Designation: D7332/D7332M – 22

Standard Test Method for
Measuring the Fastener Pull-Through Resistance of a Fiber-Reinforced Polymer Matrix Composite[1]

1. Scope

1.1 This test method determines the fastener pull-through resistance of multidirectional polymer matrix composites reinforced by high-modulus fibers. Fastener pull-through resistance is characterized by the force-versus-displacement response exhibited when a mechanical fastener is pulled through a composite plate, with the force applied perpendicular to the plane of the plate. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape or fabric, or both) reinforced composites for which the laminate is symmetric and balanced with respect to the test direction. The range of acceptable test laminates and thicknesses is defined in 8.2.

1.2 Two test procedures and configurations are provided. The first, Procedure A, is suitable for screening and fastener development purposes. The second, Procedure B, is configuration-dependent and is suitable for establishing design values. Both procedures can be used to perform comparative evaluations of candidate fasteners/fastener system designs.

1.3 The specimens described herein may not be representative of actual joints which may contain one or more free edges adjacent to the fastener, or may contain multiple fasteners that can change the actual boundary conditions.

1.4 This test method is consistent with the recommendations of CMH-17, which describes the desirable attributes of a fastener pull-through test method.

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 are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems 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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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

D3410/D3410M Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading

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

E4 Practices for Force Calibration and 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

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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]

2.2 *Industry Documents:*[4]

CMH-17-1G Composite Materials Handbook, Volume 1—Polymer Matrix Composites Guidelines for Characterization of Structural Materials

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.

NOTE 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.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *diameter-to-thickness ratio, D/h [nd], n*—the ratio of the hole diameter to the specimen thickness.

3.2.1.1 *Discussion*—The diameter-to-thickness ratio may be either a nominal value determined from nominal dimensions or an actual value determined from measured dimensions.

3.2.2 *failure force, n*—the maximum force magnitude achieved prior to the first significant (greater than 10 %) drop in applied force, as observed in force versus displacement data.

3.2.3 *initial sub-critical failure, n*—discontinuity observed in force versus displacement data prior to attaining the failure force. Sub-critical failures are characterized by minor (less than 10 %) drops in applied force, or by compliance changes (greater than 10 % change in slope), prior to attaining the failure force.

3.2.4 *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.

3.2.5 *rupture, n*—separation of the fastener and test laminate, caused by failure of the fastener, the composite plate, or both. Rupture is characterized by an extreme force drop, such that the specimen is incapable of carrying significant applied force.

3.3 *Symbols:*

A = cross-sectional area of a specimen

CV = coefficient of variation statistic of a sample population for a given property (in percent)

d = fastener or pin shank diameter

d_{csk} = countersink depth

D = specimen hole diameter

h = specimen thickness

l = specimen length

n = number of specimens per sample population

N = number of plies in laminate under test

P_f = failure force

P_i = force carried by test specimen at initial failure

P_m = maximum force carried by test specimen during test

s_{n-1} = standard deviation statistic of a sample population for a given property

w = specimen width

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

δ_i = displacement at initial failure

δ_r = displacement at rupture

4. Summary of Test Method

4.1 *Procedure A, Compressive-Loaded Fixture:*

4.1.1 Two flat square, constant rectangular cross-section composite plates, each containing a centrally located fastener hole, are placed in a multi-piece fixture that has been aligned to minimize loading eccentricities. Each plate contains four additional holes on the periphery to accommodate the test fixture components. The two plates are joined together by the fastener, with one plate being rotated 45° with respect to the second plate.

4.1.2 The plates are pried apart by the application of compressive force transmitted through the fixture, producing a tensile loading through the fastener and a compressive loading through the composite plates. Force is applied until failure of the composite specimen, the fastener, or both occurs. Applied force and crosshead displacement are recorded while loading.

4.2 *Procedure B, Tensile-Loaded Fixture:*

4.2.1 A flat square, constant rectangular cross-section composite plate containing a centrally located fastener hole is placed in a multi-piece fixture that has been aligned to minimize loading eccentricities. The plate is joined by the fastener to a yoke, which is designed to rotate as to avoid imparting a moment to the fastener.

4.2.2 A uniaxial tensile force is applied to the yoke, imparting a tensile loading on the fastener and an out-of-plane compressive loading on the composite plate. Force is applied until failure of the composite specimen, the fastener, or both occurs. Applied force and crosshead displacement are recorded while loading.

4.3 For both procedures, preferred failure modes are those associated with failure of the composite at the fastener hole. Unacceptable failure modes include those associated with the fastener (such as head, shank, or thread failure) or failure of the composite away from the fastener hole.

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[3] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096, http://www.sae.org.

5. Significance and Use

5.1 This test method is designed to produce fastener pull-through resistance data for structural design allowables, research and development. The procedures may be used to assess pull-through resistance for a variety of composite laminate thicknesses, fastener diameters, and fastener head styles. However, the flexibility of test parameters allowed by the variants makes meaningful comparison between datasets difficult if the datasets were not generated using identical test parameters.

5.2 Early composite pull-through tests using fasteners common to metal structures led to premature joint failures, and resulted in the development of fasteners specific for composite applications. These fasteners have larger heads and tails to reduce through-thickness compression stresses on the composite laminate.

5.3 General factors that influence the mechanical response of composite laminates and should therefore be reported include the following: material, methods of material preparation and lay-up, specimen stacking sequence, specimen preparation, specimen conditioning, environment of testing, specimen alignment, speed of testing, time at temperature, void content, and volume percent reinforcement.

5.4 Specific factors that influence the pull-through resistance of composite laminates and should therefore be reported include the following: hole diameter, fastener diameter, fastener head diameter, loading bar spacing to fastener hole diameter ratio (Procedure A), clearance hole diameter to fastener hole diameter ratio (Procedure B), diameter to thickness ratio, fastener torque, fastener or pin material, fastener or pin clearance, countersink angle and depth of countersink, type of grommet (if used), and type of support fixture. Fastener pull-through resistance properties which may be determined from this test method include initial sub-critical failure force/displacement, failure force, maximum force, and rupture displacement.

6. Interferences

6.1 *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 specimen preparation that contribute to data scatter include thickness variation, out-of-plane curvature, surface roughness, and failure to meet the dimensional tolerances specified in 8.2.2.

6.2 *Hole Preparation*—Because of the dominating presence of the filled hole, results from this test method are relatively insensitive to parameters that would be of concern in an unnotched tensile, compressive, or flexural property test. However, since the filled hole dominates the strength, consistent preparation of the hole, without damage to the laminate, is important to meaningful results. Damage caused by hole preparation will affect strength results and can reduce the calculated strength.

6.3 *Fastener Head Style and Countersink*—Results are affected by the head style of the fastener utilized. In general,

specimens containing protruding head fasteners exhibit the highest pull-through resistance forces, followed by (in order of decreasing pull-through resistance forces) 100° tension head fasteners, 100° shear head fasteners, and 130° shear head fasteners. Results may also be affected by the ratio of countersunk (flush) head depth to thickness; the preferred ratio is the range from 0.0 to 0.7 unless the experiment is investigating the influence of this ratio.

6.4 *Fastener-Hole Clearance*—Results are affected by the clearance arising from the difference between hole and fastener diameters. Excess clearance can change the observed specimen behavior by promoting the onset of sub-critical failures, due to a decrease in the effective area of the composite which reacts the pull-through load. Damage due to insufficient clearance during fastener installation will affect strength results. For these reasons, both the hole and fastener diameters must be accurately measured and recorded. A typical aerospace tolerance on fastener-hole clearance is +75/-0 µm [+0.003/-0.000 in.] for structural fastener holes.

6.5 *Countersink Flushness*—Countersink flushness (depth or protrusion of the fastener head in a countersunk hole) will affect strength results and may affect the observed failure mode. Countersunk head fasteners shall be installed within ±0.1 mm [±0.005 in.] from the composite surface, unless otherwise specified.

6.6 *Thickness*—Results are affected by the thickness of the specimen and the ratio of hole diameter to thickness. Fastener pull-through resistance is typically proportional to the thickness of the specimen. The preferred ratio of hole diameter to thickness is the range from 1.5 to 3.0 unless the experiment is investigating the influence of this ratio. Additionally, for both procedures the composite plate(s) must have sufficient thickness, flexural stiffness and flexural strength to transmit the fixture loading without excessive plate bending, flexural failure or bearing damage.

6.7 *Fastener Torque/Pre-load*—Results are affected by the installed fastener pre-load (clamping pressure), as this force must be overcome initially by the application of tensile loading to the fastener.

6.8 *Geometry*—Results are affected by the ratio of loading bar spacing to fastener hole diameter for Procedure A tests, and by the ratio of clearance hole diameter to fastener hole diameter for Procedure B tests. The ratio should be maintained as specified in Tables 1 and 2, unless the experiment is investigating the influence of this ratio.

6.9 *Test Fixture Characteristics*—The configuration of the test fixture can have a significant effect on test results. For Procedure A, friction between the composite plates and loading posts (resulting from plate flexure or hole misalignment) can cause force measurement errors and affect test results. For Procedure B, the configuration of the yoke, and its ability to minimize the applied moment to the test specimen, can affect test results. Additionally, for Procedure B the diameter of the clearance hole can affect the degree of bending in the composite plate.