**Designation: ~~D7136/D7136M – 15~~ D7136/D7136M – 20**

# Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event[1]

This standard is issued under the fixed designation D7136/D7136M; 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 determines the damage resistance of multidirectional polymer matrix composite laminated plates subjected to a drop-weight impact event. The composite material forms are limited to continuous-fiber reinforced polymer matrix composites, with the range of acceptable test laminates and thicknesses defined in 8.2.

1.1.1 Instructions for modifying these procedures to determine damage resistance properties of sandwich constructions are provided in Practice D7766/D7766M.



1.2 A flat, rectangular composite plate is subjected to an out-of-plane, concentrated impact using a drop-weight device with a hemispherical impactor. The potential energy of the drop-weight, as defined by the mass and drop height of the impactor, is specified prior to test. Equipment and procedures are provided for optional measurement of contact force and velocity during the impact event. The damage resistance is quantified in terms of the resulting size and type of damage in the specimen.

1.3 The test method may be used to screen materials for damage resistance, or to inflict damage into a specimen for subsequent damage tolerance testing. When the impacted plate is tested in accordance with Test Method D7137/D7137M, the overall test sequence is commonly referred to as the Compression After Impact (CAI) method. Quasi-static indentation per Test Method D6264/D6264M may be used as an alternate method of creating damage from an out-of-plane force and measuring damage resistance properties.

1.4 The damage resistance properties generated by this test method are highly dependent upon several factors, which include specimen geometry, layup, impactor geometry, impactor mass, impact force, impact energy, and boundary conditions. Thus, results are generally not scalable to other configurations, and are particular to the combination of geometric and physical conditions tested.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system ~~may~~are not ~~be~~necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the ~~other. Combining~~other, and values from the two systems ~~may result in non-conformance with the standard.~~shall not be combined.

1.5.1 Within the text, the inch-pound units are shown in brackets.

1.6 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

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[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved ~~March 15, 2015~~Oct. 1, 2020. Published ~~March 2015~~November 2020. Originally approved in 2005. Last previous edition approved in ~~2012~~2015 as ~~D7136/D7136M - 12.~~D7136/D7136M – 15. DOI: ~~10.1520/D7136_D7136M-15.~~10.1520/D7136_D7136M-20.

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

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D883 Terminology Relating to Plastics
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D2734 Test Methods for Void Content of Reinforced Plastics
D3171 Test Methods for Constituent Content of Composite Materials
D3763 Test Method for High Speed Puncture Properties of Plastics Using Load and Displacement Sensors
D3878 Terminology for Composite Materials
D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
D5687/D5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
D6264/D6264M Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Concentrated Quasi-Static Indentation Force
D7137/D7137M Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates
D7766/D7766M Practice for Damage Resistance Testing of Sandwich Constructions
E4 Practices for Force Verification of Testing Machines
E6 Terminology Relating to Methods of Mechanical Testing
E18 Test Methods for Rockwell Hardness of Metallic Materials
E122 Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E456 Terminology Relating to Quality and Statistics
~~E1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases (Withdrawn 2015)[3]~~
~~E1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases (Withdrawn 2015)[3]~~
E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

2.2 *Military Standards:*

CMH-17-3G Composite Materials Handbook, Volume 3—Polymer Matrix Composites Materials Usage, Design and Analysis[3]
MIL-HDBK-728/1 Nondestructive Testing[4]
MIL-HDBK-731A Nondestructive Testing Methods of Composite Materials—Thermography[4]
MIL-HDBK-732A Nondestructive Testing Methods of Composite Materials—Acoustic Emission[4]
MIL-HDBK-733A Nondestructive Testing Methods of Composite Materials—Radiography[4]
MIL-HDBK-787A Nondestructive Testing Methods of Composite Materials—Ultrasonics[4]
NASA Reference Publication 1092 Standard Tests for Toughened Resin Composites, Revised Edition, July 1983[5]



## 3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to composite materials. Terminology D883 defines terms relating to plastics. Terminology E6 defines terms relating to mechanical testing. Terminology E456 and Practice E177 define terms relating to statistics. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 If the term represents a physical quantity, its analytical dimensions are stated immediately following the term (or letter symbol) in fundamental dimension form, using the following ASTM standard symbology for fundamental dimensions, shown within square brackets: [*M*] for mass, [*L*] for length, [*T*] for time, [θ] for thermodynamic temperature, and [*nd*] for non-dimensional quantities. Use of these symbols is restricted to analytical dimensions when used with square brackets, as the symbols may have other definitions when used without the brackets.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
[3] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://www.sae.org.
[4] Available from U.S. Army Materials Technology Laboratory, Watertown, MA 02471.
[5] Available from National Aeronautics and Space Administration (NASA)-Langley Research Center, Hampton, VA 23681-2199.

3.2.2 *dent depth, d [L], n*—residual depth of the depression formed by an impactor after the impact event. ~~The dent depth shall be defined as the maximum distance in a direction normal to the face of the specimen from the lowest point in the dent to the plane of the impacted surface that is undisturbed by the dent.~~

3.2.2.1 *Discussion—*
The dent depth shall be defined as the maximum distance in a direction normal to the face of the specimen from the lowest point in the dent to the plane of the impacted surface that is undisturbed by the dent.

3.2.3 *nominal value, n*—a value, existing in name only, assigned to a measurable property for the purpose of convenient designation. ~~Tolerances may be applied to a nominal value to define an acceptable range for the property.~~

3.2.3.1 *Discussion—*
Tolerances may be applied to a nominal value to define an acceptable range for the property.

~~3.2.4 *principal material coordinate system, n*—a coordinate system with axes that are normal to the planes of symmetry inherent to a material.~~

~~3.2.4.1 *Discussion*—~~
~~Common usage, at least for Cartesian axes (*123*,*xyz*, and so forth), generally assigns the coordinate system axes to the normal directions of planes of symmetry in order that the highest property value in a normal direction (for elastic properties, the axis of greatest stiffness) would be *1* or *x*, and the lowest (if applicable) would be *3* or *z*. Anisotropic materials do not have a principal material coordinate system due to the total lack of symmetry, while, for isotropic materials, any coordinate system is a principal material coordinate system. In laminated composites, the principal material coordinate system has meaning only with respect to an individual orthotropic lamina. The related term for laminated composites is "reference coordinate system."~~

3.2.4 *recorded contact force, F [$MLT^{-2}$], n*—the force exerted by the impactor on the specimen during the impact event, as recorded by a force indicator.

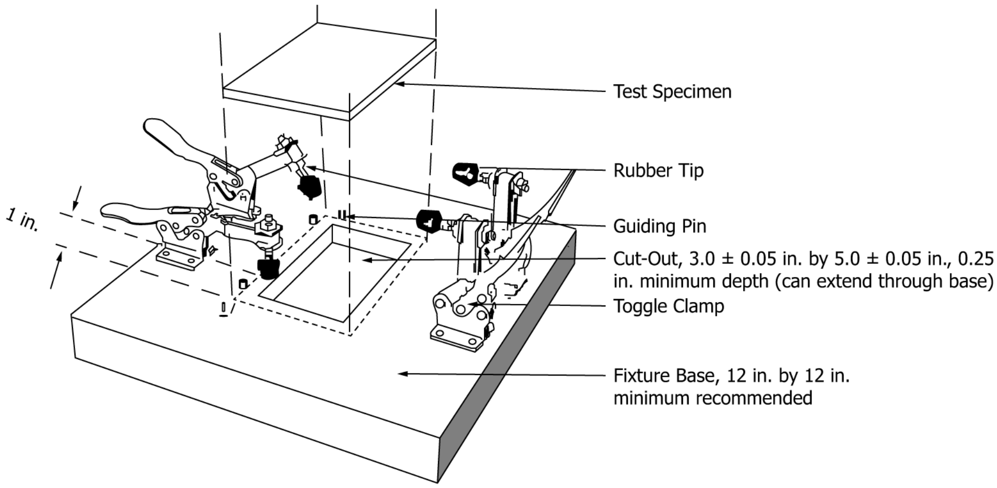
~~3.2.6 *reference coordinate system, n*—a coordinate system for laminated composites used to define ply orientations. One of the reference coordinate system axes (normally the Cartesian *x*-axis) is designated the reference axis, assigned a position, and the ply principal axis of each ply in the laminate is referenced relative to the reference axis to define the ply orientation for that ply.~~

3.2.5 *striker tip, n*—the portion or component of the impactor which comes into contact with the test specimen first during the impact event.



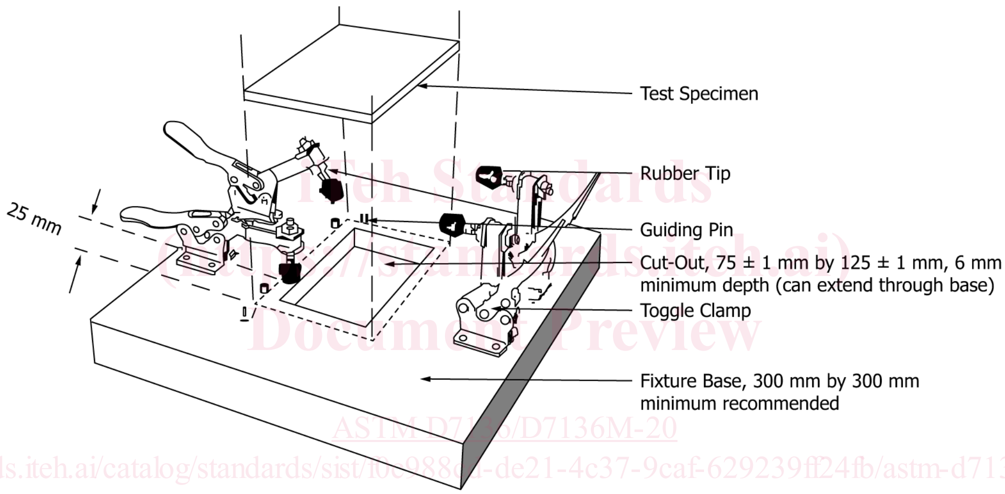
3.3 *Symbols:*

$A$ = cross-sectional area of a specimen
$C_E$ = specified ratio of impact energy to specimen thickness
$CV$ = coefficient of variation statistic of a sample population for a given property (in percent)
$D$ = damage diameter (see Fig. 11)
$d$ = dent depth
$E$ = potential energy of impactor prior to drop
$E_1$ = absorbed energy at the time at which force versus time curve has a discontinuity in force or slope
$E_a$ = energy absorbed by the specimen during the impact event
$E_i$ = actual impact energy (incident kinetic energy)
$E_{max}$ = absorbed energy at the time of maximum recorded contact force
$F$ = recorded contact force
$F_1$ = recorded contact force at which the force versus time curve has a discontinuity in force or slope
$F_{max}$ = maximum recorded contact force
$g$ = acceleration due to gravity
$h$ = specimen thickness
$H$ = impactor drop height
$l$ = specimen length
$m$ = impactor mass
$m_d$ = impactor mass for drop height calculation
$m_{dlbm}$ = impactor mass in standard gravity for drop height calculation
$n$ = number of specimens per sample population
$N$ = number of plies in laminate under test
$S_{n-1}$ = standard deviation statistic of a sample population for a given property




NOTE 1—Clamp tip centered 0.25 in. from edge of cut-out.

**FIG. 1 Impact Support Fixture (Inch-Pound Version)**






NOTE 1—Clamp tip centered 6 mm from edge of cut-out.

**FIG. 2 Impact Support Fixture (SI Version)**

$t$ = time during impactor drop and impact event
$t_i$ = time of initial contact
$t_T$ = contact duration (total duration of the impact event)
$w$ = specimen width
$v$ = impactor velocity
$v_i$ = impactor velocity at time of initial contact, $t_i$
$W_{12}$ = distance between leading edges of the two flag prongs on velocity indicator
$x_i$ = test result for an individual specimen from the sample population for a given property
$\bar{x}$ = mean or average (estimate of mean) of a sample population for a given property
$\delta$ = impactor displacement

## 4. Summary of Test Method

4.1 A drop-weight impact test is performed using a balanced, symmetric laminated plate. Damage is imparted through out-of-plane, concentrated impact (perpendicular to the plane of the laminated plate) using a drop weight with a hemispherical striker tip. The damage resistance is quantified in terms of the resulting size and type of damage in the specimen. The damage response is a function of the test configuration; comparisons cannot be made between materials unless identical test configurations, test conditions, and so forth are used.

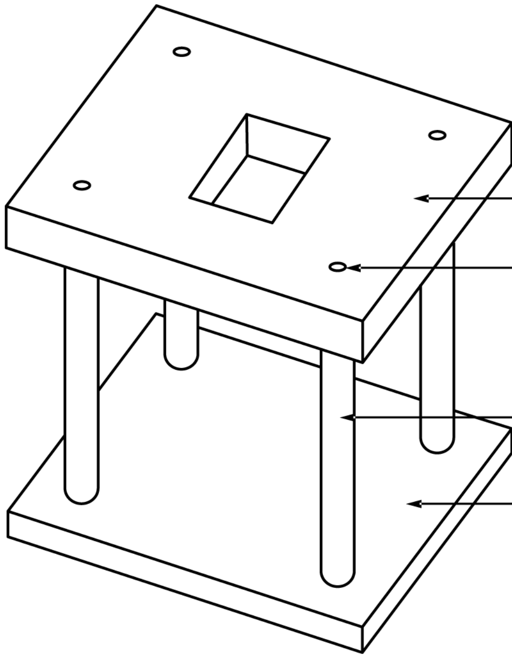



**FIG. 3 Representative Rigid Base (Inch-Pound Version)**

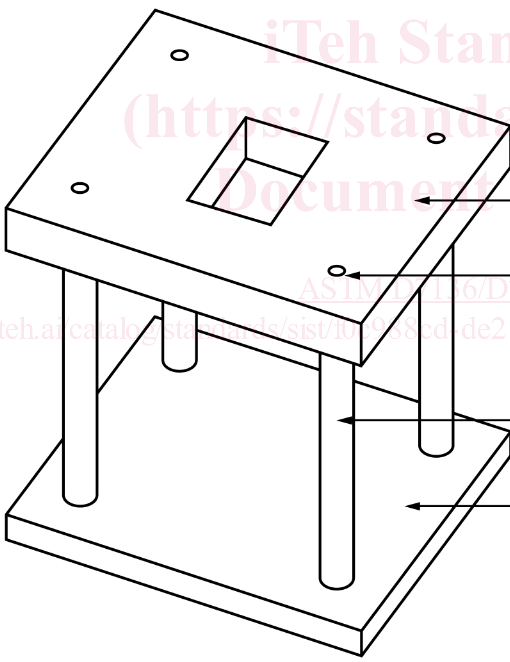



**FIG. 4 Representative Rigid Base (SI Version)**



4.2 Optional procedures for recording impact velocity and applied contact force versus time history data are provided.

4.3 Preferred damage states resulting from the impact are located in the center of the plate, sufficiently far from the plate edges such that the local states of stress at the edges and at the impact location do not interact during the damage formation event.

## 5. Significance and Use

5.1 Susceptibility to damage from concentrated out-of-plane impact forces is one of the major design concerns of many structures

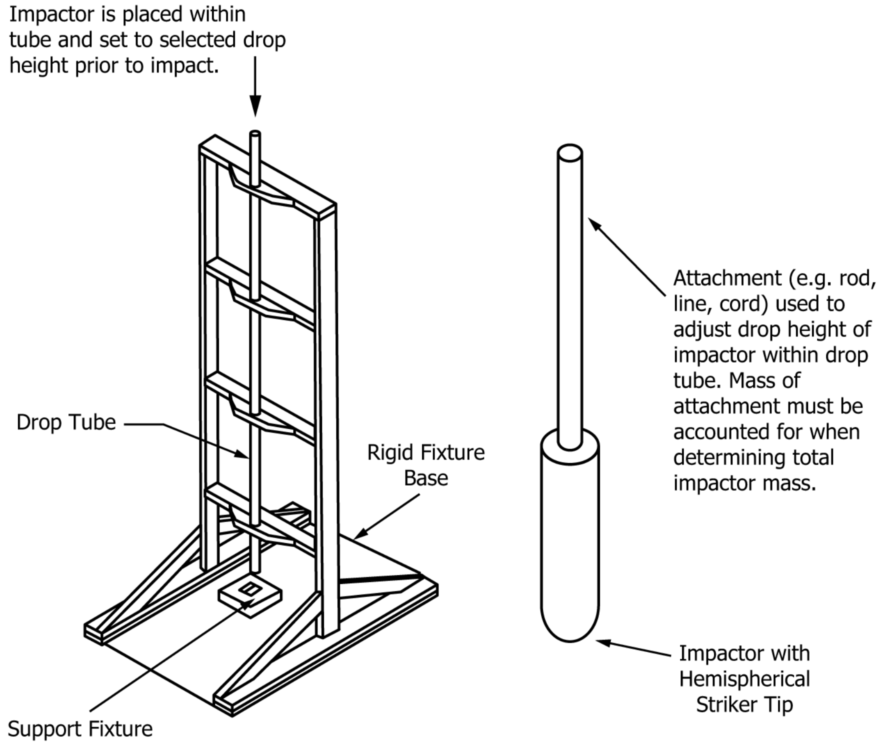



FIG. 5 Impact Device with Cylindrical Tube Impactor Guide Mechanism



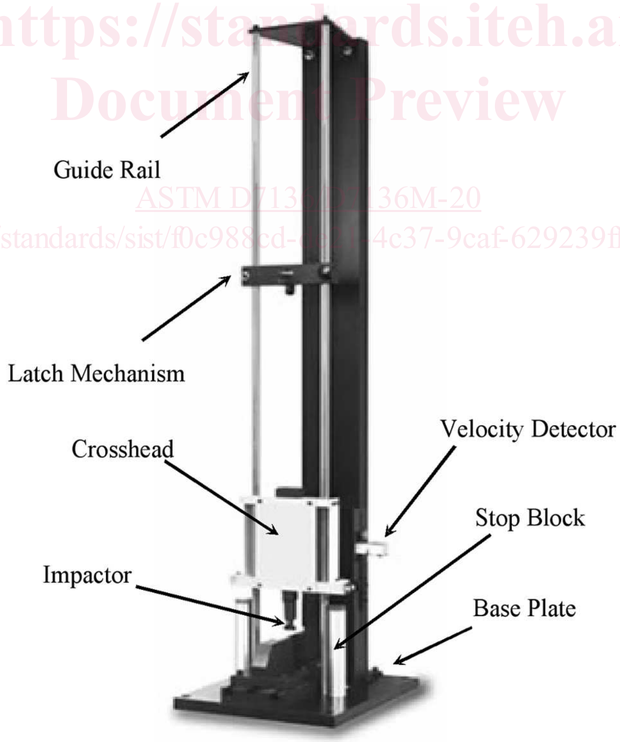



FIG. 6 Impact Device with Double Column Impactor Guide Mechanism

made of advanced composite laminates. Knowledge of the damage resistance properties of a laminated composite plate is useful for product development and material selection.

5.2 Drop-weight impact testing can serve the following purposes:

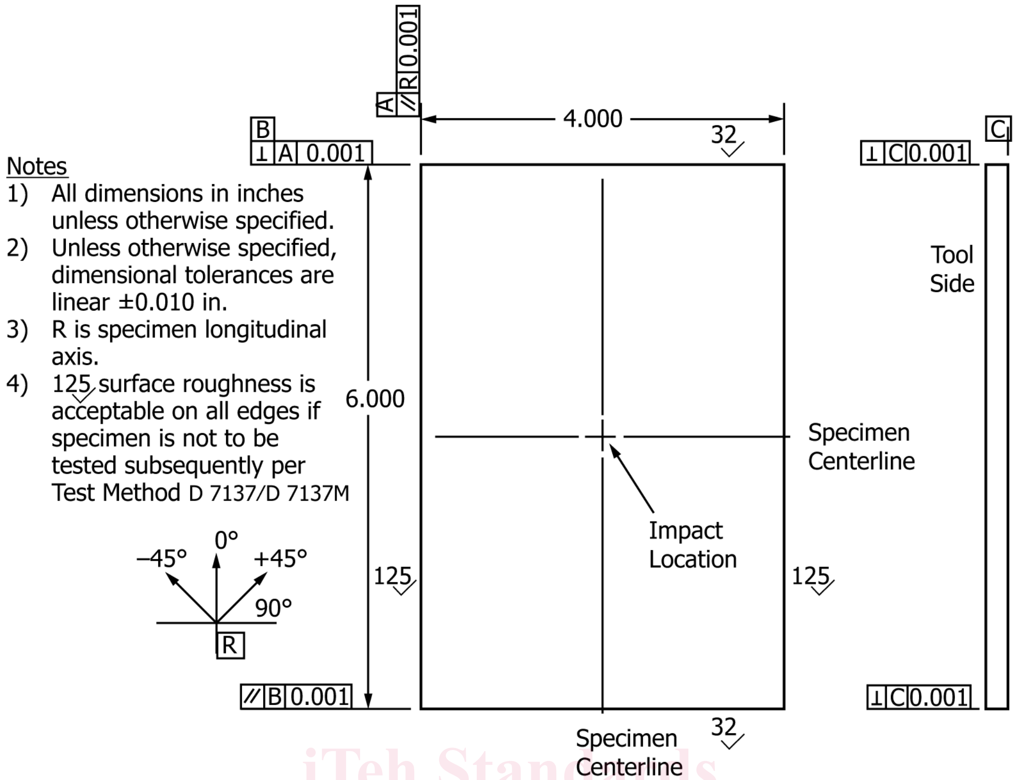



**FIG. 7 Drop-Weight Impact Test Specimen (Inch-Pound Version)**



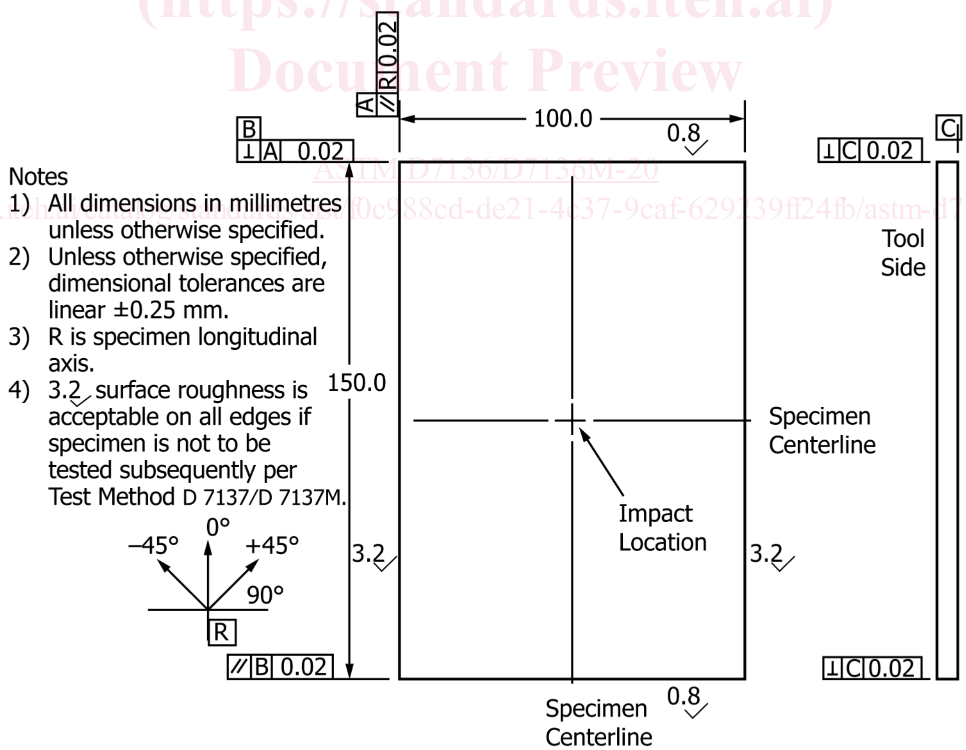



**FIG. 8 Drop-Weight Impact Test Specimen (SI Version)**

5.2.1 To establish quantitatively the effects of stacking sequence, fiber surface treatment, variations in fiber volume fraction, and processing and environmental variables on the damage resistance of a particular composite laminate to a concentrated drop-weight impact force or energy.

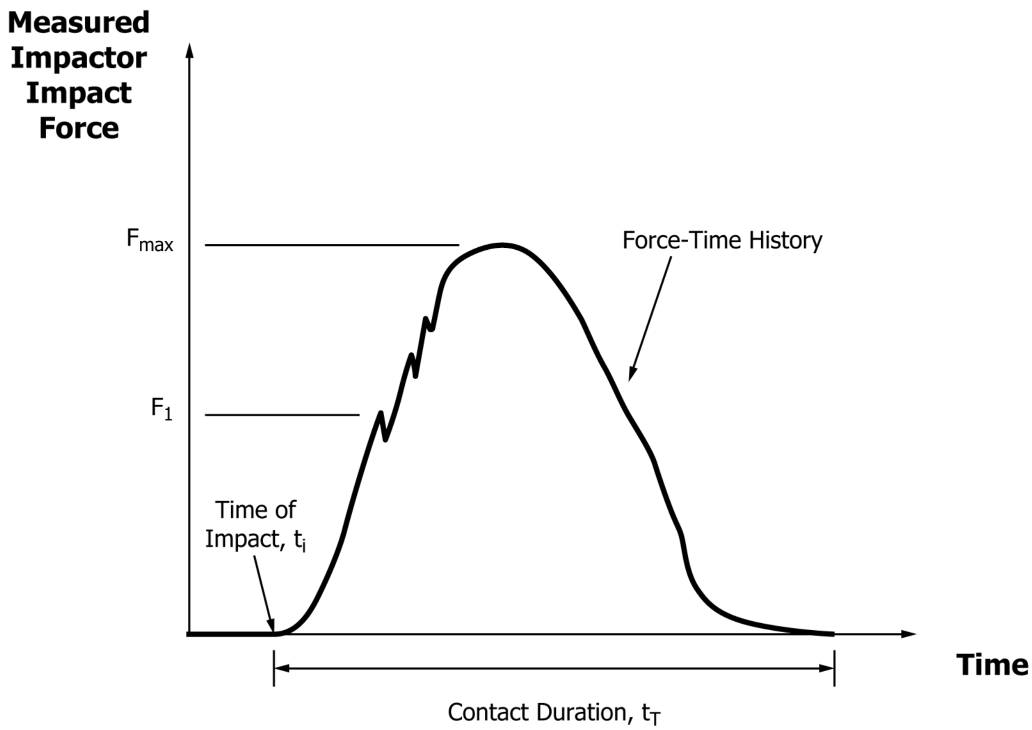



FIG. 9 Representative Impactor Force versus Time History



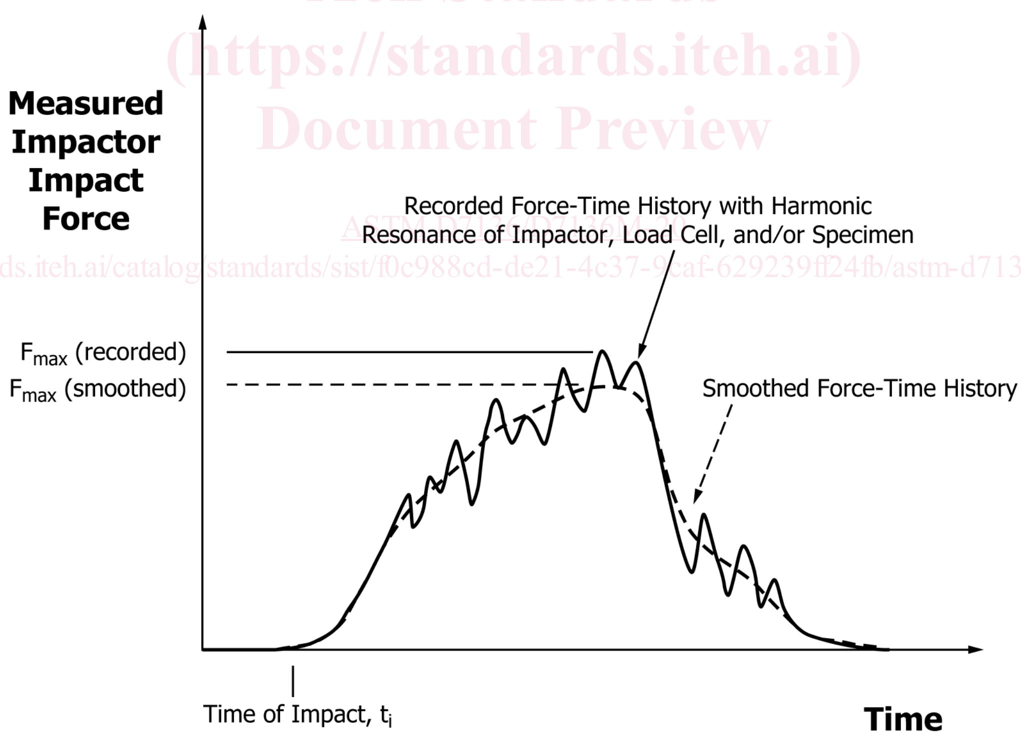



FIG. 10 Impactor Force versus Time History with Harmonic Resonance

5.2.2 To compare quantitatively the relative values of the damage resistance parameters for composite materials with different constituents. The damage response parameters can include dent depth, damage dimensions, and through-thickness locations, $F_1$, $F_{max}$,$E_1$, and $E_{max}$, as well as the force versus time curve.

5.2.3 To impart damage in a specimen for subsequent damage tolerance tests, such as Test Method D7137/D7137M.

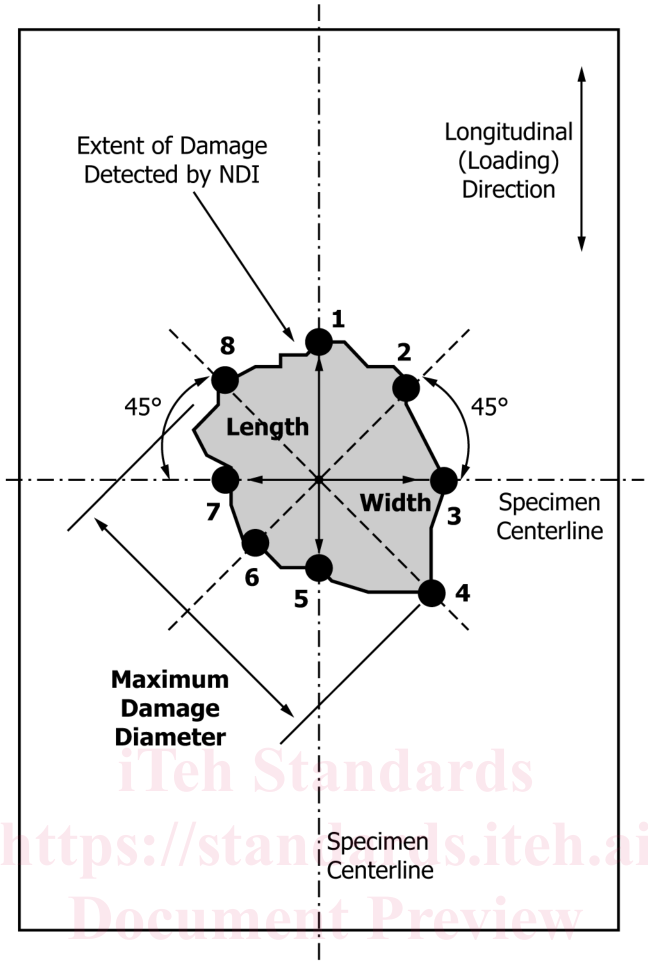



FIG. 11 Measurement of Extent of Damage



5.3 The properties obtained using this test method can provide guidance in regard to the anticipated damage resistance capability of composite structures of similar material, thickness, stacking sequence, and so forth. However, it must be understood that the damage resistance of a composite structure is highly dependent upon several factors, including geometry, thickness, stiffness, mass, support conditions, and so forth. Significant differences in the relationships between impact force/energy and the resultant damage state can result due to differences in these parameters. For example, properties obtained using this test method would more likely reflect the damage resistance characteristics of an unstiffened monolithic skin or web than that of a skin attached to substructure which resists out-of-plane deformation. Similarly, test specimen properties would be expected to be similar to those of a panel with equivalent length and width dimensions, in comparison to those of a panel significantly larger than the test specimen, which tends to divert a greater proportion of the impact energy into elastic deformation.

5.4 The standard impactor geometry has a blunt, hemispherical striker tip. Historically, for the standard laminate configuration and impact energy, this impactor geometry has generated a larger amount of internal damage for a given amount of external damage, when compared with that observed for similar impacts using sharp striker tips. Alternative impactors may be appropriate depending upon the damage resistance characteristics being examined. For example, the use of sharp striker tip geometries may be appropriate for certain damage visibility and penetration resistance assessments.

5.5 The standard test utilizes a constant impact energy normalized by specimen thickness, as defined in 11.7.1. Some testing organizations may desire to use this test method in conjunction with D7137/D7137M to assess the compressive residual strength of specimens containing a specific damage state, such as a defined dent depth, damage geometry, and so forth. In this case, the testing organization should subject several specimens, or a large panel, to multiple low velocity impacts at various impact energy levels using this test method. A relationship between impact energy and the desired damage parameter can then be developed.

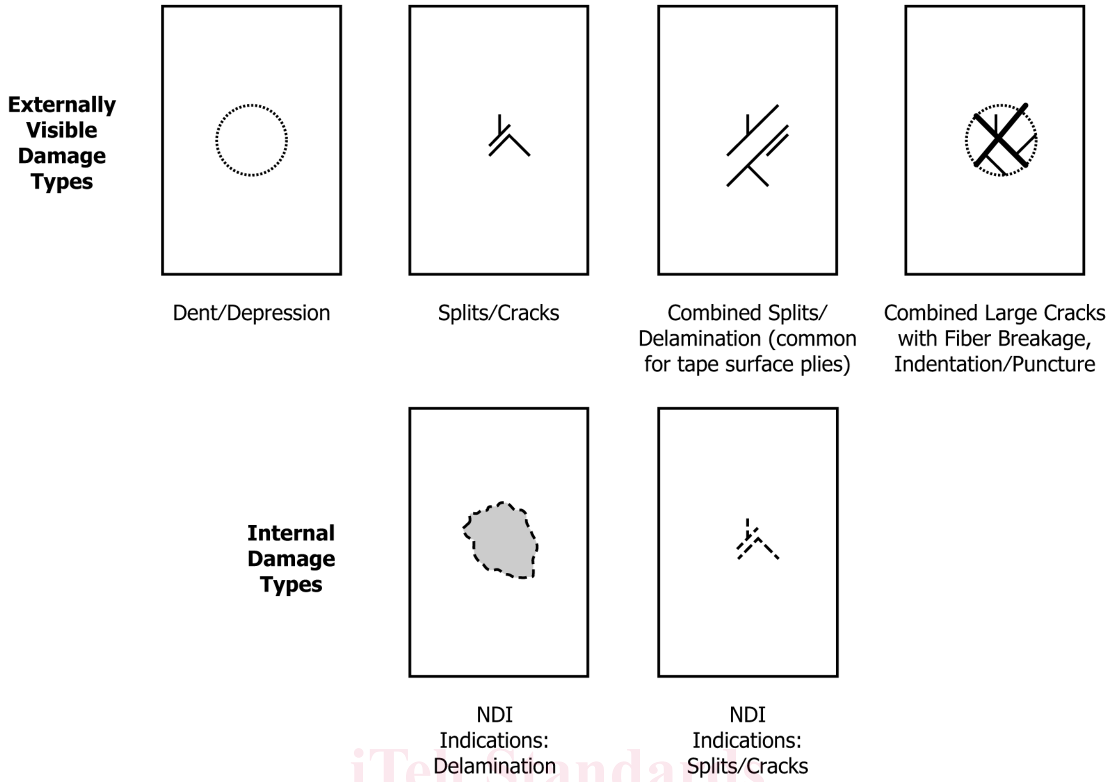



**FIG. 12 Commonly Observed Damage Modes from Out-of-Plane Drop-Weight Impact**



Subsequent drop weight impact and compressive residual strength tests can then be performed using specimens impacted at an interpolated energy level that is expected to produce the desired damage state.

## 6. Interferences



6.1 The response of a laminated plate specimen to out-of-plane drop-weight impact is dependent upon many factors, such as laminate thickness, ply thickness, stacking sequence, environment, geometry, impactor mass, striker tip geometry, impact velocity, impact energy, and boundary conditions. Consequently, comparisons cannot be made between materials unless identical test configurations, test conditions, and laminate configurations are used. Therefore, all deviations from the standard test configuration shall be reported in the results.

6.2 *Material and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. Important aspects of plate specimen preparation that contribute to data scatter include thickness variation, out-of-plane curvature, surface roughness, and failure to maintain the dimensions specified in 8.2.

6.3 *Specimen Geometry and Impact Location*—The size, shape, thickness, and stacking sequence of the plate, along with the impact location, can affect the impact deformation and damage formation behavior of the specimens significantly. The degree of laminate orthotropy can strongly affect the damage formation. Results can be affected if the impact force is not applied perpendicular to the plane of the laminated plate.

6.4 *Support Fixture Characteristics*—Results are affected by the support fixture cut-out dimensions, material, fixture bending rigidity, and the rigidity of the surface that the support fixture is located upon. The location of the clamps, clamp geometry, and the clamping force can affect the deformation of the specimen during impact.

6.5 *Impact Device Characteristics*—Results are affected by the rigidity of the impact device, friction between the impactor and guide(s) during the drop, impactor geometry, and impactor mass. Errors can result if the test specimen and specimen support fixture are not centered with respect to the impact device.

6.6 *Force Oscillations*—Force versus time histories typically contain many oscillations which may be introduced by two primary sources. The first source is the natural frequency (or frequencies) of the impactor, and is often referred to as "impactor ringing." The ringing may be more severe if the impactor components are not rigidly attached. The second source of force oscillations is the flexural vibration of the impacted specimen. The "ringing" oscillations generally occur at higher frequencies than the oscillations generated by the specimen. The high-frequency ringing oscillations do not typically represent an actual force transmitted to the specimen. However, the oscillations caused by specimen motion are actual forces applied to the specimen and should not be filtered or smoothed. For both sources, the oscillations are typically excited during initial contact and during damage formation. For further definition and examples of force oscillations, refer to Appendix X1 of Test Method D3763.

6.7 *Impact Variables*—Results are affected by differences in the drop height, impact velocity, and impact energy. Results are also affected by wave propagation and vibrations in the specimen, impactor, impact device, and support fixture during the impact event.

6.8 *Non-Destructive Inspection*—Non-destructive inspection (NDI) results are affected by the particular method utilized, the inherent variability of the NDI method, the experience of the operator, and so forth.

6.9 Force $F_1$ and absorbed energy $E_1$ do not physically represent the initiation of damage, as sub-critical matrix cracks and small delaminations may initiate at lower force and energy values. Rather, $F_1$ and $E_1$ represent the initial value of force and energy at which a change in the stiffness characteristics of the specimen can be detected, respectively.

6.10 The dent depth may "relax" or reduce with time or upon exposure to different environmental conditions.

6.11 Non-laminated, 3-D fiber-reinforced composites may form damage through different mechanisms than laminates.

## 7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 to ~~7 mm~~8 mm [0.16 to ~~0.28 in.]~~ 0.32 in.] nominal diameter ball-interface ~~shall be used to measure the specimen thickness when at least one surface is irregular (such as the bag-side of a laminate). A micrometer with a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball interface or with~~ or a flat anvil interface shall be used to measure the specimen ~~thickness when both surfaces are smooth (such as tooled surfaces).~~ thickness. A ball interface is recommended for thickness measurements when at least one surface is irregular (for example, a coarse peel ply surface which is neither smooth nor flat). A micrometer or caliper, with a flat anvil interface, shall be used ~~to measure the length and width of the specimen,~~for measuring length, width, and other machined surface dimensions, as well as the dimensions for detected damage. The accuracy of the instruments shall be suitable for reading to within 1 % of the ~~sample~~specimen dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.0025 mm [±0.0001 in.] is adequate for the thickness measurement, while an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for ~~the~~ measurement of length, width, and ~~damage dimension~~other machined surface dimensions, as well as damage dimensional measurements.

NOTE 1—For specimens intended to undergo subsequent residual strength testing, instrument accuracies shall be consistent with the requirements of Test Method D7137/D7137M.

7.2 *Support Fixture*—The impact support fixture, shown in Figs. 1 and 2, shall utilize a plate at least 20 mm [0.75 in.] thick constructed from either aluminum or steel. The cut-out in the plate shall be 75 ± 1 mm by 125 ± 1 mm [3.0 ± 0.05 in. by 5.0 ± 0.05 in.]. The face of the plate shall be flat to within 0.1 mm [0.005 in.] in the area which contacts the test specimen. Guiding pins shall be located such that the specimen shall be centrally positioned over the cut-out. Four clamps shall be used to restrain the specimen during impact. The clamps shall have a minimum holding capacity of 1100 N (200 lbf). The tips of the clamps shall be made of neoprene rubber with a durometer of 70-80 Shore A. The fixture shall be aligned to a rigid base using bolts or clamps; a representative base design is shown in Figs. 3 and 4.

NOTE 2—When impacted with the standard impactor (defined in 7.3.1) at the standard energy level defined in 11.7.1, the standard specimen has historically developed damage sizes less than half of the unsupported specimen width (38 mm [1.5 in.]). Should the expected damage area exceed this size (such as in studies for barely visible impact damage, for example), it is recommended to examine alternative specimen and fixture designs, such as NASA 1092, which are larger and can accommodate larger damage areas without significant interaction from edge support conditions.

7.3 *Impact Device*—Representative drop-weight impact testing devices are shown in Figs. 5 and 6. At a minimum, the impact device shall include a rigid base, a drop-weight impactor, a rebound catcher, and a guide mechanism. The rebound catcher is typically an inertially activated latch that trips upon the initial impact, then catches the impactor on a stop during its second decent.