Designation: D8101/D8101M – 17

Standard Test Method for Measuring the Penetration Resistance of Composite Materials to Impact by a Blunt Projectile[1]

This standard is issued under the fixed designation D8101/D8101M; 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 measures the resistance of flat composite panels in one specific clamping configuration to penetration by a blunt projectile in free flight. In this test method, the term "penetration" is defined as the case in which the projectile travels completely through the composite panel and fully exits the back side. The composite materials may be continuous fiber angle-ply, woven or braided fiber-reinforced polymer matrix composites, or chopped fiber-reinforced composites. The resistance to penetration is quantified by a statistical function that defines the probability of penetration for a given kinetic energy.

1.2 This test method is intended for composite test panels in which the thickness dimension is small compared with the test panel width and length (span to thickness greater than fifty).

1.3 This test method is intended for applications such as jet engine fan containment, open rotor engine blade containment, or other applications in which protection is needed for projectiles at velocities typically lower than seen in ballistic armor applications. The typical impact velocity that this test is intended for is in the range of 100 to 500 m/s [300 to 1500 ft/s], as opposed to higher velocities associated with armor penetration.

1.4 A flat composite panel is fixed between a circular-shaped clamping fixture and a large base fixture each with a large coaxial hole defining a region of the panel that is subjected to impact in the direction normal to the plane of the flat panel by a blunt projectile. Clamping pressure is provided by twenty-eight through bolts that pass through the front clamp, the test specimen and the back plate. The mass, geometry, desired impact kinetic energy, and impact orientation of the projectile with respect to the panel are specified before the test. Equipment and procedures are required for measuring the actual impact velocity and orientation during the test. The impact penetration resistance can be quantified by either the velocity or kinetic energy required for the projectile to penetrate the test panel fully. A number of tests are required to obtain a statistical probability of penetration for given impact conditions.

1.5 This test method measures the penetration resistance for a specific projectile and test configuration and can be used to screen materials for impact penetration resistance, compare the impact penetration resistance of different composite materials under the same test geometry conditions, or assess the effects of in-service or environmental exposure on the impact penetration resistance of materials.

1.6 The impact penetration resistance is highly dependent on the test panel materials and architecture, projectile geometry and mass, and panel boundary conditions. Results are not generally scalable to other configurations but, for the same test configurations, may be used to assess the relative impact penetration resistance of different materials and fiber architectures.

1.7 *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 not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Within the text, the inch-pound units are shown in brackets.

1.8 *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.*

1.9 *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.*

[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 April 1, 2017. Published April 2017. DOI: 10.1520/D8101_D8101M-17.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A36/A36M Specification for Carbon Structural Steel

D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement

D883 Terminology Relating to Plastics

D3171 Test Methods for Constituent Content of Composite Materials

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

E2533 Guide for Nondestructive Testing of Polymer Matrix Composites Used in Aerospace Applications

2.2 *NIJ Standard*[3]

NIJ Standard 0101.06 Body Amor—Ballistic Resistance

3. Terminology

3.1 *Definitions*—In Terminology D3878, terms are defined relating to composite materials. In Terminology D883, terms are defined related to plastics. 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:* 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 terms may have other definitions when used without the brackets.

3.2.1 *impact velocity, Vi* $[LT^{-1}]$, *n*—velocity of the projectile in the direction of projectile travel just before impact.

3.2.2 *penetrate, v*—to travel fully through a body and emerge completely on the other side.

3.2.3 *projectile face, n*—front portion of the projectile that first comes into contact with the test panel.

3.2.4 *projectile orientation, n*—angular position of the projectile as determined by a set of measurements relative to the reference coordinate system.

3.2.4.1 *Discussion*—Typically used to define the angular position of the projectile just before impact with the test specimen.

3.2.5 *Impact Penetration Resistance (IPR), n*—the kinetic energy (or associated impact velocity) of a projectile corresponding to the 50% probability of penetration.

3.2.6 *reference coordinate system, n*—coordinate system defined for the purpose of identifying the impact velocity and orientation of the projectile and the orientation of the test specimen.

3.2.6.1 *Discussion*—An example of a reference coordinate system is one in which the *X* direction is normal to the plane of the flat panel with positive values measured in the direction of the projectile travel, the *Y* direction is in the plane of the flat test panel and is horizontal with positive values measured to the right when viewing the panel from the impacted side, and the *Z* direction is vertical with positive values measured downward and the origin is at the center of the panel on the impacted face. The reference coordinate system is defined by the organization conducting the tests.

3.2.7 *residual velocity, Vr* $[LT^{-1}]$, *n*—absolute velocity of the projectile just after penetration (if penetration occurs).

3.3 *Symbols:*

3.3.1 E_a $[ML^2T^{-2}]$ —Loss in kinetic energy of the projectile as a result of the impact.

3.3.2 E_i $[ML^2T^{-2}]$ —Kinetic energy of the projectile at the time of impact.

3.3.3 E_r $[ML^2T^{-2}]$—Kinetic energy of the projectile after penetrating the test panel (if penetration occurs).

3.3.4 $M[M]$—Projectile mass.

4. Summary of Test Method

4.1 An impact test is performed by accelerating a defined projectile to a specified velocity, typically with the use of a single-stage gas gun, into a composite test panel that is supported in a fixture. The test panel is supported in a circular fixture with precision bolts extending through a front clamp and the specimen itself to avoid slipping of the specimen at the boundaries. The location of the holes is remote from the impact site so that damage is not initiated at the holes. Depending on the kinetic energy of the projectile, it may or may not damage or penetrate the test panel. The penetration resistance is quantified by either the velocity or kinetic energy required to penetrate the test panel. The penetration resistance is a function of the geometry and materials of the test panel. Comparisons between materials or material conditions cannot be made unless identical test configurations and test conditions are used.

4.2 Procedures and equipment for measuring the impact velocity and orientation of the projectile just before impact are required. Equipment for measuring the residual velocity of the projectile after penetration, if it occurs, is desirable but not required.

5. Significance and Use

5.1 Advanced composite systems are used in a number of applications as shields to prevent penetration by projectiles. In general, the use of composites is more effective for blunt, rather than sharp, projectiles or in hybrid systems in which an additional shield can be used to blunt a sharp projectile.

[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 the National Institute of Justice, Washington, DC, www.jij.gov/publications.

Knowledge of the penetration impact resistance of different material systems or the effects of environmental or in-service load exposure to the penetration resistance of given materials is useful for product development and material selection.

5.2 An impact test used to measure the penetration resistance of a material can serve the following purposes:

5.2.1 To quantify the effect of fiber architecture, stacking sequence, fiber and matrix material selection, and processing parameters on the penetration resistance of different composite materials;

5.2.2 To measure the effects of environmental or in-service load exposure on the penetration impact resistance of a given material system; and

5.2.3 As a tool for quality assurance requirements for materials designed for penetration resistance applications.

5.3 The penetration resistance values obtained with this test method are most commonly used in material specification and selection and research and development activities. The data are not intended for use in establishing design allowables, as the results are specific to the geometry and physical conditions tested and are not generally scalable to other configurations.

5.4 The reporting section requires items that tend to influence the penetration resistance of material systems. These include the following: fiber and matrix materials, fiber architecture, layup sequence, methods of material fabrication, environmental exposure parameters, specimen geometry and overall thickness, void content, specimen conditioning, testing environment and exposure time, specimen fixture and alignment, projectile mass and geometry, and projectile orientation at impact. Additional reporting requirements include size and description of damage, results of any pre- and post-test nondestructive inspection, impact velocity, accuracy of the velocity measurement apparatus, and whether or not the projectile penetrated the panel. Residual velocity is a desirable, but not a necessary, value to be reported.

5.5 The reporting section shall also include the parameters of a statistical function that gives the probability of penetration as a function of impact kinetic energy (see 14.4).

5.6 The relevant measurements that result from the impact test are the kinetic energy and impact velocity of the projectile and whether or not the projectile penetrated the specimen. An optional item to be measured is the loss in kinetic energy of the projectile as a function of impact velocity if measurements of the residual velocity are recorded.

6. Interferences

6.1 The impact penetration resistance is dependent on many factors, such as test specimen thickness, areal density, fiber architecture, fiber and matrix materials, fiber volume ratio, pre-test environmental and load exposure, test environment, boundary conditions, projectile geometry, and projectile mass. Consequently, comparisons cannot be made between materials unless identical test configurations, test conditions, and material thickness are used. Therefore, all deviations from the standard test configuration shall be reported in the results.

6.2 *Materials and Specimen Preparation*—Poor material fabrication practices, lack of control of fiber placement and stacking sequence alignment, and damage induced by improper specimen machining are known causes of high material data scatter in composites in general. Important aspects of panel specimen preparation that contribute to data scatter include thickness variation and out-of-plane curvature.

6.3 *Impact Location and Projectile Orientation*—The location of the projectile impact shall occur at the center of the panel for results to be valid. Lack of control over the impact location will produce scatter in the results and invalidate comparisons between different materials or environmental exposure conditions. The orientation of the projectile shall be such that its center of mass is aligned with the impact direction and the impact direction is normal to the plane of the test specimen. Differences in projectile orientation between tests will lead to data scatter.

6.4 *Support Fixture Characteristics*—Results are affected by the dimensions, as well as the corresponding mass and rigidity of the support fixture. Bolt torque differences will affect the boundary conditions and lead to inconsistent results. The support fixture shall be significantly more rigid than the test specimen for results to be valid.

6.5 *Impact Device Characteristics*—The method of accelerating the projectile will affect the repeatability of the projectile impact velocity and orientation. Lack of control over repeatability will require a greater number of tests to ensure statistically valid results are obtained.

6.6 *Velocity and Orientation Measurement Equipment*—Valid results are directly dependent on the accuracy of the velocity and orientation measurements.

6.7 *Damage Modes*—Damage mode differences between materials will affect the evaluation of results. Widespread damage that extends to the specimen boundaries may invalidate results.

6.8 *Nondestructive Inspection*—Nondestructive testing (NDT) results are affected by a number of factors, including the particular Practice or Test Method used, the inherent variability of the NDT Practice or Test Method, and the experience of the operator.

7. Apparatus

7.1 *Micrometers and Calipers*—A micrometer with a 4 to 7 mm [0.16 to 0.28 in.] nominal diameter ball interface or a flat anvil interface shall be used to measure the specimen thickness. A ball interface is recommended for thickness measurements when at least one surface is irregular (for example, a coarse peel ply surface that is neither smooth nor flat). A micrometer or caliper with a flat anvil interface shall be used for measuring length, width, and other machined surface dimensions. The use of alternative measurement devices is permitted if specified (or agreed to) by the test requestor and reported by the testing laboratory. The accuracy of the instrument(s) shall be suitable for reading to within 1 % of the specimen dimensions. For typical specimen geometries, an instrument with an accuracy of ±0.0025 mm [±0.0001 in.] is adequate for thickness measurements, while an instrument with an accuracy of ±0.025 mm [±0.001 in.] is adequate for measurement of length, width, and other machined surface dimensions.

7.2 *Balance or Weighing Scale*—An analytical balance or weighing scale is required that is capable of measuring the mass of the projectile accurately to within ±0.5 %.

7.3 *Velocity Measurement*—The impact device shall be instrumented to measure the velocity of the impactor at a given point before impact. Several approaches to velocity measurement are available, and the selection of a particular method is dependent upon the desired measurement accuracy. One commonly used approach to velocity measurement uses a pair of laser beams pointed in a direction normal to the path of the projectile and separated by a known distance. The laser beams are directed at detectors that measure the light intensity. As the projectile interrupts the laser beam, the detector signal changes state, indicating an interruption in the light path. The time between the detections and the distance between the beams are used to calculate the projectile velocity. An alternate approach is to use photogrammetry to track targets on the projectile to compute velocity. The required accuracy of the velocity measurement system, and the associated method for verifying the measurement accuracy, shall be specified by the test requestor.

NOTE 1—It is recommended that the test requestor specify the required accuracy of the velocity measurement as a percentage of indicated value.

7.4 *Attitude Measurement*—Equipment shall be used for measuring the orientation of the projectile just before impact. The accuracy of data shall be reported. An example of equipment that may be used is a pair of calibrated high-speed cameras and a digital image correlation system. The required accuracy of the orientation measurement system, and the associated method for verifying the measurement accuracy, shall be specified by the test requestor.

7.5 *Impact Location Measurement*—Impact Location Measurement—Tools shall be used for measuring the impact location relative to the center point of the specimen. The accuracy of the equipment shall be reported. An example of equipment that may be used is a standard machinist scale.

7.6 In general, any device capable of accelerating the projectile in free flight into the test specimen with a repeatable velocity and orientation at sufficient speeds to penetrate the panel is acceptable. The device should be designed in such a way to minimize axial spin in the projectile. A schematic of an example of such a device is shown in Fig. 1. This device is a single-stage compressed gas gun and consists of a pressure vessel, a burst valve, and a gun barrel aimed at the test specimen. For safety, the test specimen should be located inside of a closed containment structure vented to allow pressure in the structure to be released. The device shown in Fig. 1 has a pressure vessel volume of approximately 0.011 m^3 [671 in.^{3}]. The burst valve consists of a pair of thin biaxially oriented polyethylene terephthalate (BoPET) polyester sheets with a thickness of approximately 0.125 mm [0.005 in.] with a nichrome wire sandwiched between them in a circular shape slightly smaller diameter than the gun barrel. The gun barrel has a length of approximately 3.7 m [12 ft] and a machined-smooth bore with a diameter approximately 0.05 mm [0.002 in.] greater than the diameter of the projectile. To operate the device, a projectile is loaded into the breach of the gun, and the pressure vessel is connected to the gun barrel with the polyester sandwiched between the two. Helium or nitrogen is introduced into the pressure vessel to the desired pressure. A voltage is applied to the nichrome wire, which heats up and causes the polyester sheets to rupture. The released gas accelerates the projectile down the gun barrel. Before impact, and after exiting the gun barrel, there is a region of free flight, which shall be long enough for the velocity and the orientation of the projectile to be measured.

7.7 *Support Fixture*—The impact test fixture, shown schematically in Fig. 2, is constructed from structural steel, Specification A36/A36M or equivalent or higher strength, and consists of a heavy back frame with a circular aperture and a circular front frame with through bolts that thread into nuts on the back of the frame. The inner diameter of the front frame and the circular aperture of the back frame is 254 mm [10 in.]. The test specimen is sandwiched between the two components. The test specimen shall extend a minimum of 25.4 mm [1 in.] beyond the circular aperture of the back frame so that it is completely clamped between the two parts of the fixture. The specimen contains machined holes to accommodate the through bolts. To minimize slippage at the specimen boundaries, the bolts are precision shoulder type with a

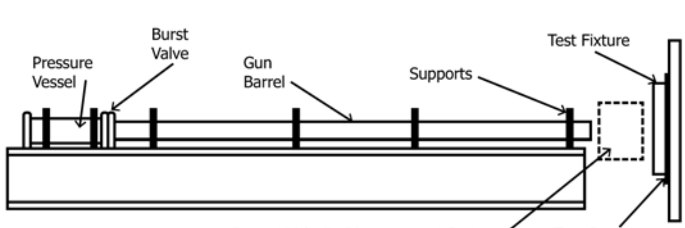

FIG. 1 Schematic of a Gas Gun Used for Accelerating Projectiles into Composite Panels

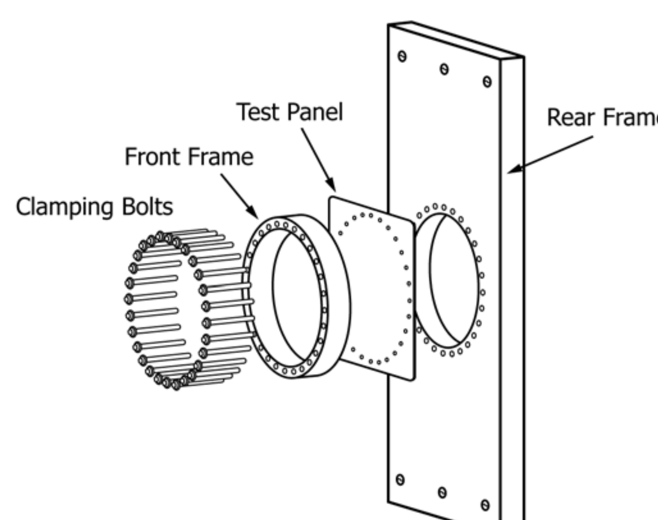

FIG. 2 Exploded View of Impact Test Fixture, including Front Frame, Test Panel, Back Frame, and Clamping Bolts

minimum tensile strength of 965 MPa [140 ksi]. The holes in the front frame and the specimen are precision machined to accommodate a clearance fit. All bolts should be torqued to a minimum value of 25 N-m [220 in.-lb]. Number the bolts sequentially from 1 to 28 around the bolt circle. Using a torque wrench, tighten the nut on each stud in an appropriate sequence to distribute the pressure on the test panel. A recommended order for tightening the bolts is 1, 15, 8, 22, 5, 19, 12, 26, 3, 17, 10, 24, 6, 20, 13, 27, 2, 16, 9, 23, 7, 21, 14, 28, 4, 18, 11, and 25. Tighten the bolts according to the following increments:

7.7.1 Tighten each stud to approximately 40 % of the final torque,

7.7.2 Tighten each stud to approximately 70 % of the final torque, and

7.7.3 Tighten each stud to 100 % of the final torque.

7.7.4 *Support Fixture Details*—Detailed drawings for manufacturing a support fixture that satisfies the requirements of the test method are contained in Figs. 3-8. The supporting frame shall be stiff and heavy compared to the test specimen. Thus, the front and rear frame are specified to be manufactured from steel, both with a thickness of 50 mm [2 in.].

7.8 *Projectile*—The projectile used for this test is shown in Fig. 9 and Fig. 10. It is a 2024-T351 aluminum thin-walled, cup-shaped projectile with a well-defined front face radius. The critical dimensions are the inner and outer radius of the front face, the overall diameter, and the wall thickness. The projectile shown in Fig. 9 and Fig. 10 is the recommended projectile; if it is necessary to alter the mass of the projectile to achieve penetration velocities in the range of interest for a given application, the thickness of the front face can be varied. This shall be done without changing the front face inner or outer radii. However, results are invalidated if the front face thickness is reduced to the point at which the impact test results in visible permanent deformation of the projectile. The mass of the projectile for both the SI and inch-pound versions of the test method is specified to be 50 ± 0.5 g [1.8 ± 0.02 oz]. If the front face thickness is altered, the mass of all projectiles in a given test series shall be within plus or minus 1 % of the stated mass. Typically, a projectile is used only once as it may sustain plastic deformation as a result of either impacting the test panel or secondary impacts after impacting the panel. If a projectile is to be reused, it shall be inspected to ensure that its dimensions are within the required tolerances.

8. Hazards

8.1 The use of compressed gas as a propellant and free-flying projectiles always presents safety issues.

8.2 Ensure that, if used to propel the projectile, the pressure vessel has been safety checked, relief valves are in place and functional, and all hoses and piping are according to applicable safety codes.

8.3 3 Ensure that the test fixture is contained within safety shields so that the projectile cannot rebound and injure laboratory personnel.

8.4 Ensure that the compressed gas, when released, is properly vented so as not to cause an overpressure situation in the test laboratory or the containment structure.

9. Sampling and Test Specimens

9.1 *Sampling*—Test at least six specimens per test condition over a range of impact velocities that spans the velocity

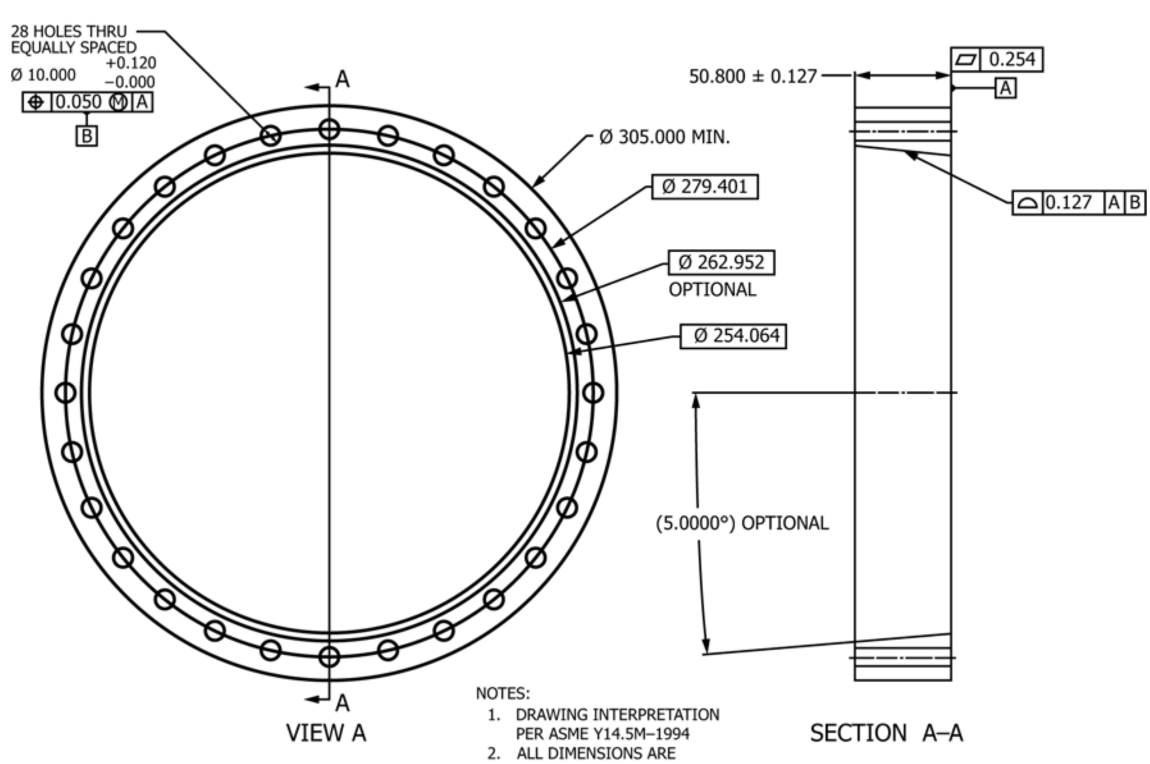

FIG. 3 Front Frame (SI Version)

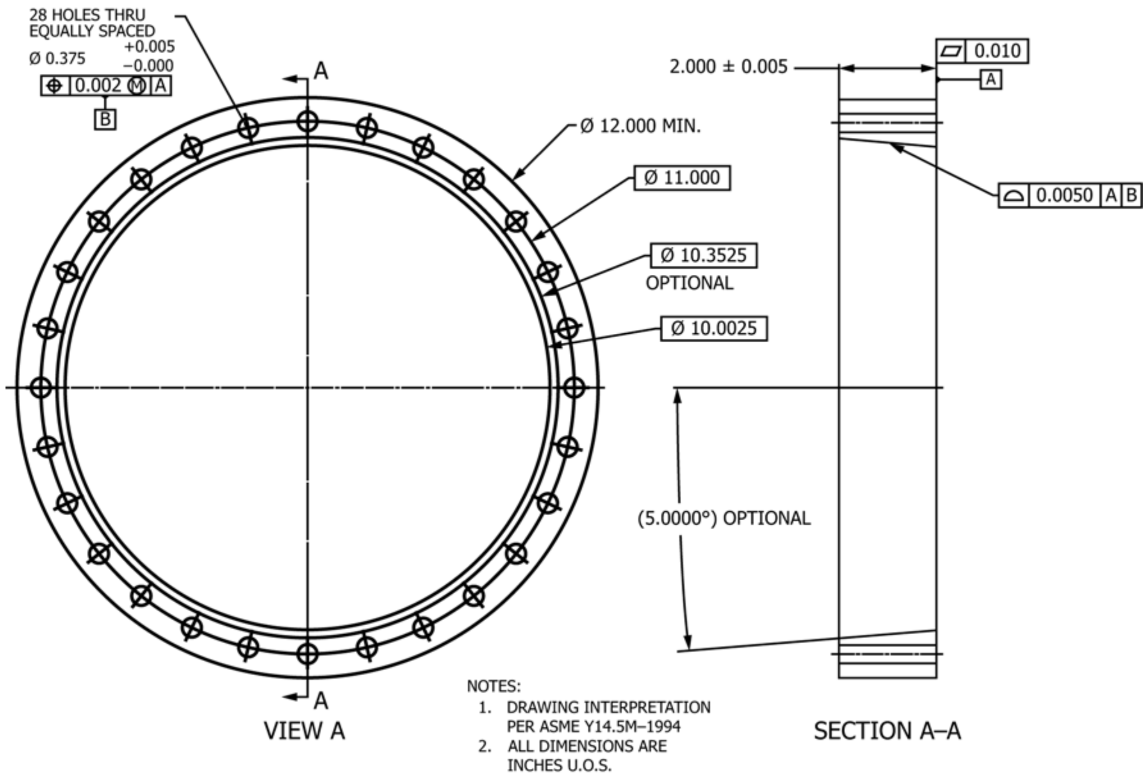

FIG. 4 Front Frame (Inch-Pound Version)

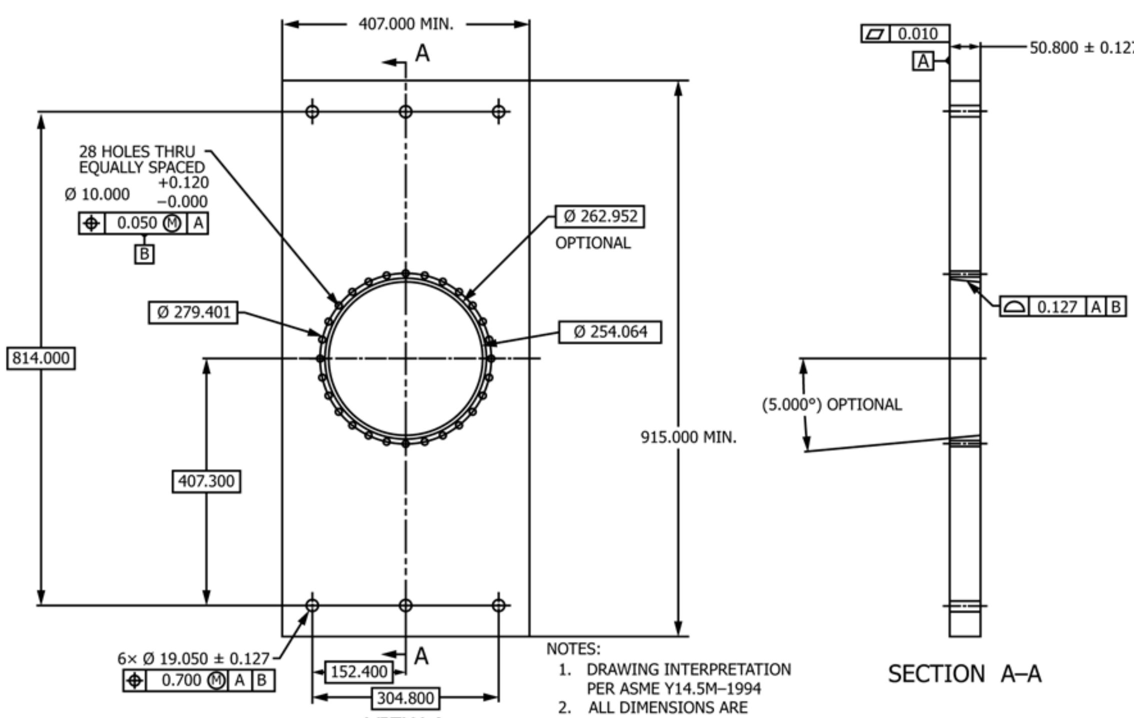

FIG. 5 Rear Frame (SI Version)

required to penetrate the specimen. The projectile shall penetrate the specimen in at least three of the tests and not penetrate in at least three tests. Because of statistical variation in materials and testing procedures, there may be some overlap in results in which the kinetic energy in a penetrated test is lower than the kinetic energy in a non-penetrated test. In either

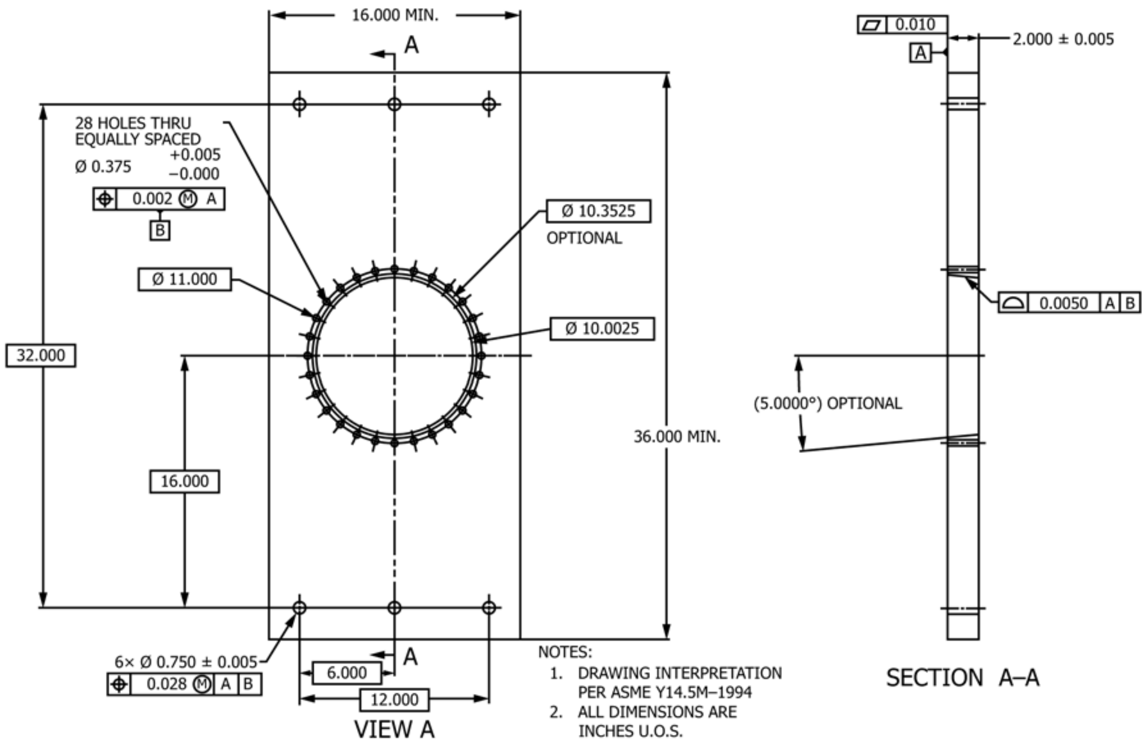

FIG. 6 Rear Frame (Inch-Pound Version)

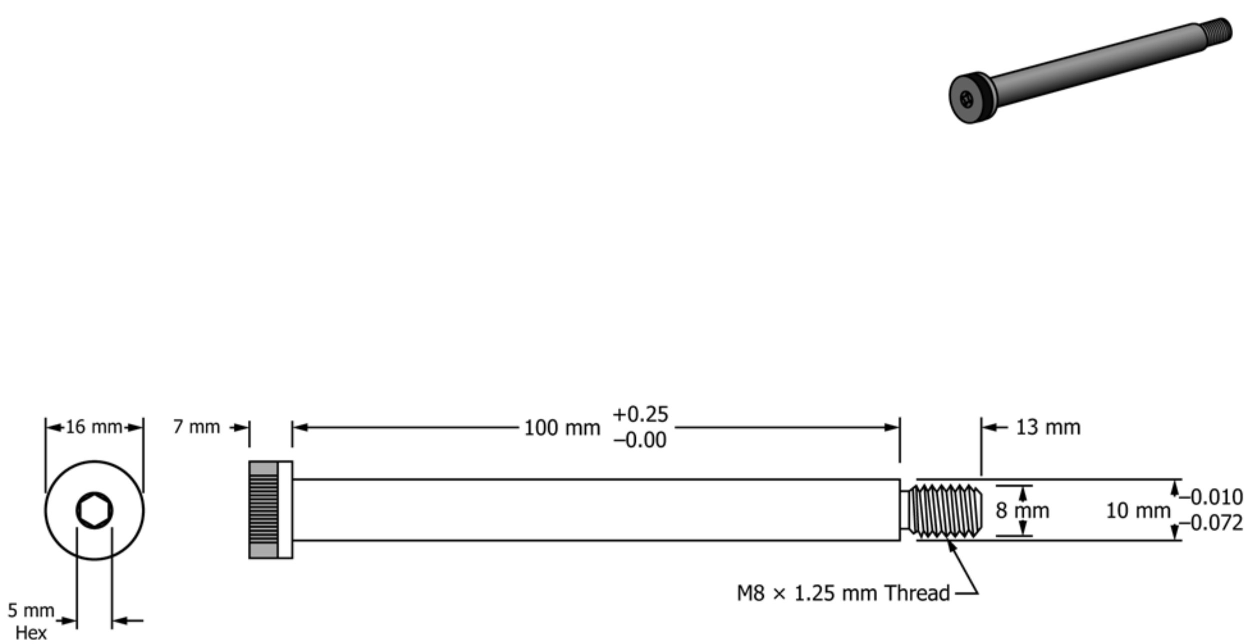

FIG. 7 Precision Shoulder Bolts for Clamping Fixture (SI Version)

case, the kinetic energy in at least two of the penetrated tests and two of the non-penetrated tests shall all fall within 20 % of the lowest of the four values.

9.2 *Geometry*—The geometry of the panel specimen is shown in Fig. 11 and Fig. 12. The standard specimen thickness is 2.0 to 4.0 mm [0.08 to 0.16 in.]. There are no restrictions on the stacking sequence, layup, or fabric used for this specimen.

9.3 *Specimen Preparation*—Guide D5687/D5687M provides recommended specimen preparation practices and should be followed when applicable.

9.3.1 *Panel Fabrication*—For polymer composites, control of alignment between layers is critical. Lack of control in alignment will lead to scatter in results. Report the panel fabrication method. Panels shall be of uniform thickness over

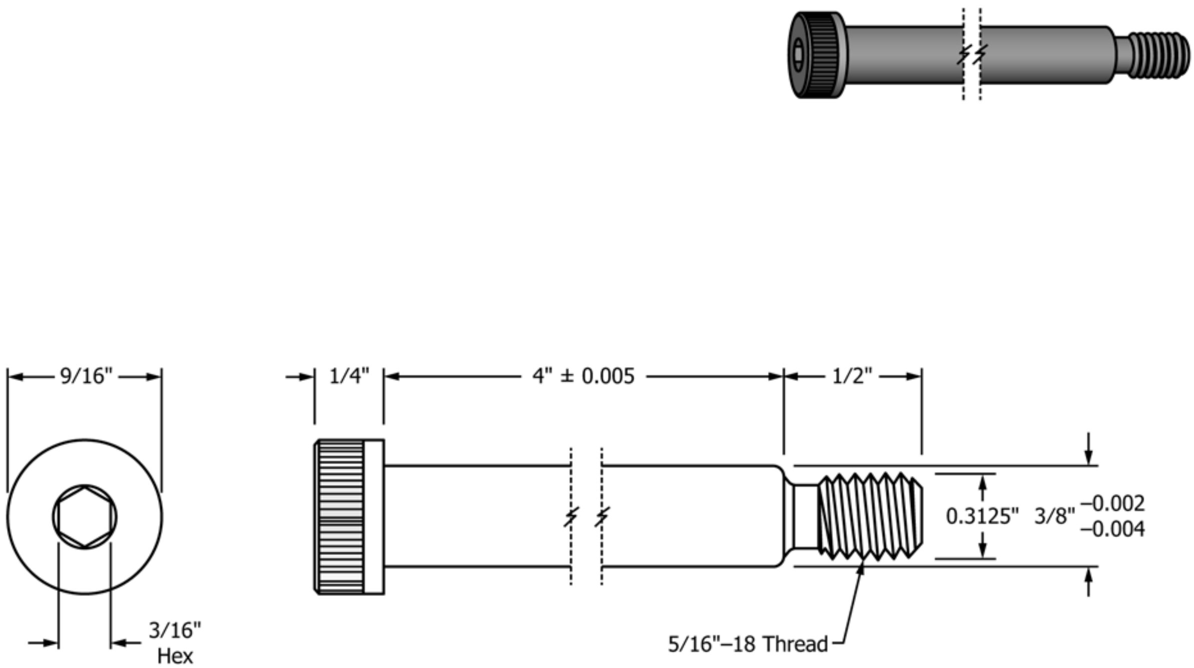

FIG. 8 Precision Shoulder Bolts for Clamping Fixture (Inch-Pound Version)

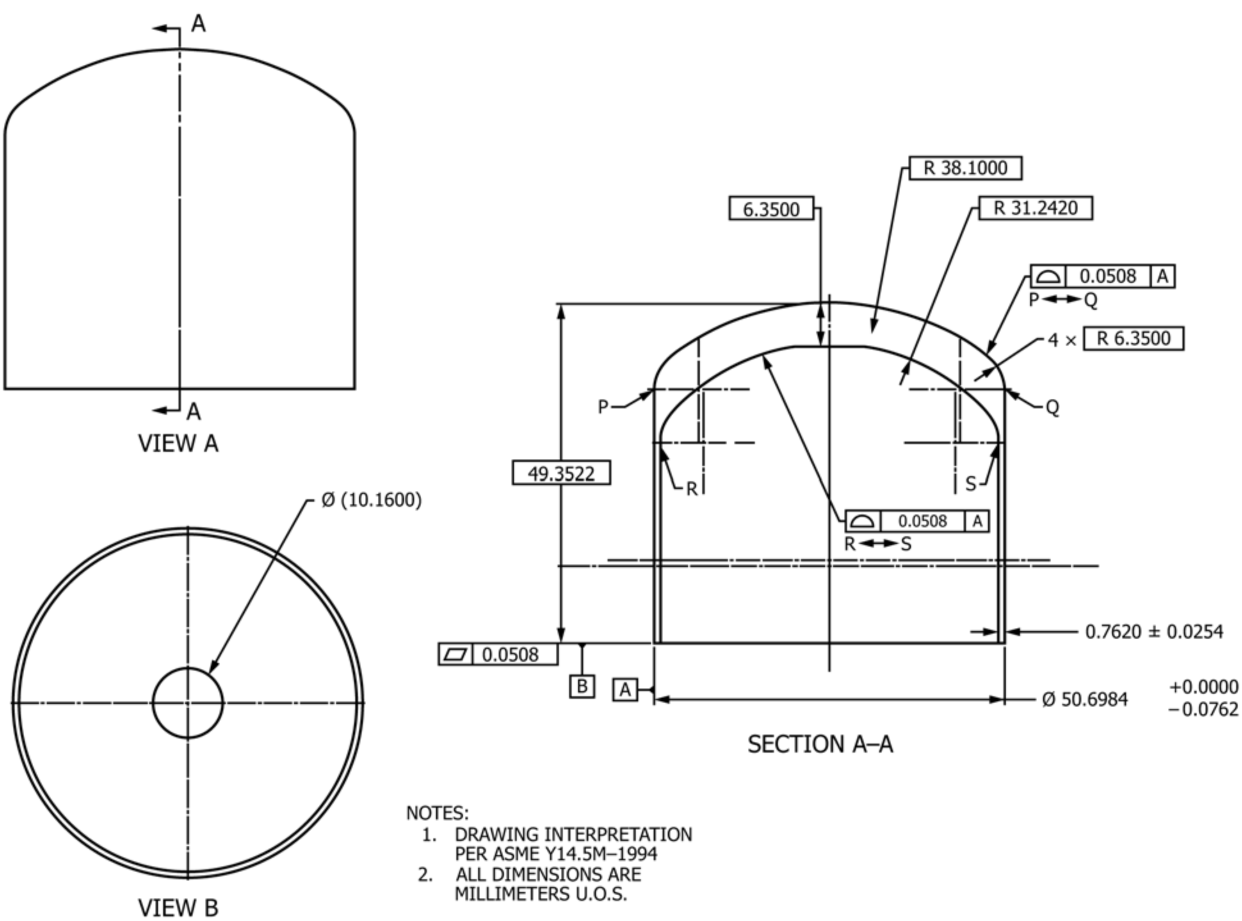

FIG. 9 Standard Projectile (SI Version)

the entire surface with a coefficient of variation in thickness measurements of less than 2 %.

9.3.2 *Machining Methods*—To minimize slippage at the boundaries, the support holes shall be machined to allow for a

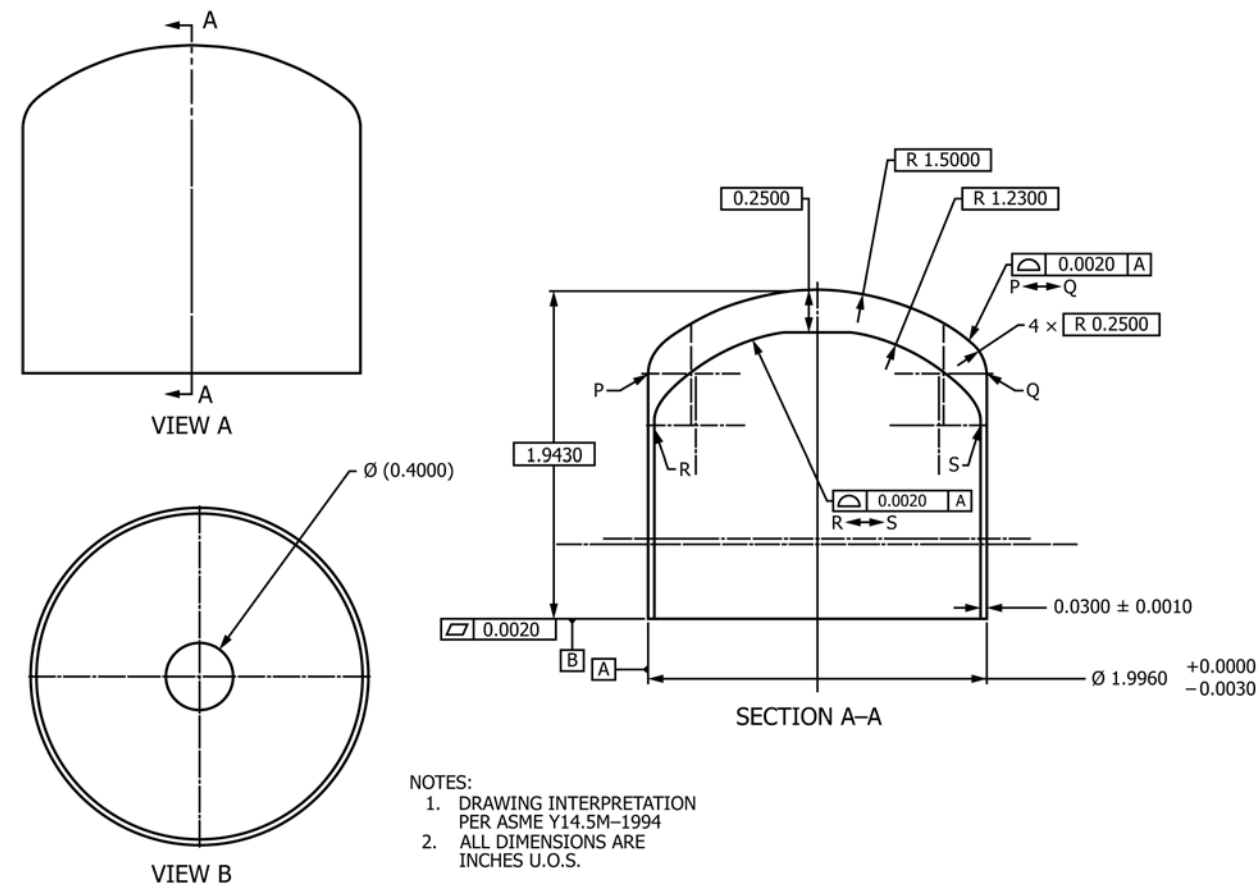

FIG. 10 Standard Projectile (Inch-Pound Version)

clearance fit with the shoulder bolts. It is highly recommended to create the matched set by simultaneously creating the holes (line-bore) in the two test fixture plates that accept the shoulder bolts, marking a top dead center location on each portion of the fixture for aligning the matched set. It is also recommended that the front fixture plate be used as a guide when drilling the corresponding holes in the test specimen panels. It is, however, acceptable to use computer numerical control (CNC) machines or other accurate machining methods to generate the test fixture plates and panel specimens. A recommendation concerning the geometric dimensioning and tolerancing can be found in Figs. 3-6, Fig. 11 and Fig. 12. Similar dimensions and tolerances are recommended for the line-bore option at the assembly level as well. All deviations from the standard test geometry and tolerance definition recommended shall be reported in the results.

9.3.3 *Labeling*—Label the panel specimens so that they will be distinct from each other and traceable back to the raw material, and will neither influence the test nor be affected by it.

10. Calibration

10.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

11. Conditioning

11.1 The recommended pre-test condition is affective moisture equilibrium at a specific relative humidity as established by Test Method D5229/D5229M unless otherwise specified by the test requestor.

11.2 The pre-test specimen conditioning process, to include specified environmental exposure levels and resulting moisture content, shall be reported with the test data.

NOTE 2—The term "moisture," as used in Test Method D5229/D5229M, includes not only the vapor of a liquid and its condensate, but the liquid itself in large quantities, as for immersion.

11.3 If no explicit conditioning process is performed, the specimen-conditioning process shall be reported as "unconditioned" and the moisture content as "unknown."

12. Procedure

12.1 *Parameters to be Specified and Recorded before the Test*

12.1.1 Record specimen materials, layup, architecture, overall dimensions, and thickness.

12.1.2 Record density and fiber volume ratio if measured (see Note 3).

NOTE 3—If specific gravity, density, reinforcement volume, or void volume are to be reported, then obtain these samples from the same panels

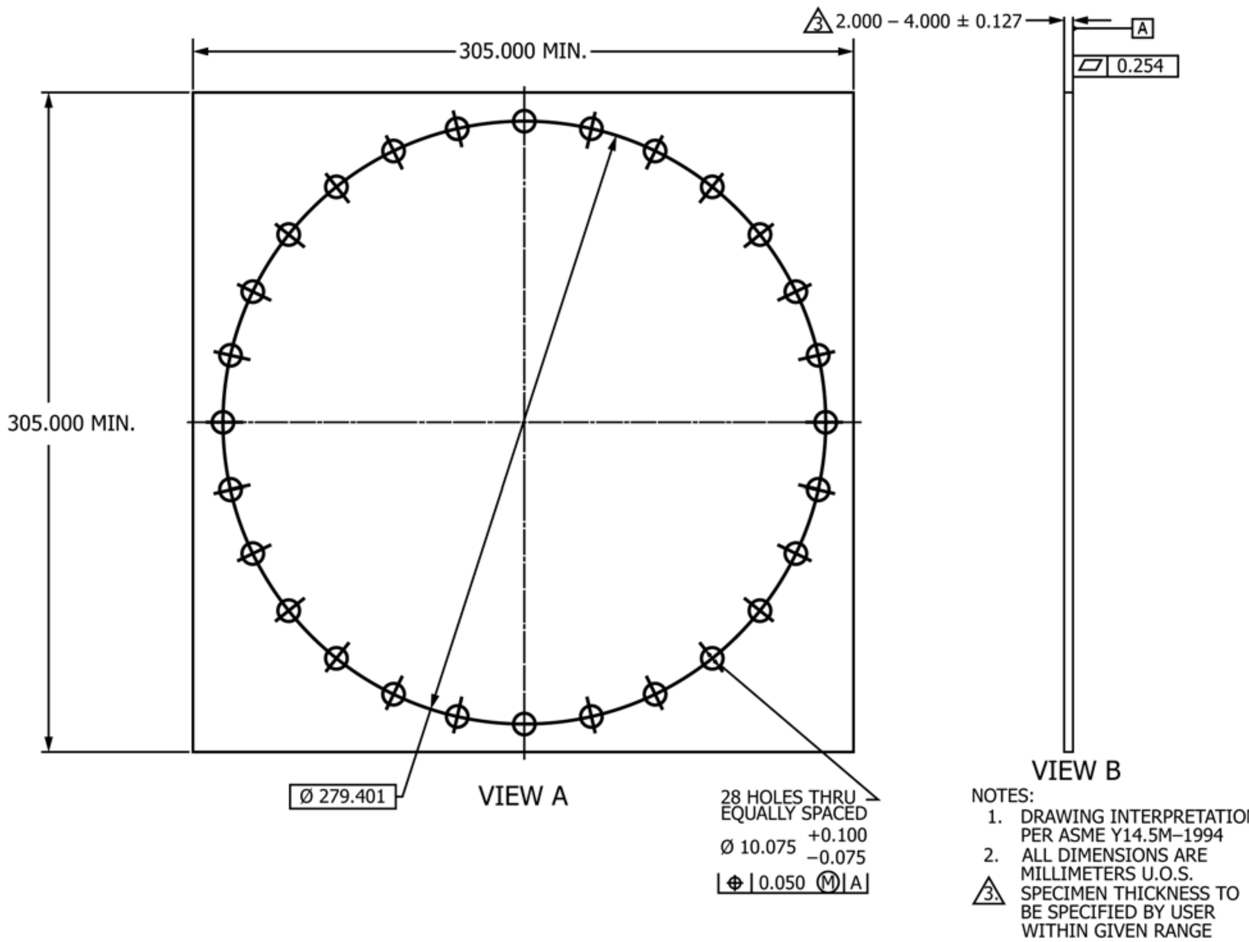

FIG. 11 Panel Specimen (SI Version)

being tested. Specific gravity may be evaluated by means of Test Method D792. Volume percent of the constituents may be evaluated by one of the procedures of Test Methods D3171.

12.1.3 Record all environmental conditioning parameters, if used.

12.1.4 Record mass, material, and geometry of projectile.

12.1.5 Specify and record an initial desired velocity based on previous experience or published information on test data for similar materials.

NOTE 4—If no previous experience or published information exists, it is recommended that an initial velocity be selected that is relatively high so that penetration occurs. The energy absorbed by the panel can be calculated from the difference between the impact and residual velocities (see 14.3). This will give an initial estimate of the energy and velocity required to penetrate the specimen.

12.1.6 Record model numbers, locations, frame rate, and resolution (if digital) of all cameras used to record video data.

12.1.7 Mark a point at the center of the panel by intersecting perpendicular lines from the center of two pairs of mounting holes. The center point location shall be accurate to within 3 mm (0.125 in.). The mark shall be made in such a way that it causes no damage to, or weakening of, the test specimen.

12.2 *General Instructions*

12.2.1 Report any deviations from this test method, whether intentional or inadvertent.

12.2.2 If NDT is to be used to assess impact damage following final specimen machining, but before conditioning, perform baseline NDT to detect flaws that may exist before impact testing. All NDT shall be performed in accordance with the Practices and Test Methods referenced in Guide E2533.

12.2.3 Condition the specimens as required. Store the specimens in the conditioned environment until test time if the test environment is different from the conditioning environment.

12.2.4 Following final specimen machining and any conditioning, but before all testing, measure the specimen thickness in four locations near the impact location and record the thickness as the average of the four measurements. The accuracy of all measurements shall be within 1 % of the dimension. Record the dimensions to three significant figures in units of millimeters [inches].

12.3 *Test Environment*—If possible, test the specimen under the same fluid exposure level used for conditioning. However, cases such as elevated temperature testing of a moist specimen may place unrealistic requirements on the capabilities of common impact test chambers. In such cases, the impact test environment may need to be modified during the impact test. For example, it may be necessary to conduct the test at elevated temperature with no fluid exposure control but with a specified

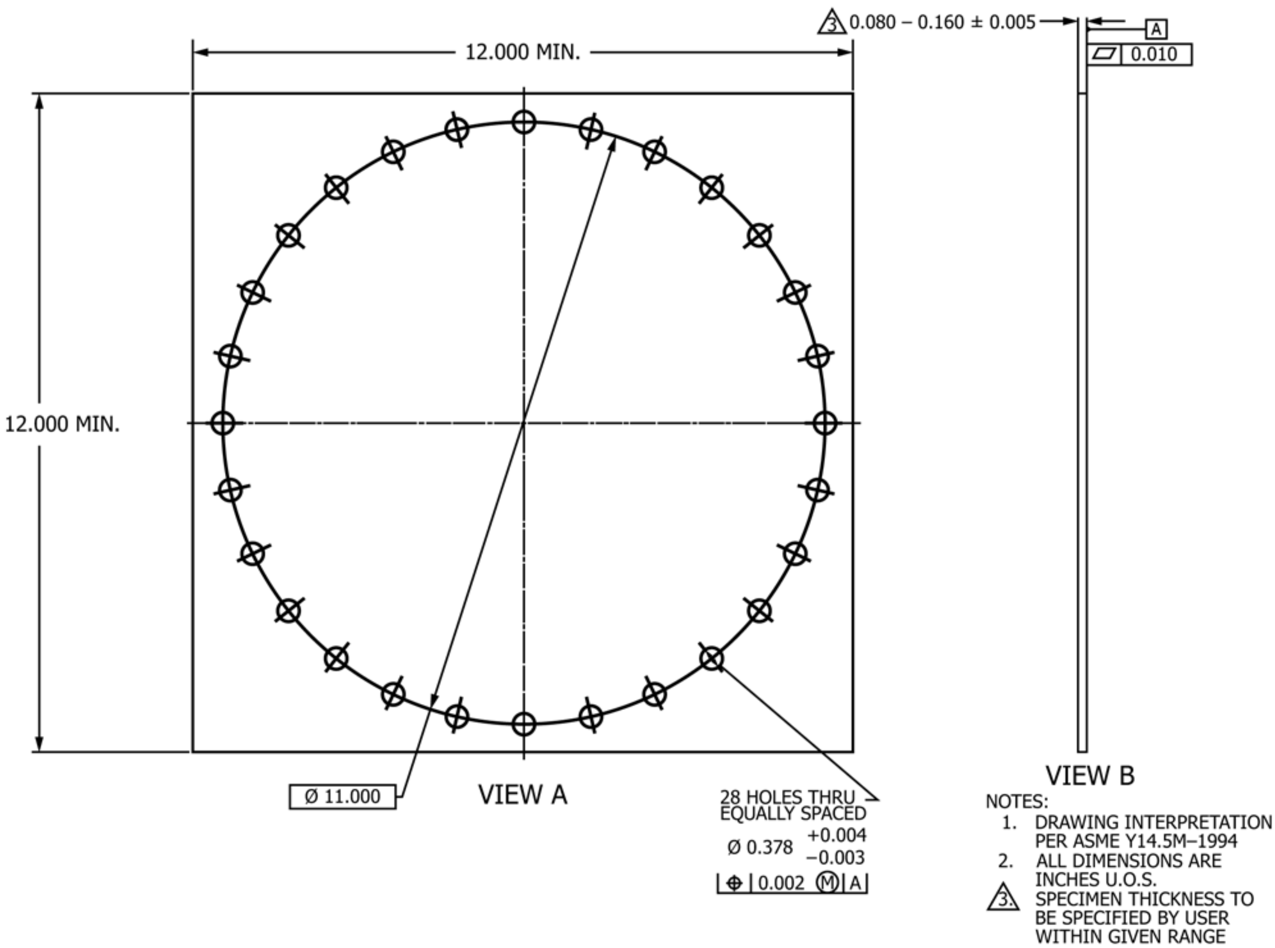

FIG. 12 Panel Specimen (Inch-Pound Version)

limit on time to test after withdrawal from the conditioning chamber. Record any modifications to the test environment.

12.4 *Test Specimen*—Mount the test specimen in the fixture and torque all bolts to the value specified in 7.7. Test specimens shall be unambiguously identified so that the test specimen can be associated with the specific test.

12.5 *Impactor Preparation*—Use lasers, mirrors, and leveling devices to ensure that the impact gun or accelerating device is centered on the test specimen and aligned with the normal to the test specimen. Install projectile in the impact gun or accelerating device and set the device parameters for the desired velocity.

12.6 *Instrumentation*—Ensure that all cameras and recording devices are properly armed.

12.7 *Data Recording*—Conduct the impact test. Ensure that all camera information and other recorded data are properly stored.

12.8 *Damage*—Preferred damage to the test panel, if penetration occurs, is a well-defined hole, similar in diameter to the projectile diameter, as opposed to large-scale fracturing of the test panel.

12.8.1 Record whether or not the projectile penetrated the panel and photograph the damaged region of the panel while still in the test fixture. Note the general type of damage induced in the specimen such as whether localized or distributed, directions of cracks, any tearing, and so forth.

12.9 *Impact Location*—Identify the center of the impact location and measure the location relative to the center of the panel.

12.10 *Velocity*—Compute the impact velocity, residual velocity (if obtained), and orientation of the projectile just before impact. The computations depend on the type of equipment used to record velocity. Examples include calibrated cameras, velocity screens, and lasers.

13. Validation

13.1 Test results shall be rejected for any specimen when the specimen fails in such a way that the fractures extend to the specimen boundaries.

13.2 Test results shall be rejected for specimens when the impact location is more than 20 mm [0.75 in.] from the center of the panel.

13.3 Test results shall be rejected for any test in which the angle between the longitudinal axis of the projectile and the normal to the plane of the test panel is greater than 5° at the time of impact.

13.4 If a significant number of specimens in a sample population exhibit damage originating or extending significantly away from the impact location, the impact support conditions shall be re-examined. In this case, it may be deemed that this test is not appropriate for measuring the impact penetration resistance of the material being studied. An example of a situation where this can occur would be when testing unidirectional composites where the projectile splits the specimen rather than generating localized damage or a hole.

14. Calculation

14.1 Impact kinetic energy, E_i, is computed from the projectile mass, M, and the projectile impact velocity, V_i as:

$$E_i = \frac{MV_i^2}{2} \quad (1)$$

14.2 Residual kinetic energy, E_r, is computed from the projectile mass, M, and the projectile residual velocity, V_r, as:

$$E_r = \frac{MV_r^2}{2} \quad (2)$$

14.3 Loss in kinetic energy of the projectile as a result of the impact is computed as:

$$E_a = E_i - E_r \quad (3)$$

14.4 The probability of penetration, π, is computed using a logistic regression model (see NIJ Standard-0101.06):[4]

$$\pi = \frac{\exp(b_o + b_1 X)}{1+\exp(b_o + b_1 X)} \quad (4)$$

where:

X = impact kinetic energy and
b_0 *and* b_1 = regression parameters that shall be obtained through an iterative process.

14.4.1 Here, π would take on a value between 0 and 1. While this regression model is somewhat arbitrary, it is appropriate for situations such as the present when the response variable, penetration, is binary (no penetration = 0, penetration = 1). To ensure consistency between test laboratories, this method is recommended. The method of maximum likelihood is used to estimate the parameters in Eq 4. It requires the maximization of the joint probability function, or more precisely the logarithm of the joint probability function, with respect to the two parameters, b_0 and b_1. Details of the procedure can be found in section 14.3 of the reference given in Footnote 4. The maximization procedure leads to the following set of two nonlinear equations:

$$\Sigma_{i=1}^{n} Y_i - \Sigma_{i=1}^{n} \frac{\exp(b_0 + b_1 X_i)}{1+\exp(b_0 + b_1 X_i)} = 0 \quad (5)$$

$$\Sigma_{i=1}^{n} Y_i X_i - \Sigma_{i=1}^{n} \frac{X_i \exp(b_0 + b_1 X_i)}{1+\exp(b_0 + b_1 X_i)} = 0 \quad (6)$$

14.4.2 In these equations, X_i are individual kinetic energy values and Y_i are the associated responses (0 or 1, corresponding to "not penetrated" and "penetrated" respectively). The value n is the number of impact tests. These equations shall be solved numerically for b_0 and b_1, typically using either a commercial statistics analysis program or another numerical search procedure.

15. Report

15.1 Report the following information, or references pointing to other documentation containing this information, to the maximum extent possible (reporting of items beyond the control of a given testing laboratory such as might occur with material details of panel fabrication parameters shall be the responsibility of the requestor):

15.1.1 The revision level or date of issue of this test method;

15.1.2 The name(s) of the test operator(s);

15.1.3 Any variations to this test method, anomalies noticed during testing, or equipment problems encountered during testing;

15.1.4 Identification of all the applicable constituent information including: material specification, material type, manufacturer's material designation, manufacturer's batch or lot number, source (if not from the manufacturer), date of certification, expiration of certification, filament diameter, tow or yarn filament count, twist and angles, sizing, form (for example, angle-ply, weave, or braid) fiber areal weight, matrix type, matrix content, and volatiles content;

15.1.5 Description of the fabrication steps used to prepare the parent composite material including: fabrication start date, fabrication end date, process specification, cure cycle, consolidation method, and a description of the equipment used;

15.1.6 Description of the fiber architecture and stacking sequence of the composite panel;

15.1.7 If requested, report density, volume percent reinforcement, and void content test methods, specimen sampling method and geometries, test parameters, and test results;

15.1.8 Method of preparing the test specimen, including specimen labeling, scheme and method, specimen geometry, sampling method, and specimen cutting and machining method;

15.1.9 Type and configuration of test machine, data acquisition equipment, and data sampling rates;

15.1.10 Velocity measurement method and equipment and key parameters;

15.1.11 Measured dimensions for each specimen (before and after damage and conditioning, if appropriate);

15.1.12 Measured or computed areal density of each specimen in which computed areal weight is based on measured density and thickness;

15.1.13 Conditioning parameters and results;

15.1.14 Relative humidity and temperature of the testing laboratory;

15.1.15 Environment of the test machine environmental chamber (if used) and soak time at environment;

15.1.16 Number of specimens tested;

15.1.17 Mass of projectile and specimen, type of balance or weighing scale, and measurement accuracy;

15.1.18 Geometry of projectile;

15.1.19 Impact velocity and residual velocity (if measured) for penetrated tests;

15.1.20 Accuracy of velocity measurement apparatus;

[4] Kutner, M., Nachtsheim, C., Netter, J., Li, W., *Applied Linear Statistical Models*, 5th edition (2004).

15.1.21 Orientation of the projectile just before impact;

15.1.22 Accuracy of orientation measurement apparatus;

15.1.23 Distance of impact location from center of panel;

15.1.24 Accuracy of impact location measurement device;

15.1.25 Computed impact kinetic energy and residual kinetic energy (if measured) for penetrated tests;

15.1.26 Results of nondestructive evaluation tests, including method, specification, inspection parameters, and operator(s) both before and after impact;

15.1.27 Damage geometry, including dimensions of any hole and extent of damage and qualitative description of damage type;

15.1.28 Description of any permanent deformation of the projectile as a result of impact with the test panel; and

15.1.29 The results of a statistical analysis, including the parameters for a probability of penetration function as described in 14.4.

16. Precision and Bias

16.1 *Precision*—The data required for the development of a precision statement is not available for this test method. Precision and bias data will be available within five years of approval and publication of this test method.

16.2 *Bias*—Sources of potential bias include systematic errors in velocity measurement, projectile mass measurement, and test specimen thickness measurement. Assuming the respective instruments are properly calibrated, no bias is anticipated with this test method.

17. Keywords

17.1 composite materials; impact testing; penetration resistance

APPENDIX

Nonmandatory Information

X1. EXAMPLE OF A TEST SERIES AND THE COMPUTATION OF THE PROBABILITY OF PENETRATION FUNCTION

X1.1 Six tests are conducted, all using a 50.0 g [1.8 oz] projectile (Tests 1 to 6 in Table X1.1). As required in 9.1, in three tests the projectile penetrated the panel and in three it did not. We consider the two highest velocity tests that did not penetrate and the two lowest velocity tests that did penetrate, that is, Tests 2, 3, 4, and 5. The requirement in 9.1 is that the kinetic energy in at least two of the penetrated tests and two of the non-penetrated tests shall all fall within 20 % of the lowest of the four values. In our case, the kinetic energy in Test 5 is 26 % higher than that of Test 2, so the requirement is not met. Another test, Test 7, is run (Table X1.1) with an impact velocity of 124.7 m/s and an impact kinetic energy of 388.7 J and the projectile does not penetrate the panel. We now consider Tests 3, 7, 4, and 5. In this case, the kinetic energy of Test 5 is 15.9 % higher than that of Test 3 and so the test series meets the requirements of 9.1.

TABLE X1.1 Six Tests Using 50.0 g [1.8 oz] Projectile

Test	Impact Velocity, m/s	Impact KE, J	Penetration
1	95.4	227	0
2	114.0	324.9	0
3	118.9	353.4	0
4	122.5	375.1	1
5	128.0	409.6	1
6	147.8	546.1	1
7 (Added Test)	124.7	388.7	0

X1.2 For the statistical analysis, the energy values are converted to kJ, to avoid using numbers that are too large. Using a statistical package on this set of seven tests, the computed values for b_0 and b_1 are -26.058 and 68.174 kJ^{-1}, respectively. The resulting probability of penetration curve (Eq 4), and the test data are shown in Fig. X1.1. The computed function can be used to calculate the probability of penetration for different levels. For example, the 50 % probability of penetration occurs at a kinetic energy of 382.2 J.

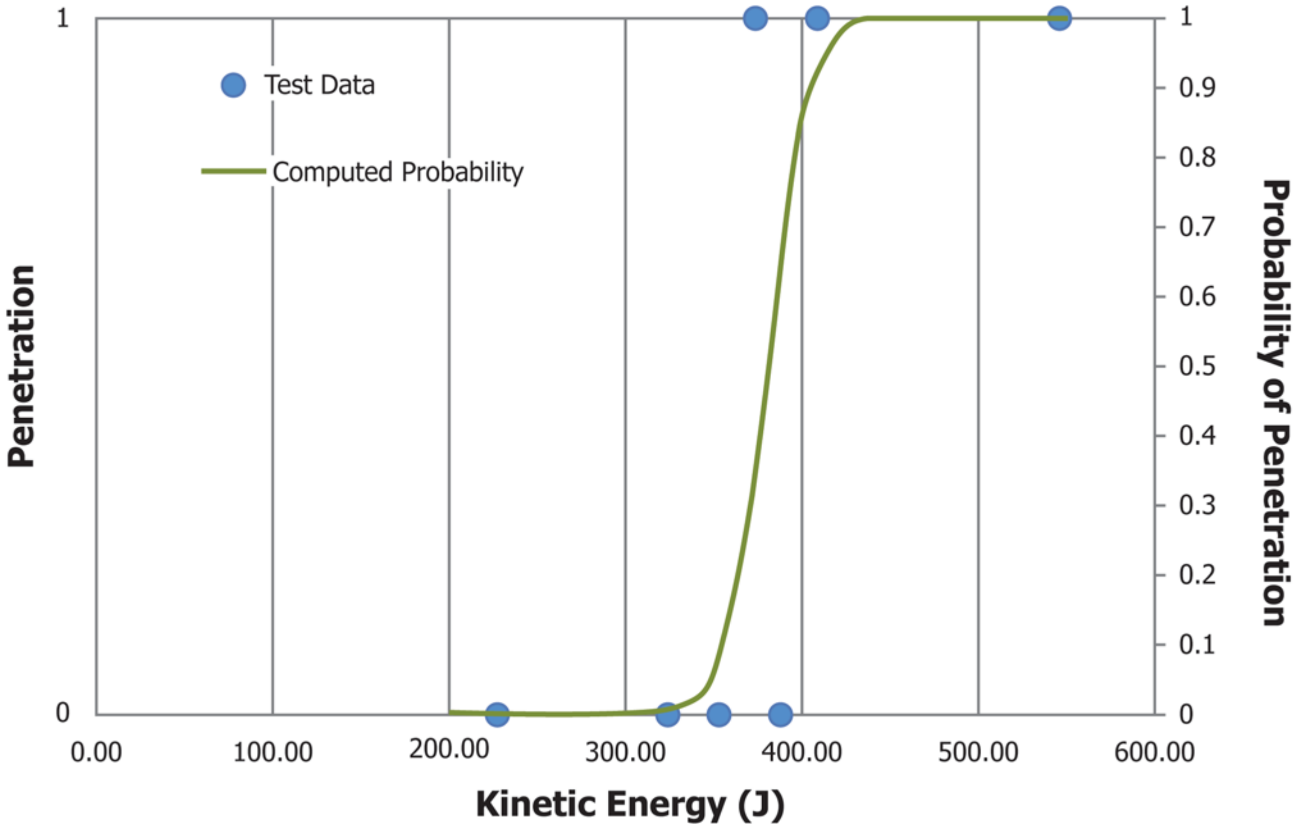

FIG. X1.1 Test Data and Computed Probability for Data Analysis Example