Sampling of Plastics[3]

D 2188 Practice for Statistical Design in Interlaboratory Testing of Plastics[4]

D 2444 Test Method for Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)[5]

D 2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)[6]

D 4000 Classification System for Specifying Plastic Materials[7]

D 4066 Specification for Nylon Injection and Extrusion Materials[7]

E 171 Specification for Standard Atmospheres for Conditioning and Testing Materials[8]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[9]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[9]

3. Terminology

3.1 *Definitions*—For definitions of plastic terms used in these test methods, see Terminology D 883 and Terminology D 1600.

3.2 *Descriptions of Terms Specific to This Standard:*

3.2.1 *failure* (*of test specimen*)—the presence of any crack or split created by the impact of the falling tup, that can be seen by the naked eye under normal laboratory lighting conditions.

3.2.2 *mean failure energy* (*mean impact resistance*)—the energy required to produce 50 % failures, equal to the product of the drop height and the mean-failure weight, or the product of the constant weight and mean failure height.

3.2.3 *mean failure height* (*impact failure height*)—the height at which a standard weight, when dropped on test specimens, will cause 50 % failures.

3.2.4 *mean failure weight* (*impact failure weight*)—the weight of tup that, when dropped on test specimens from a standard height, will cause 50 % of them to fail.

3.2.5 *tup*—See 7.2 and Fig. 3.

NOTE 1—Cracks usually start at the surface opposite the one that is struck. Occasionally incipient cracking in glass-reinforced polymers, for example, may be difficult to differentiate from the reinforcing fibers. In such cases, a penetrating dye may be used to confirm the onset of crack formation.

4. Summary of Test Methods

4.1 Two basically different test methods, F and G, are described. These differ in the design of the machine and method of holding and striking the specimen. Each test method has characteristics that may dictate its use.

4.2 In Test Method F (Sections 7 to 15), a free-falling dart (tup) is allowed to strike a supported specimen directly. Either a dart having a fixed weight may be dropped from various heights, or a dart having an adjustable weight may be

[1] These test methods are under the jurisdiction of ASTM Committee D-20 on Plastics and are the direct responsibility of Subcommittee D20.10 on Mechanical Properties.

Current edition approved June 15, 1994. Published August 1994. Originally published as D 3029 – 72. Last previous edition D 3029 – 93.

[2] *Annual Book of ASTM Standards*, Vol 10.01.

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

[4] Discontinued, see *1982 Annual Book of ASTM Standards*, Vol 08.02.

[5] *Annual Book of ASTM Standards*, Vol 08.04.

[6] *Annual Book of ASTM Standards*, Vol 06.01.

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

[8] *Annual Book of ASTM Standards*, Vol 15.09.

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

TABLE 1 Tup and Support Ring Dimensions

Geometry	Tup Diameter	Inside Diameter Support Ring
	Test Method F	
	Dimensions, mm (in.)	
FA	15.86 ± 0.10 (0.625 ± 0.004)	76.20 ± 1.6 (3.00 ± 0.06)
FB	12.7 ± 0.1 (0.500 ± 0.003)	38.1 ± 0.8 (1.5 ± 0.03)
FC	38.1 ± 0.4 (1.5 ± 0.010)	127.0 ± 2.5 (5.00 ± 0.10)
	Test Method G	
GA	15.86 ± 0.10 (0.625 ± 0.004)	76.20 ± 0.25 (3.00 ± 0.01)
GB	15.86 ± 0.10 (0.625 ± 0.004)	31.75 ± 0.025 (1.25 ± 0.001)
GC	15.86 ± 0.10 (0.625 ± 0.004)	16.26 ± 0.025 (0.640 ± 0.001)

dropped from a fixed height. (See Fig. 1.)

4.3 In Test Method G (Sections 16 to 24), a weight falls through a guide tube and strikes an impactor resting on top of a supported specimen. The fixed weight is dropped from various heights. (See Fig. 4.)

4.4 Either procedure determines the energy (mass × height) that will cause 50 % of the specimens tested to fail (mean failure energy).

4.5 The technique used to determine mean failure energy is commonly called the Bruceton Staircase Method, or the Up-and-Down Method (**1**).[10] Testing is concentrated near the mean, reducing the number of specimens required to obtain a reasonably precise estimate of the impact resistance.

4.6 Each test method permits the use of different tup and test specimen geometries to obtain different modes of failure, permit easier sampling, or test limited amounts of material. There is no known means for correlating the results of tests made by different methods or procedures.

5. Significance and Use

5.1 Plastics are viscoelastic and therefore may be sensitive to changes in velocity of weights falling on their surfaces. However, the velocity of a free-falling object is dependent on the square root of the drop height. A change of a factor of two in the drop height will cause a change of only 1.4 in velocity. Hagan, et al (**2**) found that the mean failure energy of sheeting was constant at drop heights between 0.30 and 1.4 m. This suggests that a constant weight-variable height method will give the same results as the constant height-variable weight technique. On the other hand, different materials respond differently to changes in the velocity of impact. Equivalence of these test methods should not be taken for granted. While both constant-weight and constant-height techniques are permitted by these test methods, Test Method F, using a fixed height, should be used for those materials that are found to be rate-sensitive in the range of velocities encountered in falling-weight types of impact tests.

5.2 The test geometry used in Test Method F, Geometry FA, employs the same tup nose diameter and sample support ring as Test Method G, Geometry GA. (See 16.1 and Table 1.)

5.3 Test Method F, Geometry FB, causes a greater stress concentration and results in failure of tough or thick specimens that do not fail with Geometry FA (**3**). This approach causes a punch shear type of failure on thick sheet similar to that discussed in 4.5. If this is undesirable, Geometery FC may be used. Because of the smaller test area, it is more suitable for research and development.

5.3.1 The conical configuration of the 12.7-mm diameter tup used in Geometry FB minimizes problems with tup penetration and sticking in failed specimens of some ductile materials.

5.4 The test conditions of Test Method F, Geometry FC, are the same as those of Method A of Test Methods D 1709. They have been used in specifications for extruded sheeting. A limitation of this geometry is that considerable material is required.

5.5 The test conditions of Test Method G, Geometry GB are equivalent to the geometry used for the Gardner Variable Height Impact Test (**4**). It requires about the same amount of material as Test Method F, Geometry FB.

5.6 The test conditions of Test Method G, Geometry GC cause a punch-shear type of failure because the support-plate hole is close to the diameter of the impactor.

5.7 Because of the nature of impact testing, the selection of a test method and tup must be somewhat arbitrary. While any one of the tup geometries may be selected, knowledge of the final or intended end-use application should be considered.

5.8 Clamping of the test specimen will improve the precision of the data. Therefore, clamping is recommended. However, with rigid specimens valid determinations can be made without clamping. Unclamped specimens tend to exhibit somewhat greater impact resistance.

5.9 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.

6. Interferences

6.1 Falling-weight impact test results are dependent on the geometry of both the falling weight and the support. Thus, impact tests should be used only to obtain relative rankings of materials. Impact values cannot be considered absolute unless the geometry of the test equipment and specimen conform to the end-use requirement. Data obtained by different procedures within this test method, or with different geometries, cannot, in general, be compared directly with each other. However, the relative ranking of materials may be expected to be the same between two test methods if the mode of failure and the impact velocities are the same.

6.1.1 Falling-weight impact types of tests are not suitable for predicting the relative ranking of materials at impact velocities differing greatly from those imposed by these test methods.

6.2 As cracks usually start at the surface opposite the one

[10] The boldface numbers in parentheses refer to the list of references at the end of these test methods.

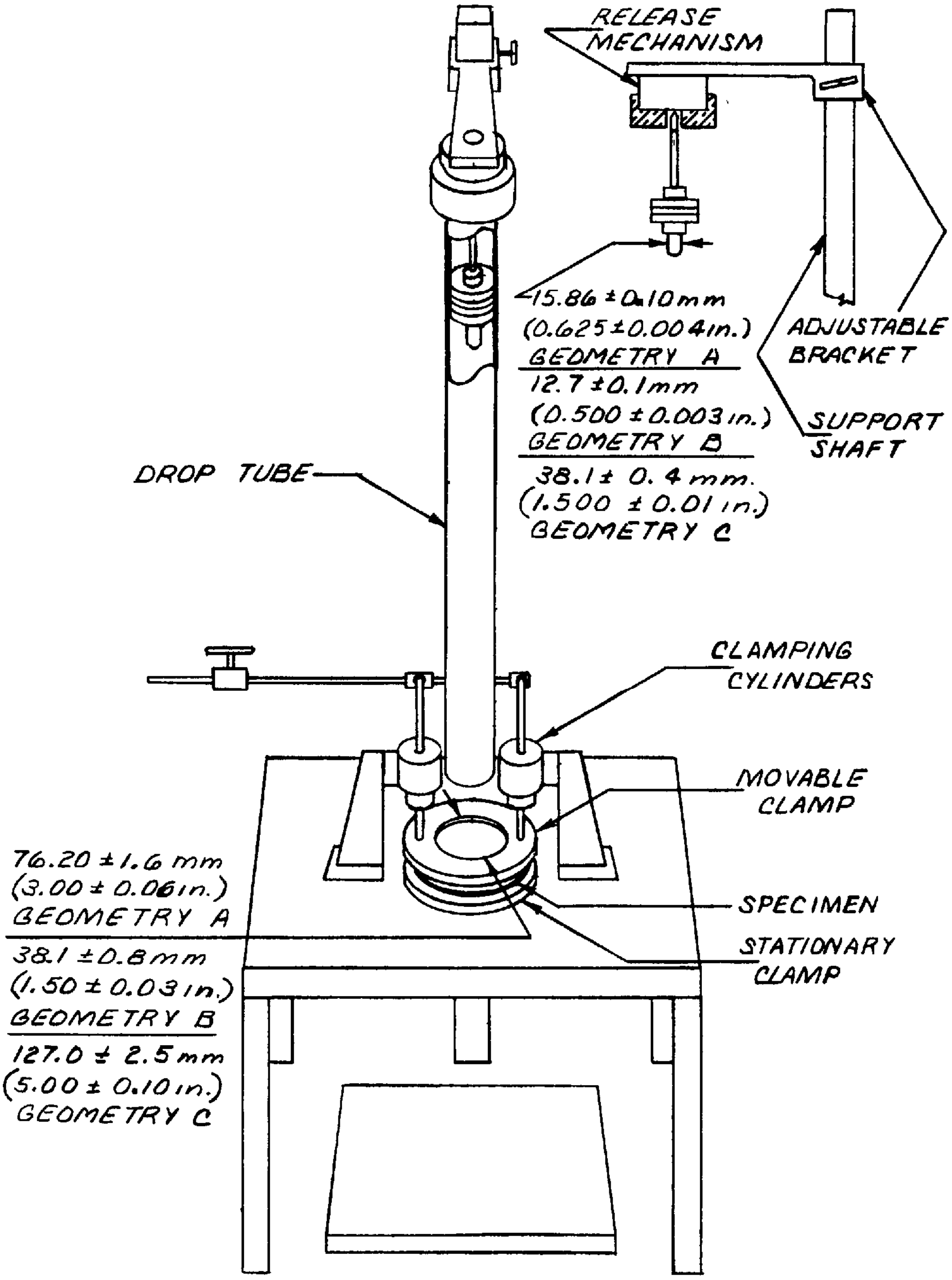


FIG. 1 One Type of Drop Weight Impact Tester Used for Test Method F

that is struck, the results obtained can be greatly influenced by the quality of the test specimens. Therefore, the composition of this surface layer and the degree of orientation introduced during the formation of the specimen (such as may occur during injection molding, if sub-standard conditions are used) are very important variables. Flaws in this surface will also affect results.

6.3 Impact properties of plastic materials can be very sensitive to temperature. This test can be carried out at any reasonable temperature and humidity, thus representing actual use environments. However, this test method is intended primarily for rating materials under specific impact conditions.

6.4 The apparatus used in Test Method G may not have sufficient energy available to cause failure of some specimens under the conditions of this procedure.

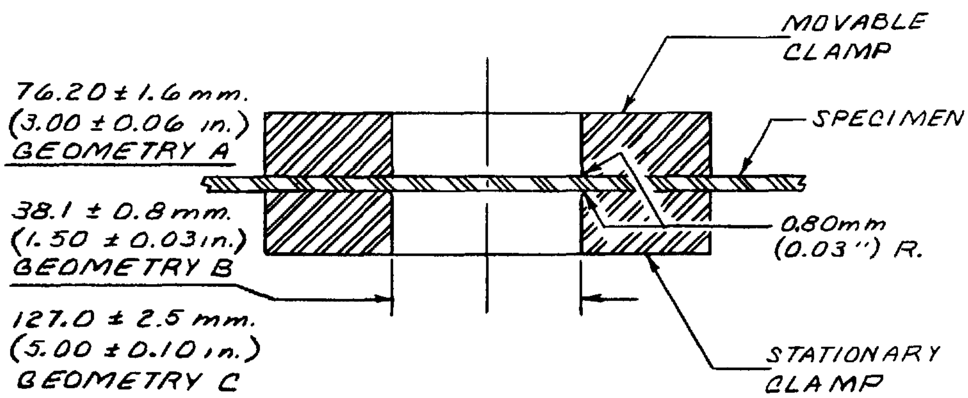
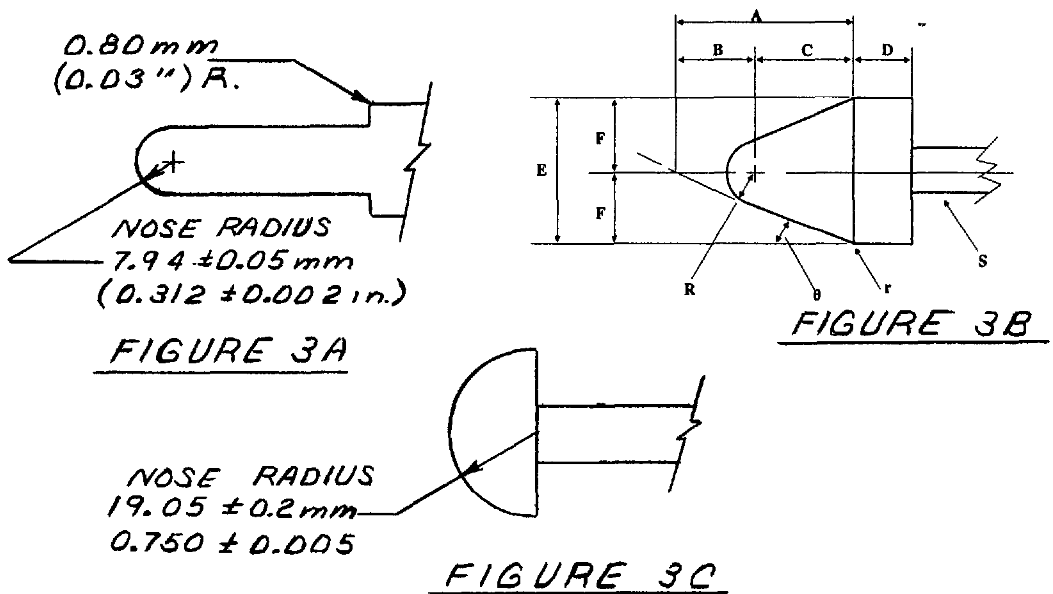


FIG. 2 Support Plate/Specimen/Clamp Configuration for Test Method F



Dimensions of Conical Dart (3B)

NOTE—Unless specified, the tolerance on all dimensions shall be ±2%.

Position	Dimension, mm	Dimension, in.
A	27.2	1.07
B	15	0.59
C	12.2	0.48
D	6.4	0.25
E	25.4	1
F	12.7	0.5
R (nose radius)	6.35 ± 0.05	0.250 ± 0.002
r (radius)	0.8	0.03
S (diameter)[A]	6.4	0.25
θ	25 ± 1°	25 ± 1°

[A] Larger diameter shafts may be used.

FIG. 3 Tup Geometries for Test Method F Geometries A(3A), B(3B), and C(3C)

TEST METHOD F—FREE-FALLING DART STRIKING SPECIMEN

7. Apparatus

7.1 *Testing Machine*—The apparatus shall be constructed essentially as is shown in Fig. 1. The apparatus is similar in design to that used in Test Methods D 1709 and D 2444. The geometry of the specimen clamp and tup shall conform to the dimensions given in 7.1.1 and 7.2.

7.1.1 *Specimen Clamp*—For flat specimens, a two-piece annular specimen clamp similar to that shown in Fig. 2 is recommended. For Geometry FA, the inside diameter should be 76.20 ± 1.6 mm (3.00 ± 0.06 in.). For Geometry

FB, the inside diameter should be 38.1 ± 0.80 mm (1.50 ± 0.03 in.). For Geometry FC, the inside diameter should be 127.0 ± 2.5 mm (5.00 ± 0.10 in.). See Table 1. The inside edge of the upper or supporting surface of the lower clamp should be rounded slightly; a radius of 0.8 mm (0.03 in.) has been found to be satisfactory.

7.1.1.1 Contoured specimens shall be firmly held in a jig so that the point of impact will be the same for each specimen.

7.1.2 *Tup Support*, capable of supporting a 13.5-kg (30-lb) weight, with a release mechanism and a centering device to ensure uniform, reproducible drops.

NOTE 2—Reproducible drops may be assured through the use of a tube or cage within which the tup fails. In this event, care should be exercised so that any friction that develops will not reduce the velocity of the tup appreciably.

7.1.3 *Positioning Device*—Means shall be provided for positioning the tup so that the distance from the impinging surface of the tup head to the test specimen is as specified.

7.2 *Tup:*

7.2.1 The tup used in Geometry FA shall have a 15.86 ± 0.10-mm (0.625 ± 0.004-in.) diameter hemispherical head of tool steel hardened to 54 HRC or harder. A steel shaft about 13 mm (0.5 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal axis at 90° to that surface. The length of the shaft shall be great enough to accommodate the maximum number of weights required. See Fig. 3A and Table 1.

7.2.2 The tup used in Geometry FB shall be made of tool steel hardened to 54 HRC or harder. The head shall have a diameter of 12.7 ± 0.1 mm (0.500 ± 0.003 in.) with a conical (50° included angle) configuration such that the conical surface is tangent to the hemispherical nose. A 6.4-mm (0.25-in.) diameter shaft is satisfactory. See Fig. 3B and Table 1.

7.2.3 The tup used for Geometry FC shall be made of tool steel hardened to 54 HRC or harder. The hemispherical head shall have a diameter of 38.1 ± 0.4 mm (1.5 ± 0.015 in.). A steel shaft about 13 mm (0.5 in.) in diameter shall be attached to the center of the flat surface of the head with its longitudinal axis at 90° to that surface. The length of the shaft shall be great enough to accommodate the maximum number of weights required.

7.2.4 The tup head shall be free of nicks, scratches, or other surface irregularities.

7.3 *Weights*—Cylindrical steel weights are required that have a center hole into which the tup shaft will fit. A variety of weights are needed if different materials or thicknesses are to be tested. For a material of quite low impact resistance, the tup weight may need to be adjusted by increments of 10 g or less. Materials of high impact resistance may require increments of 1 kg or more.

7.4 *Micrometer*, for measurement of specimen thickness. It should be accurate to 1 % of the average thickness of the specimens used. See Test Methods D 374 for descriptions of suitable micrometers.

7.5 The weight of the tup head and shaft assembly and the additional weights required must be accurate to ±1 %.

8. Hazards

8.1 *Safety Precautions:*

8.1.1 Cushioning and shielding devices shall be provided to protect personnel and to avoid damage to the impinging surface of the tup. A tube or cage can contain the tup if it rebounds after striking a specimen.

8.1.2 When heavy weights are used, it is hazardous for an operator to attempt to catch a rebounding tup. Fig. 2 of Test Method D 2444 shows an effective mechanical "rebound catcher" employed in conjunction with a drop tube.

9. Sampling

9.1 Unless otherwise agreed upon between the manufacturer and the producer, the material shall be sampled in accordance with Sections 9 through 14 of Practice D 1898.

10. Test Specimens

10.1 Flat test specimens shall be large enough so that they can be clamped firmly if clamping is desirable.

10.2 The thickness of any specimen in a sample shall not differ by more than 5 % from the average specimen thickness of that sample. However, if variations greater than 5 % are unavoidable in a sample that is obtained from parts, the sample may be tested, but the data shall not be used for referee purposes. Machining specimens to reduce thickness variation is not permissible.

10.3 When the approximate mean failure weight for a given sample is known, 20 specimens will usually yield sufficiently precise results. If the approximate mean failure weight is unknown, six or more additional specimens should be used to determine the appropriate starting point of the test.

10.4 The specimen shall be carefully examined visually to ensure that samples are free of cracks or other obvious imperfections or damages, unless these imperfections constitute variables under study. Samples known to be defective should not be tested for specification purposes. Production parts, however, should be tested in the as-received condition to determine conformance to specified standards.

10.5 Select a suitable method for making the specimen that will not affect the impact resistance of the material.

NOTE 3—As few as ten specimens often yield sufficiently reliable estimates of the mean failure weight. However, in such cases the estimated standard deviation will be relatively large (**1**).

11. Conditioning

11.1 Unless otherwise specified, condition the test specimens at 23 ± 2°C (73.4 ± 3.6°F) and 50 ± 5 % relative humidity for not less than 40 h prior to test, in accordance with Procedure A of Practice D 618 and Specification E 171, for those tests where conditioning is required. In cases of disagreement, the tolerances shall be ±1°C (±1.8°F) and ±2 % relative humidity.

11.1.1 Note that for some hygroscopic materials, such as nylons, the material specifications (for example, Specification D 4066) call for testing "dry as-molded specimens." Such requirements take precedence over the above routine preconditioning to 50 % relative humidity and require sealing the specimens in water vapor-impermeable containers as soon as molded and not removing them until ready for testing.

11.2 Conduct tests in the standard laboratory atmosphere of 23 ± 2°C (73.4 ± 0.6°F) and at 50 ± 5 % relative humidity, unless otherwise specified.

12. Procedure

12.1 Determine the number of specimens for each sample to be tested, as specified in 10.3.

12.2 Mark the specimens and condition as specified in 11.1.

12.3 Prepare the test apparatus for the geometry (FA, FB, FC) selected.

12.4 Measure and record the thickness of each specimen in the area of impact.

12.5 Choose a specimen at random from the sample. A random-numbers table may be used if desired.

12.6 Clamp or position the specimen. The same surface or area should be the target each time (see 6.2). When clamping is employed, the force should be sufficient to prevent motion of the clamped portion of the specimen when the tup strikes.

12.7 Adjust the total weight of the tup to that amount which is expected to cause half the specimens to fail.

12.8 Position the tup the proper distance from the surface of the specimen. Unless otherwise specified, this distance shall be 0.660 ± 0.008 m (26.0 ± 0.3 in.).

NOTE 4—If failures cannot be produced with the maximum available missile weight, the drop height can be increased. The test temperature could be reduced by (*a*) use of an ice-water mixture, or (*b*) by air-conditioned environment to provide one of the temperatures given in 3.3 of Practice D 618. Conversely, if the unloaded tup causes failures when dropped 0.660 m, the drop height can be decreased. A moderate change in dart velocity will not usually affect the mean failure energy appreciably. Refer to 4.1.

12.9 Release the tup. Be sure that it hits the center of the specimen. If the tup bounces, catch it to prevent multiple impact damage to the specimen's surface (see 8.1.3).

12.10 Remove the specimen and examine it to determine whether or not it has failed. Permanent deformation alone is not considered failure, but note the extent of such deformation (depth, area). For some polymers, for example, glass-reinforced polyester, incipient cracking may be difficult to determine with the naked eye. Exposure of the stressed surface to a penetrating dye, such as gentian violet, may be used to determine the onset of cracking.

12.11 If the first specimen fails, remove one increment of weight from the tup while keeping the drop height constant, or decrease the drop height while keeping the weight constant (see 12.12). If the first specimen does not fail, add one increment of weight to the tup or increase the drop height one increment, as above. Then test the second specimen.

12.12 In this manner, select the impact height or weight for each test from the results observed with the specimen just previously tested. Test each specimen only once.

12.13 For best results, the weight or height increment used should be approximately equivalent to s, the estimated standard deviation of the test for that sample. An increment of 0.5 to 2 times s is satisfactory (see 13.4).

NOTE 5—An increment of 10 % of the estimated mean failure weight or mean failure height has been found to be acceptable in most instances.

12.14 Keep a running plot of the data, as shown in Appendix X1. Use one symbol, such as *X*, to indicate a failure and a different symbol, such as *O*, to indicate a nonfailure at each weight or height level.

13. Calculation

13.1 *Mean Failure Weight*—If a constant-height procedure was used, calculate the mean failure weight from the test data obtained, as follows:

$$w = w_o + d_w(A/N \pm 0.5)$$

13.2 *Mean Failure Height*—If a constant-weight procedure was used, calculate the mean failure height from the test data obtained, as follows:

$$h = h_o + d_h(A/N \pm 0.5)$$

where:

w = mean failure weight, kg (or lb),
h = mean failure height, mm (or in.),
d_w = increment of tup weight, kg (or lb),
d_h = increment of tup height, mm (or in.),
N = total number of failures or nonfailures, whichever is smaller. For ease of notation, call whichever are used events,
w_o = smallest weight at which an event occurred, kg (or lb),
h_o = lowest height at which an event occurred, mm (or in.),
A = $\sum_{i=0}^{k} in_i$,
i = 0, 1, 2 . . . k (counting index, starts at h_o or w_o),
n_i = number of events that occurred at h_i or w_i,
w_i = $w_o + id_w$, and
h_i = $h_o + id_h$.

In calculating w *or* h, the negative sign is used when the events are failures. The positive sign is used when the events are nonfailures. Refer to the example in Appendix X1.

13.3 *Mean Failure Energy*—Compute the mean failure energy as follows:

where:

MFE = mean failure energy, J (or in.·lbf),
MFE = hwf,
h = mean failure height or constant height as applicable, mm (or in.),
w = mean failure weight or constant weight as applicable, kg (or lb), and
f = factor for conversion to joules.

Use $f = 9.80665 \times 10^{-3}$ if h = mm and w = kg; Use 0.11299 if h = in. and w = lb; Use f = 1.0 for inch-pound units (in·lbf., in., lb).

13.4 *Estimated Standard Deviation of the Sample*—If desired for record purposes, the estimated standard deviation of the sample for either variable weight or variable height can be calculated as follows:

$$s_w = 1.62d_w\,[B/N - (A/N)^2] + 0.047d_w \text{ or}$$
$$s_h = 1.62d_h\,[B/N - (A/N)^2] + 0.047d_h$$

where:

s_w = estimated standard deviation, weight, kg (or lb),
s_h = estimated standard deviation, height, mm (or in.), and
B = $\sum_{i=0}^{k} i^2 n_i$.

The above calculation is valid for $[B/N - (A/N)^2] > 0.3$. If the value is <0.3, use Table I from Ref. 3.

13.5 *Estimated Standard Deviation of the Sample Mean*—Calculate the estimated standard deviation of the sample mean failure height or weight as follows:

$$s_{\bar{w}} = Gs_w/\sqrt{N}$$
or
$$s_{\bar{h}} = Gs_h/\sqrt{N}$$

where:

$s_{\bar{h}}$ = estimated standard deviation of the mean height, mm (or in.),

$s_{\bar{w}}$ = estimated standard deviation of the mean weight, kg (or lb), and

G = factor that is a function of s/d (see Appendix X2).

A sample computation of s_w may be found in Appendix X1.

NOTE 6—For values of G at other levels of s/d, see Fig. 22 in Ref (5).

13.6 *Estimated Standard Deviation of the Mean Failure Energy*—Calculate the estimated standard deviation of the mean-failure energy as follows:

$$S_{MFE} = s_{\bar{h}}\, w\, f,$$
or
$$S_{MFE} = s_{\bar{w}}\, h\, f, \text{ as applicable}$$

where:

S_{MFE} = estimated standard deviation of the mean failure energy.

14. Report

14.1 Report the following information:

14.1.1 Complete identification of the sample tested, including type of material, source, manufacturer's code, form, principal dimensions, and previous history.

14.1.2 Method of preparation of specimens.

14.1.3 Means of clamping, if any.

14.1.4 Statement of geometry (FA, FB, FC) and procedure used—constant weight or constant height.

14.1.5 Thickness of specimens tested (average and range).

14.1.6 Number of tests specimens employed to determine the mean failure height or weight.

14.1.7 Mean failure energy.

14.1.8 Types of failure, for example: (*a*) crack or cracks on one surface only (the plaque could still hold water), (*b*) cracks that penetrate the entire thickness (water would probably penetrate through the plaque), (*c*) brittle shatter (the plaque is in several pieces after impact), or (*d*) ductile failure (the plaque is penetrated by a blunt tear). Report other observed deformation due to impact, whether the specimens fail or not.

14.1.9 Date of test and operator name.

14.1.10 Test temperature.

14.1.11 In no case shall results obtained with arbitrary geometries differing from those contained in these test methods be reported as values obtained by Test Methods D 3029.

15. Precision and Bias

15.1 Tables 2 and 3 are based on a round robin[11] conducted in 1972 involving three materials tested by six laboratories. Data from only four laboratories were used in calculating the values in these tables. Each test result was the mean of multiple individual determinations (Bruceton Staircase Procedure). Each laboratory obtained one test result for a material.

TABLE 2 Precision, Test Method FB

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r[B]	r[C]
Polymethyl Methacrylate (PMMA)	0.35	12.6	35.7
Styrene-Butadiene (SB)[A]	9.26	18.7	52.9
Acrylonitrile-Butadiene-Styrene (ABS)[A]	11.8	14.9	42.2

[A] Data generated in three laboratories.
[B] V_r = Within-laboratory coefficient of variation of the mean.
[C] $r = 2.83\ V_r$.

TABLE 3 Precision, Test Method FC

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r[A]	r[B]
Polymethyl Methacrylate (PMMA)	1.33	4.13	11.7
Styrene-Butadiene (SB)	48.3	18.3	51.8

[A] V_r = within-laboratory coefficient of variation of the mean.
[B] $r = 2.83\ V_r$.

15.1.1 *Polymethylmethacrylate (PMMA)*—Specimens were cut from samples of 3.18-mm (0.125-in.) thickness extruded sheet.

15.1.2 *Styrene-Butadiene (SB)*—Specimens were cut from samples of 2.54-mm (0.100-in.) thickness extruded sheet.

15.1.3 *Acrylonitrile-Butadiene-Styrene (ABS)*—Specimens were cut from samples of 2.64-mm (0.104-in.) thickness extruded sheet.

NOTE 7—**Caution:** The following explanations of r and R (15.2 through 15.2.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 2 and 3 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be 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 laboratory and materials, or between specific laboratories. The principles of 15.2 through 15.2.3 would then be valid for such data.

15.2 *Concept of r and R*—If V_r, and V_R have been calculated from a large enough body of data, and for test results that were means from testing multiple individual specimens. (Bruceton Staircase Procedure).

15.2.1 *Repeatability, r*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, the two test results should be judged not equivalent if they differ by more than the r value for that material.

15.2.2 *Reproducibility, R*—In comparing two test results for the same material, obtained by different operators using different equipment in different laboratories, reproducibility statistics were not calculated because data from only four and three laboratories do not justify making these calculations.

15.2.3 Any judgment in accordance with 15.2.1 would have an approximate 95 % (0.95) probability of being correct.

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

15.4 Efforts to form a task group to address between-laboratory reproducibility of these test methods have been unsuccessful. Persons interested in participating in such a task group should contact ASTM Headquarters.

[11] Supporting data are available from ASTM Headquarters. Request RR: D20 - 1030.

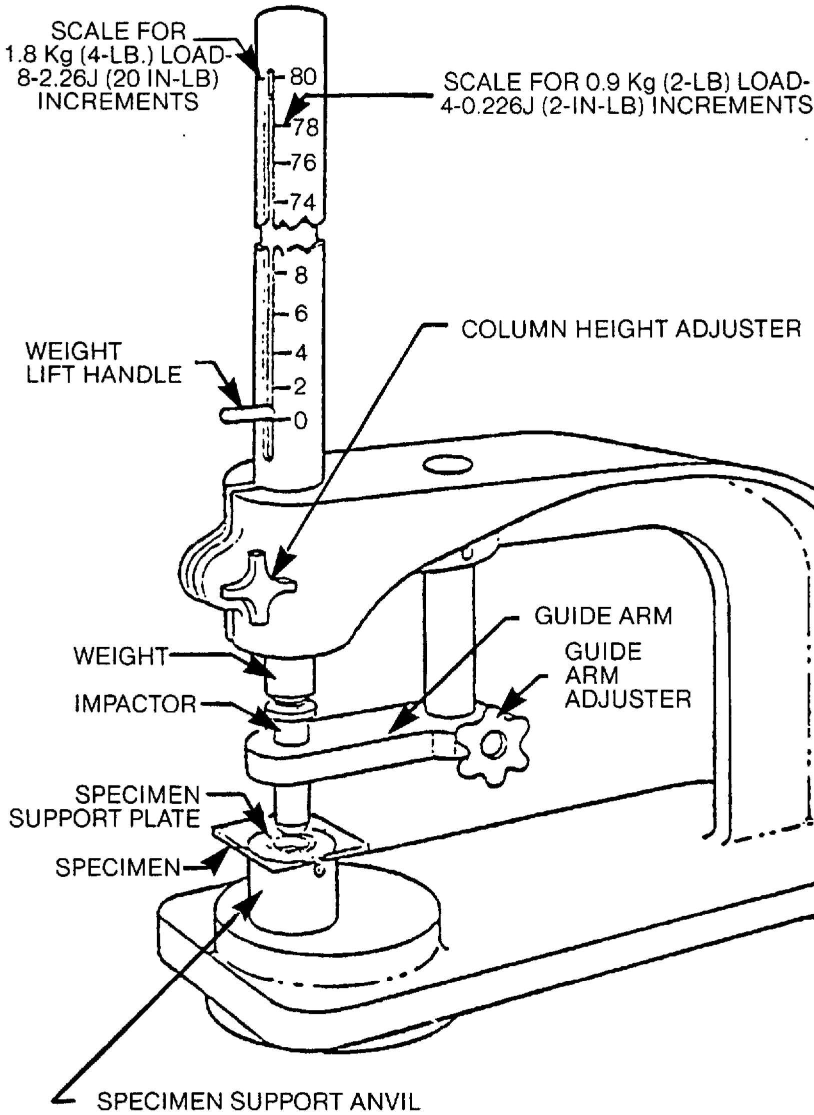


FIG. 4 Impact Tester Used in Test Method G

TEST METHOD G—FALLING WEIGHT STRIKING AN IMPACTOR

16. Apparatus

16.1 *Testing Mechanism*—The apparatus is shown in Fig. 4. This apparatus can either be adapted from Test Method D 2794 or obtained commercially[12] and shall consist of the following: suitable base to withstand the impact shock; steel-rod impact weights weighing 0.9 kg (2 lb), 1.8 kg (4 lb), or 3.6 kg (8 lb); a hardened-steel impactor having a round nose with a diameter of 15.86 ± 0.10 mm (0.625 ± 0.004 in.); a slotted guide tube 1.0 m (40 in.) in length, in which the impact weights slide, having graduations in newton-metres (inch-pound increments) or multiples thereof. A bracket is used to hold the tube in vertical position by attaching it to the base and also to hold the hand knob, which is a pivot-arm alignment for the impactor, about 50 mm (2 in.) under the tube. This instrument must be mounted firmly to a rigid table or bench. The top edge of the opening in each specimen support plate should be rounded to a 1.6-mm (0.062-in.) radius.

16.1.1 With Geometry GA, a specimen-support plate with a hole 76.20 ± 0.25 mm (3.00 ± 0.01 in.) in diameter is mounted in the apparatus. A suggested design is given in Fig. 5.

16.1.2 With Geometry GB, the specimen-support plate has a 31.75 ± 0.025-mm (1.25 ± 0.001-in.) diameter hole. This geometry can be achieved by removing the removable support ring on the standard Gardner instrument.

[12] Gardner Variable Height Impact Tester, Models IG-1120 or IG-1120-M, available from Gardner Laboratory, Inc., Bethesda, MD 20014 (either apparatus has been found satisfactory for this purpose), or Custom Scientific Instruments, Inc., Model CS-126G, P.O. Box A, Whippany, NJ 07981, or Testing Machines Inc., 400 Bayview Ave., Amityville, L.I., NY 11701.

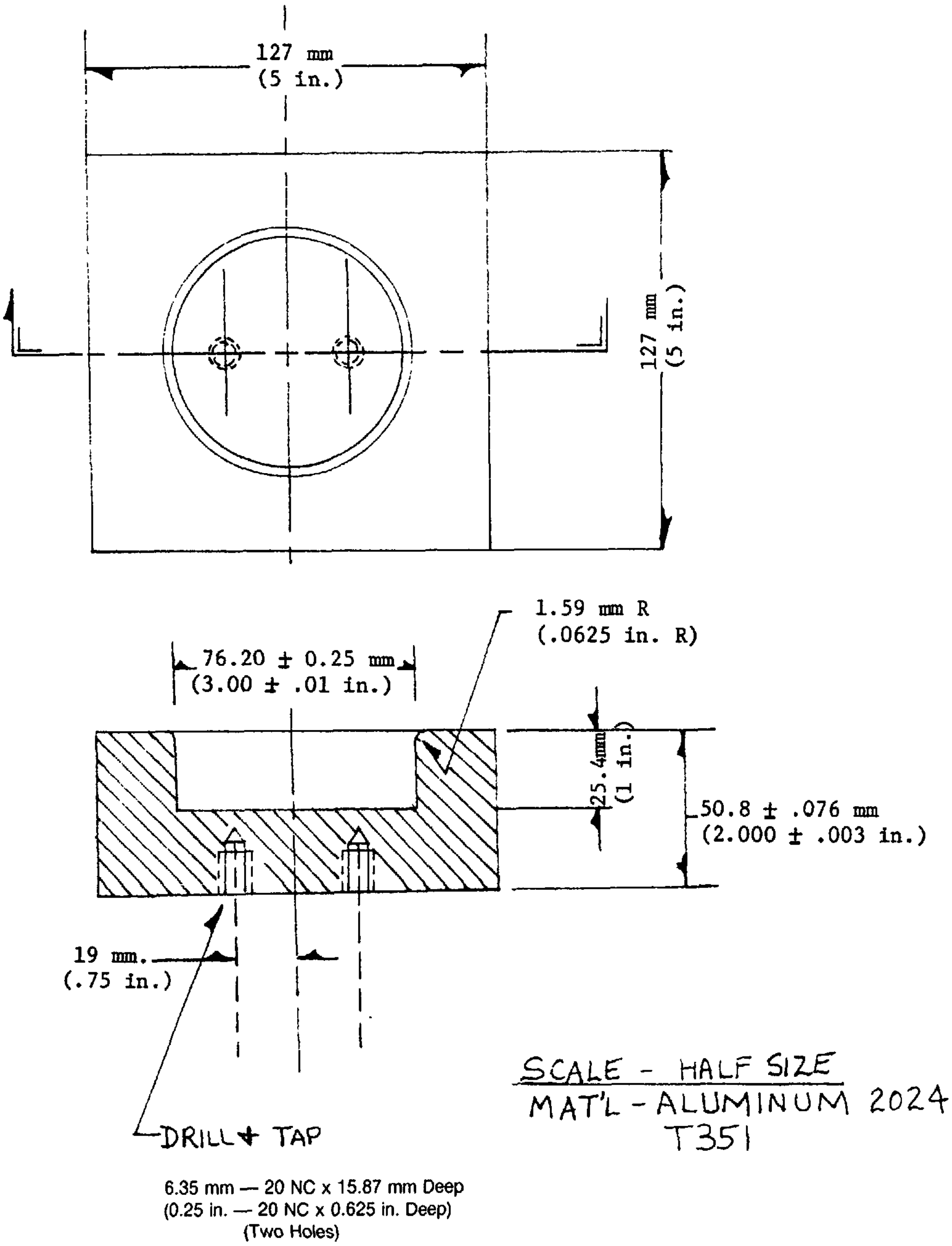


FIG. 5 Support Plate for Test Method G, Geometry A

16.1.3 With Geometry GC, the standard removable specimen-support plate, with a hole 16.26 ± 0.025 mm (0.640 ± 0.001 in.) in diameter, is mounted in the specimen support-anvil. See Fig. 6.

16.2 *Micrometer*—See 7.4.

17. Sampling

17.1 Same as in 9.1.

18. Test Specimens

18.1 The diameter or width of flat test specimens shall be at least 25 mm (1.00 in.) greater than the diameter of the hole in the support plate. The specimens shall be free of obvious imperfections, unless the imperfections constitute a variable under study.

18.2 Same as in 10.2.

18.3 Same as in 10.3.

18.4 Same as in 10.4.

18.5 Same as in 10.5.

19. Conditioning

19.1 Same as in 11.1

19.1.1 Same as in 11.1.1.

19.2 Same as in 11.2.

20. Procedure

20.1 Same as in 12.1.

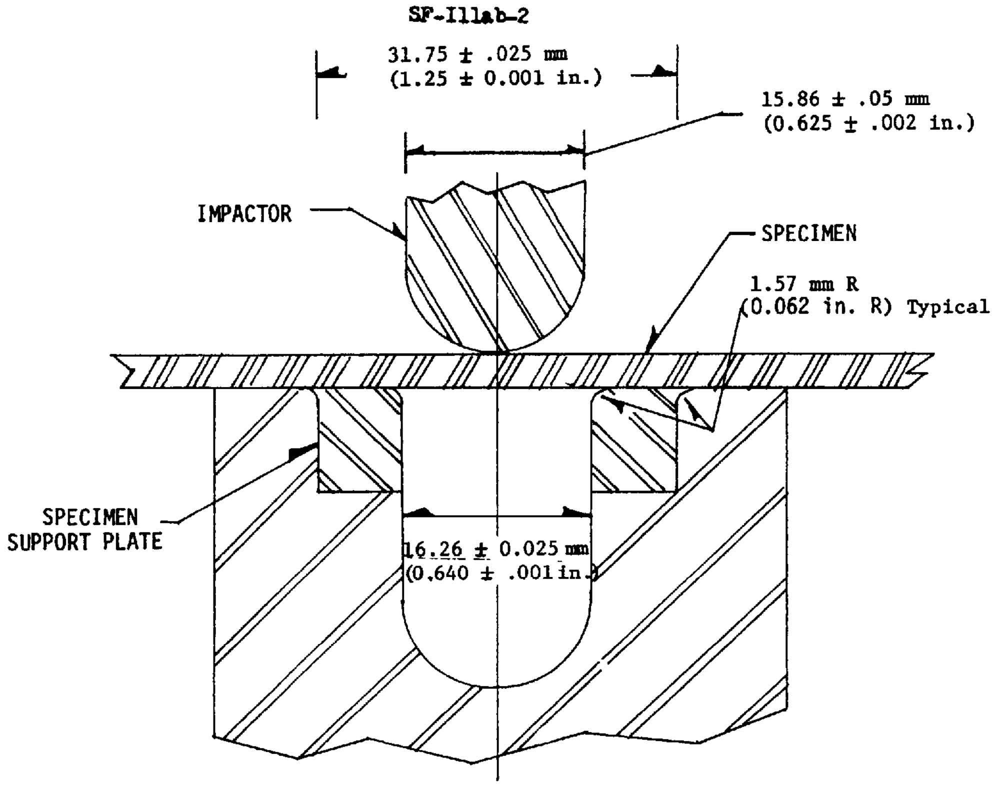


FIG. 6 Impactor/Specimen/Support Plate Configuration for Test Method G (Geometry GC shown)

20.2 Same as in 12.2.
20.3 Same as in 12.3.
20.4 Same as in 12.4.
20.5 Same as in 12.5.
20.6 Position the specimen. The same surface or area, or both, of the test specimen should be the target each time (see 6.2). If clamping is employed, the clamping force should be sufficient to prevent motion of the specimen.

NOTE 7—Normally the specimen is not clamped because the test apparatus does not have provision for clamping. However, the apparatus can be modified to permit clamping, which should improve the precision of the measurement (see 4.9).

20.7 Place the test specimen on the tester anvil, after raising the weight and impactor foot. Be sure the specimen is flat against the specimen-support plate before the impactor foot is brought in contact with the top surface of the specimen. (Figure 3 shows the position of the test specimen.) Raise the weight in the tube to the desired impact value, as shown on the appropriate scale, and release it so that the weight drops on the impactor.
20.8 Same as in 12.10.
20.9 Same as in 12.11, using the constant-weight technique.
20.10 Same as in 12.12.
20.11 Same as in 12.13.
20.12 Same as in 12.14.

21. Calculation

21.1 *Mean Failure Height*—Same as in 13.2.
21.2 *Mean Failure Energy*—Same as in 13.3.
21.3 *Estimated Standard Deviation of the Mean Failure Energy*—Same as in 13.6.

22. Report

22.1 Same as in 14.1.

23. Precision and Bias

23.1 Tables 4, 5, and 6 are based on a round robin[13] conducted in 1977 involving four materials tested by four laboratories. Data from only three laboratories were used in calculating the values in these tables. Each test result was the mean of multiple individual determinations (Bruceton Staircase Procedure). Each laboratory obtained two test results for a material.

NOTE 8—**Caution:** The following explanations of *r* and *R* (23.2 through 23.2.3) are only intended to present a meaningful way of considering the approximate precision of this test method. The data in Tables 4 and 6 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and may not be 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 laboratory and materials, or between specific laboratories. The principles of 23.2 through 23.2.3 would then be valid for such data.

23.1.1 *Glass-Reinforced Nylon (33 % Glass)*—101 by 101 by 3.2 mm (4 by 4 by ⅛ in.), cut from injection-molded plaques.
23.1.2 *Acetal (Homopolymer)*—101 by 101 by 3.2 mm (4

[13] Supporting data are available from ASTM Headquarters. Request RR: D20 - 1060.

TABLE 4 Precision, Test Method GA

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r[A]	r[B]
33 % glass-reinforced nylon (PA)	0.75	4.66	13.2
Acetal (POM)	2.12	6.90	19.5
Impact polystyrene	15.1	2.20	6.23

[A] V_r = within-laboratory coefficient of variation of the mean.
[B] $r = 2.83\ V_r$.

TABLE 5 Precision, Test Method GB

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r[A]	r[B]
33 % glass-reinforced nylon (PA)	0.99	3.18	8.99
Acetal (POM)	2.57	11.6	32.8
Impact polystyrene	10.3	12.3	34.7
Acrylonitrile-butadiene-styrene (ABS)	26.9	6.56	18.6

[A] V_r = within-laboratory coefficient of variation of the mean.
[B] $r = 2.83\ V_r$.

by 4 by ⅛ in.), cut from injection-molded plaques.

23.1.3 *Impact Polystyrene*—101 by 101 by 3.2 mm (4 by 4 by ⅛ in.), cut from extruded sheet.

23.1.4 *ABS*—101 mm diameter by 3.2 mm (4 in. diameter by ⅛ in.), injection-molded disks.

23.2 *Concept of r and R*—If V_r and V_R have been calculated from a large enough body of data, and for test results that were means from testing multiple individual specimens (Bruceton Staircase Procedure).

23.2.1 *Repeatability, r*—In comparing two test results for the same material, obtained by the same operator using the same equipment on the same day, the two test results should be judged not equivalent if they differ by more than the *r* value for that material.

TABLE 6 Precision, Test Method GC

Material	Mean, J	Values Expressed as Percent of the Mean	
		V_r[A]	r[B]
33 % glass-reinforced nylon (PA)	1.82	1.92	5.44
Acetal (POM)	4.56	7.02	19.9
Impact polystyrene	14.8	18.6	52.7

[A] V_r = within-laboratory coefficient of variation of the mean.
[B] $r = 2.83\ V_r$.

23.2.2 *Reproducibility, R*—In comparing two test results for the same material, obtained by different operators using different equipment in different laboratories, reproducibility statistics were not calculated because data from only three laboratories do not justify making these calculations.

23.2.3 Any judgement in accordance with 23.2.1 would have an approximate 95 % (0.95) probability of being correct.

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

23.4 Efforts to form a task group to address between-laboratory reproducibility of these methods have been unsuccessful. Persons interested in participating in such a task group should contact ASTM Headquarters.

24. Keywords

24.1 dart impact; falling weight impact; gardner impact; impact; impact resistance; mean failure energy; mean failure height; mean failure weight; rigid plastic; tup

REFERENCES

(1) Brownlee, K. A., Hodgest, J. L., Jr., and Rosenblatt, Murray, "The Up-and-Down Method with Small Samples," *American Statistical Association Journal*, Vol 48, 1953, pp. 262–277.

(2) Hagan, R. S., Schmitz, J. V., and Davis, D. A., "Impact Testing of High Impact Thermoplastic Sheet," *Technical Papers, 17th Annual Technical Conference of SPE, SPPPB*, Vol VII, January 1961.

(3) "Test Method A—Falling Dart Impact, Proposed Method of Test for Impact Resistance of Fabricated Plastics Parts," *Proposed Test Methods for Plastics Parts Used in Appliances*, Society of the Plastics Industry, New York, NY, January 1965.

(4) "Test Method B—Gardner Impact," *ibid.*

(5) Weaver, O. R., "Using Attributes to Measure a Continuous Variable in Impact Testing Plastic Bottles," *Materials Research and Standards*, Vol 6, No. 6, June 1966, pp. 285–291.

(6) Natrella, M. G., "*Experimental Statistics*," National Bureau of Standards Handbook 91, October 1966, pp. 10–22 and 10–23.

APPENDIXES

(Nonmandatory Information)

X1. SAMPLE CALCULATIONS

Total Dart Weight, kg	Outcome of Test (X = failure; O = non-failure)																				n_x	n_o	i	n_i	in_i	i^2n_i
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20						
9.00						X															1	0	2	1	2	4
8.00					O		X		X				X		X						4	1	1	4	4	4
7.00		X		O				O		X		O		O		X		X		O	4	5	0	4	0	0
6.00	O		O								O						O		O		0	5				
																				Totals	9 (N_x)	11 (N_o)		9 (N)	6 (A)	8 (B)

w_O = 7.00; $N = N_X = 9$; $d = 1.00$

$w = w_O + d(A/N - 0.5)$

$= 7.00 + 1.00\,(6/9 - 0.5)$

$= 7.17$ kg

$s = 1.620\,d[((NB - A^2)/9^2) + 0.029]$

$= 1.620\,(1.00)\,[((9.8 - 6^2)/9^2) + 0.029]$

0.77 kg

$s/d = 0.77/1.00 = 0.77$; $G = 1.035$ (from Appendix X2)

$s_w = Gs/\sqrt{N} = 1.035\,(0.77)/\sqrt{9} = 0.27$ kg

X2. VALUES OF G FOR OBTAINING THE ESTIMATED STANDARD DEVIATION OF THE MEAN

s/d	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.40						1.18	1.175	1.17	1.16	1.155
0.50	1.15	1.145	1.14	1.135	1.13	1.125	1.12	1.11	1.105	1.10
0.60	1.095	1.09	1.085	1.08	1.075	1.07	1.07	1.065	1.06	1.06
0.70	1.055	1.055	1.05	1.05	1.045	1.04	1.04	1.035	1.035	1.03
0.80	1.03	1.025	1.025	1.02	1.02	1.02	1.015	1.015	1.015	1.01
0.90	1.01	1.01	1.005	1.005	1.005	1.00	1.00	1.00	.0995	0.995
1.00	0.995	0.99	0.99	0.99	0.985	0.985	0.985	0.985	0.98	0.98
1.10	0.98	0.98	0.98	0.975	0.975	0.975	0.975	0.975	0.975	0.97
1.20	0.97	0.97	0.97	0.97	0.97	0.97	0.965	0.965	0.965	0.965
1.30	0.965	0.965	0.965	0.965	0.96	0.96	0.96	0.96	0.96	0.96
1.40	0.96	0.96	0.96	0.955	0.955	0.955	0.955	0.955	0.955	0.955
1.50	0.955	0.955	0.955	0.95	0.95	0.95	0.95	0.95	0.95	0.95
1.60	0.95	0.95	0.95	0.95	0.945	0.945	0.945	0.945	0.945	0.945
1.70	0.945	0.945	0.945	0.945	0.945	0.945	0.94	0.94	0.94	0.94
1.80	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.935
1.90	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935	0.935
2.00	0.935	0.935	0.935	0.93	0.93	0.93	0.93	0.93	0.93	0.93