ASTM D 3332 - 88
Standard Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines

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Standard Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines[1]

1. Scope

1.1 These test methods cover the determination of the shock fragility of products. This fragility information may be used in designing shipping containers for transporting the products. It may also be used to improve product ruggedness. Unit or consumer packages, which are transported within an outer container, are considered to be the product for purposes of these test methods. Two methods are outlined as follows:

1.1.1 *Method A* is used first to determine the product's critical velocity.

1.1.2 *Method B* is used second to determine the product's critical acceleration.

1.2 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 996 Terminology of Packaging and Distribution Environments[2]

D 2463 Test Method for Drop Impact Resistance of Blow-Molded Thermoplastic Containers[3]

D 4332 Practice for Conditioning Containers, Packages, or Package Components for Testing[2]

E 122 Practice for Choice of Sample Size to Estimate the Average Quality of a Lot or Process[4]

E 680 Test Method for Drop Weight Impact Sensitivity of Solid Phase Hazardous Materials[4]

3. Definitions

3.1 *acceleration of gravity* (g)—386.1 in./s^2 (9.806 m/s^2).

3.2 *critical acceleration* (A_c)—the maximum-faired acceleration level (see 8.3) above which product failure (or damage) occurs. A product usually has a different critical acceleration for each direction in which it is tested.

3.3 *critical velocity* (V_c)—the velocity change (see 8.2) below which product failure is unaffected by shock-pulse maximum-faired acceleration or waveform. A product usually has a different critical velocity for each direction in which it is tested.

3.4 *cushioning material*—a material used to isolate or reduce the effect of externally applied shock or vibration forces, or both.

3.5 *damage*—product failure that occurs during a shock test. Damage can render the product unacceptable because it becomes inoperable, fails to meet performance specifications, when its appearance is unacceptably altered, or some combination of these failure modes.

3.6 *damage boundary*—see Annex A3.

3.7 *shock pulse programmer*—a device used to control the parameters of the acceleration versus time shock pulse generated by a shock test machine.

3.8 *shock test machine drop height*—the distance through which the carriage of the shock test machine free falls before striking the shock pulse programmer.

3.9 Other definitions are given in Terminology D 996.

4. Significance and Use

4.1 These test methods are intended to provide the user with data on product shock fragility that can be used in choosing optimum-cushioning materials for shipping containers or for product redesign.

5. Apparatus

5.1 *Shock Test Machine:*

5.1.1 The machine shall consist of a flat horizontal test surface (carriage) of sufficient strength and rigidity to remain flat and horizontal under the stresses developed during the test. The test surface shall be guided to fall vertically without rotation or translation in other directions.

5.1.2 The machine shall incorporate sufficient carriage drop height to produce the shock pulses of 8.2 and 8.3. Drop height control shall be provided to permit reproducibility within ±0.25 in. (±6 mm).

5.1.3 The machine shall be equipped to produce shock pulses at the carriage as specified in 8.2 and 8.3.

5.1.4 Means shall be provided to arrest the motion of the carriage after impact to prevent secondary shock.

5.2 *Instrumentation:*

5.2.1 *Acceleration*—An accelerometer, a signal conditioner, and a data storage apparatus are required to record acceleration-time histories. The accelerometer shall be rigidly attached to the base structure of the product, or to the fixture, at or near a point where the fixture is fastened to the carriage. If the fixture is rigid enough so as not to distort the shock pulse imparted to the product, then the accelerometer may be mounted on the carriage. In some cases, when a

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[1] These test methods are under the jurisdiction of ASTM Committee D-10 on Packaging and are the direct responsibility of Subcommittee D10.15 on Fragility Assessment.

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

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

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

product contains heavy resiliently supported masses which will severely distort the shock pulses, it may be necessary to precalibrate the shock machine. In this case the accelerometer is fastened to the carriage and a rigid mass weighing the same as the product is subjected to a series of shock pulses. The instrumentation system shall have sufficient response to permit measurements in the following ranges:

5.2.1.1 *Method A*—5 Hz or less to at least 1000 Hz.

5.2.1.2 *Method B*—3 Hz or less to at least 330 Hz.

5.2.1.3 *Accuracy*—Reading to be within ±5 % of the actual value.

5.2.1.4 *Cross-Axis Sensitivity*—Less than 5 % of the actual value.

5.2.2 *Velocity*—Instrumentation to measure the shock table's velocity change is required. This may be a device which electronically integrates the area under the shock pulse waveform. Alternatively, it can be measured by photodiode-type devices which measure shock table impact and rebound velocity. Calculation which assumes the shock pulse to be a perfect geometric figure usually is grossly inaccurate and should not be used.

6. Sampling

6.1 The sampling and the number of test specimens depend on the specific purposes and needs of the testing. Sample size determination based on Practice E 122 or other established statistical procedures is recommended.

7. Conditioning

7.1 If temperature and humidity conditioning is required for the product being tested, refer to Practice D 4332 for standard conditioning procedures. Conduct all tests with the same conditions prevailing, unless otherwise specified.

8. Procedure

8.1 Mount the product to be tested on the carriage of the shock test machine. The product should be supported by a fixture similar in shape and configuration to the cushion which will support the product in its shipping container. The fixture should be as rigid as possible so as not to distort the shock pulse imparted to the product. Securely fasten the fixture and product to the carriage so that it will not leave the surface of the carriage during the shock test.

NOTE 1—The points at which the fixture supports the product are very important because the dynamic response of the product is strongly influenced by the location of these support points.

NOTE 2—If the orientation of the product can change during handling impacts, then a test may be required for each of the directions in which the input shock can occur. Multidirectional tests are recommended since most products have different fragilities in different orientations.

8.2 *Method A—Critical Velocity Shock Test:*

8.2.1 *Scope*—This test method is used to determine the critical-velocity (V_c) portion of the damage boundary plot of a product.

8.2.1.1 A shock pulse having any waveform and having a duration (T_p) not longer than 3 ms may be used to perform this test. Shock pulse waveform is not limited since the critical velocity portion of the damage boundary is unaffected by shock pulse shape. Normally, since they are relatively easy to control, shock pulses having a half sine shock waveform are used. Occasionally, when testing small very rigid products, pulse durations shorter than 3 ms may be required.

8.2.2 *Procedure:*

8.2.2.1 Set the shock test machine so that the shock pulse produced has a velocity change below the anticipated critical velocity of the product.

8.2.2.2 Perform one shock test.

8.2.2.3 Examine or functionally test the product to determine if damage due to shock has occurred.

8.2.2.4 If no damage has occurred, set the shock test machine for a higher velocity change and repeat the shock test. Acceptable increment size is strongly influenced by the product being tested. For example, an increment of 5 in./s (0.13 m/s) may be appropriate for most products, but unacceptable for high value products.

8.2.2.5 Repeat 8.2.2.2 to 8.2.2.4 with incrementally increasing velocity change until product damage occurs. This point is shown as "Test No. 7" of Fig. A3.1.

8.2.2.6 Common practice is to define the critical velocity (V_c) as the midpoint between the last successful test and the test which produced failure. Depending on the purpose of the test, use of the last successful test point before failure may be considered as a more conservative estimate of (V_c).

8.3 *Method B—Critical Acceleration Shock Test:*

8.3.1 *Scope*—This test method is used to determine the critical acceleration (A_c) portion of the damage boundary plot of a product.

8.3.1.1 When a product's critical acceleration is known, package cushioning materials can be chosen to protect it.

8.3.1.2 If no cushioning materials are to be used in the package, it may be unnecessary to perform this test. In this case only the critical velocity test may suffice.

8.3.1.3 Trapezoidal shock pulses are normally used to perform this test. Although, in theory, a true square wave shock pulse is most desirable, it is not possible to obtain infinitely short rise and fall times. On the basis of much testing experience, it has been determined that rise and fall times (see Fig. A2.1) of 1.8 ms, or less, are required. Longer rise and fall times cause the critical acceleration line of the damage boundary curve to deviate from the horizontal, introducing errors in the test results. For the same reason waveforms having faired shapes which are not trapezoidal should not be used for this test. Their use would cause the critical acceleration line of the damage boundary curve to vary widely as a function of velocity change. As an example, if a half sine shock pulse waveform is used, a deeply scalloped critical acceleration line is produced and the test data becomes meaningless.

8.3.2 *Procedure:*

8.3.2.1 Set the shock test machine so that it will produce a trapezoidal shock pulse having a velocity change of at least 1.57 times as great as the critical velocity determined in Method A (8.2). For an added safety margin, a factor of 2 or more is normally used. This is required to avoid the rounded intersection of the critical velocity and critical acceleration lines. Maximum-faired acceleration level of the first shock pulse should be below the anticipated failure level of the product.

8.3.2.2 Perform one shock test.

8.3.2.3 Examine the recorded shock pulse to be certain the desired maximum-faired acceleration and velocity change were obtained.

8.3.2.4 Examine or functionally test the product to determine if damage due to shock has occurred.

8.3.2.5 If no damage has occurred, set the shock test machine for a higher maximum-faired acceleration level. Be certain the velocity change of subsequent shock pulses is maintained at or above the level determined in 8.3.2.1. Acceptable increment size is strongly influenced by the product being tested. For example, an increment of 5 *g*'s may be appropriate for most products, but unacceptable for high-value products.

8.3.2.6 Repeat 8.3.2.2 to 8.3.2.5 with incrementally increasing maximum-faired acceleration until product damage occurs. This point is known as "Test No. 14" of Fig. A3.1. Common practice is to define the critical acceleration (A_c) as the midpoint between the last successful test and the test which produced failure. Depending on the purpose of the test, use of the last successful test point before failure may be considered as a more conservative estimate of (A_c).

9. Report

9.1 *The report shall include the following:*

9.1.1 Complete identification of the product being tested including type, manufacturer's code numbers, general description of configuration, and its pretest condition.

9.1.2 Method of mounting the product on the carriage of the shock test machine.

9.1.3 Type of instrumentation used and critical settings thereof.

9.1.4 Recordings of the shock pulses which caused product damage.

9.1.5 Record of shock test machine drop height for each shock pulse that caused product damage.

9.1.6 Record of damage including photograph of product damage, if visible.

9.1.7 Record waveform, maximum-faired acceleration, pulse duration, and velocity change of the shock pulses.

9.1.8 Record of conditioning used.

9.1.9 Plots of the product's damage boundaries.

9.1.10 If multiple products are used, record sampling methods, average or median test levels, and standard deviations.

10. Precision and Bias

10.1 *Precision*—The within-laboratory or repeatability standard deviation is largely dependent on the particular item being tested. A research report[5] describes an interlaboratory test program of three types of items (in packages) for a critical velocity shock test. The repeatability standard deviations were 6.7, 14.7, and 21.5 in./s (0.17, 0.37, and 0.55 m/s). Other items may have more or less variability. The between laboratory or reproducibility standard deviation was 5.7 in./s (0.15 m/s).

10.2 *Bias*—No justifiable statement can be made on the bias of these test methods since a true value cannot be established by an accepted referee method.

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[5] Available on loan from ASTM Headquarters. Request Research Report RR:D10-1004.

ANNEXES

(Mandatory Information)

A1. HALF-SINE SHOCK PULSE VELOCITY CHANGE, USING INTEGRATING INSTRUMENTATION

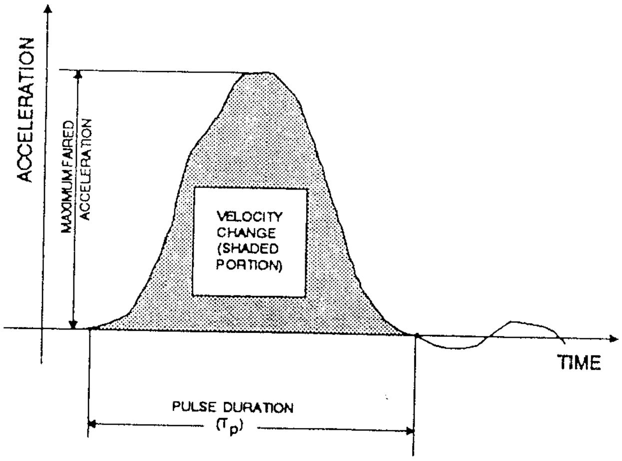

FIG. A1.1 **Half-Sine Shock Pulse Diagram**

A1.1 *Integrating Instrumentation*—Integrate the area under the curve from the point where the acceleration level first leaves the zero axis in a positive direction to the point where the acceleration next returns to zero (see Fig. A1.1).

A2. TRAPEZOIDAL SHOCK PULSE VELOCITY CHANGE USING INTEGRATING INSTRUMENTATION

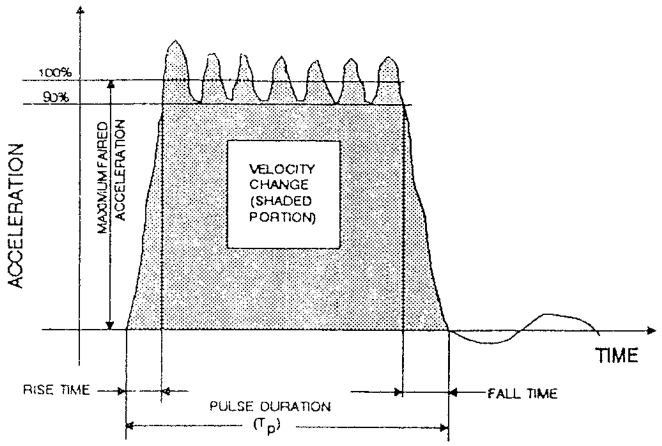

FIG. A2.1 Trapezoidal Shock Pulse Diagram

A2.1 *Integrating Instrumentation*—Integrate the area under the curve from the point where the acceleration level first leaves the zero axis in a positive direction to the point where the level next returns to zero (see Fig. A2.1).

A3. DAMAGE BOUNDARY

A3.1 Sensitivity to shock of a product is dependent on three parameters of the shock pulse: shock pulse shape, shock-pulse velocity change, and shock-pulse maximum-faired acceleration. For a given product, the interrelation of these three parameters is shown by damage boundary as plotted in Fig. A3.1.

A3.2 For shock pulses having peak acceleration and velocity-change values falling in the shaded area, product damage will occur. Shock pulses having values outside the shaded area will not damage the product. For most products the damage boundary will be different for each direction in which the shock occurs.

A3.3 The example plotted in Fig. A3.1 is based on tests conducted in accordance with Methods A and B. A sample of the product was subjected to half-sine shock pulses in accordance with Method A.

A3.3.1 Tests numbered 1 to 7 with both drop height and acceleration increasing successively, were performed. Failure occurred in the seventh test establishing the vertical critical-velocity line midway between the sixth and seventh test levels (see 8.2.2.6).

A3.3.2 Then another sample or a repaired sample of the product was subjected to trapezoidal shock pulses in accordance with Method B (8.3). Each trapezoidal shock pulse had a velocity change of more than two times the critical velocity (V_c) determined previously. Each trapezoidal shock pulse has a failed acceleration level incrementally higher than the previous shock pulse. Failure occurred in the fourteenth test, establishing the horizontal critical acceleration line (A_c) midway between the thirteenth and fourteenth test levels (see 8.3.2.6).

A3.4 When the damage boundary has plotted three things

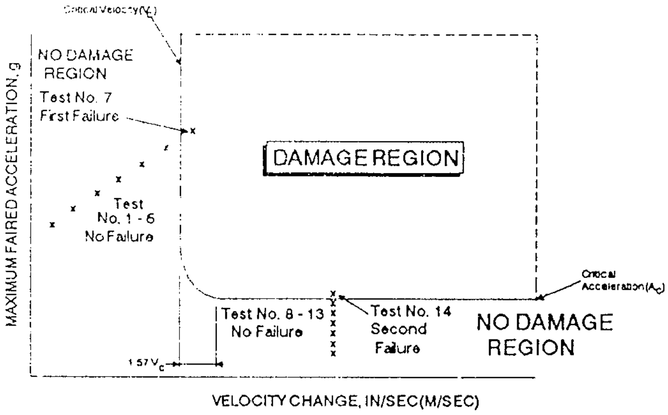

FIG. A3.1 Damage Boundary

can be learned from it:

A3.4.1 If the velocity change that the product will undergo in shipment is below the critical velocity (V_c), no cushioning is required.

A3.4.2 If the critical velocity (V_c) is below the velocity change which the product will be subjected to during unpackaged product handling, then the product should be modified to increase its critical velocity. Examples of unpackaged product handling are movement of the finished product on a production line, before packaging and customer handling and installation upon receipt. In these cases, the test will have shown that the unmodified product is too fragile to be handled in its normal production or in-use environment.

A3.4.3 If the velocity change that the product will undergo in shipment is above the critical velocity (V_c), package cushioning should be designed so that it transmits no more than the critical acceleration (A_c).

A3.4.4 The actual shape of the pulse transmitted to the product by the cushion is usually not known. The pulse shape depends on the dynamic force-versus-deflection characteristics of the cushion and will vary for different cushion materials, cushion deflections, etc. The damage boundary of a trapezoidal-shock pulse envelopes damage boundaries produced by other waveforms. For this reason shocks transmitted by some cushion materials will be less severe than those produced by the trapezoidal-shock pulse test. None will be more severe than those produced by the trapezoidal shock pulse. Therefore, the test in accordance with Method B (8.3) introduces a safety factor.

A3.4.5 As shown in Fig. A3.1, the corner where the critical velocity and critical acceleration lines intersect is rounded. To avoid inconclusive test results, the critical acceleration test is conducted at velocity changes at least two times the product's critical velocity. In this way the rounded region of the damage boundary is avoided.

A4. EFFECT OF MULTIPLE SHOCKS

A4.1 Methods A and B require that the product being tested be subjected to a series of shocks of incrementally increasing severity. Most products are not affected by this multiplicity of tests. However, some products will fail prematurely due to cumulative effects. When a second sample of such a product is subjected to a single shock pulse at the same level which caused the first sample to fail, it will not fail. Only when it is subjected to even higher level shocks will it fail. For a product of this type, it is important to determine the probable number of shocks which it will be subjected to in shipment. If significantly fewer shocks than those used in the test are anticipated, then the test data will have to be corrected. Usually multiple samples of such a product are tested.

A4.2 If only a few samples of the product are available, a simplified calculation technique may be used to determine the effect of multiple shocks. After the tests of the first sample, successive samples are tested at shock levels beginning near the failure level of the first sample. Three to five new or repaired test items are often used for each test orientation and for each part of the damage boundary (V_c and A_c). The failure level is then defined as the average (arithmetic mean) of the midpoints between the last tests and the test which produced failure (excluding the first sample, which failed prematurely due to cumulative effects). This procedure is less accurate than the procedure described in A4.3.

A4.3 A test procedure known as the "up-and-down" or "staircase" method is well suited for use in product fragility testing. Several specimens are tested sequentially with the test specimen being discarded or repaired after each individual shock test. The first specimen is tested at the estimated failure point. If it fails at that shock level, the next specimen is tested at a level which is a fixed increment lower. If it passes, the specimen is tested at a shock level which is incrementally higher. The shock input for each test is thus determined by the previous test result.

A4.3.1 At the completion of a fixed number of tests, often ten or more, an average or median value and the standard deviation are calculated. This procedure is repeated for each orientation and each part of the damage boundary (V_c and A_c) which is of interest. When possible analyze the data for normality (reasonable conformance with Gaussian probability distribution).

A4.3.2 Several texts[6,7,8] on experimental statistics, listed below, describe this procedure and computations in detail. In addition, Test Methods D 2463 and E 680 also describe this procedure.

A4.4 The effect of multiple shocks should be considered even if only a single sample of the product is available for testing. If the product is complex, usually some sub-element of the product will fail first. Frequently, even though the product may be a prototype, additional sub-elements are available to replace the one which was damaged. In this case the procedure of A4.2 may be used.

A4.4.1 If all parts of the product are one-of-a-kind and no more are available, then a correction factor allowing for the effects of multiple tests may have to be used. Such a factor will vary widely for different types of products. As more product samples become available, test results should be refined using the procedures of either A4.2 or A4.3.

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[6] Dixon, W.J., and Massey, F.J., *Introduction to Statistical Analysis*, McGraw Hill, 1969, p. 377–393.

[7] Lipson, C., and Sheth, N.J., *Statistical Design and Analysis of Engineering Experiments*, McGraw Hill, 1973, pp. 270–274.

[8] Natrella, M.G., *Experimental Statistics*, NBS Handbook 91, U.S. Government Printing Office, 1963, p. 10–1, 10–22, and 10–23.