



Designation: D 6484/D 6484M – 99^{e1}

Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates¹

This standard is issued under the fixed designation D 6484/D 6484M; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

^{e1} NOTE—The designation was editorially corrected to make it a dual designation in November 2000.

1. Scope

1.1 This test method determines the open-hole compressive strength of multidirectional polymer matrix composite laminates reinforced by high-modulus fibers. The composite material forms are limited to continuous-fiber or discontinuous-fiber (tape or fabric, or both) reinforced composites in which the laminate is balanced and symmetric with respect to the test direction. The range of acceptable test laminates and thicknesses are described in 8.2.1.

1.2 *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.*

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

2. Referenced Documents

2.1 ASTM Standards:

- D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement²
- D 883 Terminology Relating to Plastics²
- D 2584 Test Method for Ignition Loss of Cured Reinforced Resins³
- D 2734 Test Method for Void Content of Reinforced Plastics³
- D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials⁴
- D 3171 Test Method for Fiber Content of Resin-Matrix

Composites by Matrix Digestion⁴

- D 3878 Terminology of High-Modulus Reinforcing Fibers and Their Composites⁴
- D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials⁴
- D 5687/D 5687M Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation⁴
- E 4 Practices for Force Verification of Testing Machines⁵
- E 6 Terminology Relating to Methods of Mechanical Testing⁵
- E 83 Practice for Verification and Classification of Extensometers⁵
- E 122 Practice for Choice of Sample Size to Estimate a Measure of Quality for a Lot or Process⁶
- E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods⁶
- E 456 Terminology Relating to Quality and Statistics⁶
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁶
- E 1309 Guide for Identification of Composite Materials in Computerized Material Property Databases⁴
- E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases⁴
- E 1471 Guide for Identification of Fibers, Fillers, and Core Materials in Computerized Material Property Databases⁴

3. Terminology

3.1 *Definitions*—Terminology D 3878 defines terms relating to high-modulus fibers and their composites. Terminology D 883 defines terms relating to plastics. Terminology E 6 defines terms relating to mechanical testing. Terminology E 456 and Practice E 177 define terms relating to statistics. In the event of a conflict between terms, Terminology D 3878 shall have precedence over the other terminologies.

3.2 *Definitions of Terms Specific to This Standard:*

NOTE 1—If the term represents a physical quantity, its analytical

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.

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² *Annual Book of ASTM Standards*, Vol 08.01.

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

⁴ *Annual Book of ASTM Standards*, Vol 15.03.

⁵ *Annual Book of ASTM Standards*, Vol 03.01.

⁶ *Annual Book of ASTM Standards*, Vol 14.02.

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, $[\theta]$ for thermodynamic temperature, and $[nd]$ for nondimensional 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.

3.2.1 *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.

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

3.2.3 *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 *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 *specially orthotropic, adj*—a description of an orthotropic material as viewed in its principal material coordinate system. In laminated composites, a specially orthotropic laminate is a balanced and symmetric laminate of the $[0_i/90_j]_{ns}$ family as viewed from the reference coordinate system, such that the membrane-bending coupling terms of the laminate constitutive relation are zero.

3.3 Symbols:

A —cross-sectional area of a coupon

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

B_z —edgewise percent bending

D —hole diameter

h —coupon thickness

n —number of coupons per sample population

N —number of plies in laminate under test

F_x^{ohcu} —ultimate open hole (notched) compressive strength in the test direction

P_{max} —maximum load carried by test coupon before failure

S_{n-1} —standard deviation statistic of a sample population for a given property

w —coupon width

x_1 —test result for an individual coupon from the sample population for a given property

\bar{x} —mean or average (estimate of mean) of a sample population for a given property

σ —normal stress

4. Summary of Test Method

4.1 A uniaxial compression test of a balanced, symmetric laminate is performed with a centrally located hole. Edge-mounted extensometer displacement transducers are optional. Ultimate strength is calculated based on the gross cross-sectional area, disregarding the presence of the hole. While the hole causes a stress concentration and reduced net section, it is common aerospace practice to develop notched design allowable strengths based on gross section stress to account for various stress concentrations (fastener holes, free edges, flaws, damage, and so forth) not explicitly modeled in the stress analysis.

4.2 The test specimen is face-supported in a multipiece bolted support fixture. The specimen/fixture assembly is clamped in hydraulic wedge grips and the load is sheared into the support fixture and then sheared into the test specimen.

4.3 The only acceptable failure mode for ultimate open-hole compressive strength is one which passes through the hole in the test specimen.

5. Significance and Use

5.1 This test method is designed to produce notched compressive strength data for structural design allowables, material specifications, research and development, and quality assurance. Factors that influence the notched compressive strength and should therefore be reported include the following: material; methods of material fabrication; accuracy of lay-up; laminate stacking sequence and overall thickness; specimen geometry; specimen preparation (especially of the hole); specimen conditioning; environment of testing; specimen alignment and gripping; speed of testing; void content; and volume percent reinforcement. Properties that may be derived from this test method include open-hole (notched) compressive strength (OHC).

6. Interferences

6.1 *Hole Preparation*—Because of the dominating presence of the notch, and the lack of need to measure the material response, results from this test method are relatively insensitive to parameters that would be of concern in an unnotched compressive property test. However, since the notch 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. Some types of damage, such as delaminations, can blunt the stress concentration caused by the hole, increasing the load-carrying capacity of the coupon and the calculated strength.

6.2 *Geometry*—Results are affected by the ratio of specimen width to hole diameter; this ratio should be maintained at 6, unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of hole diameter to thickness; the preferred ratio is the range from 1.5 to 3.0 unless the experiment is investigating the influence of this ratio. Results may also be affected by the ratio of ungripped

specimen length to specimen width; this ratio should be maintained at 2.7, unless the experiment is investigating the influence of this ratio.

6.3 *Support Fixture*—Results are affected by the amount of lateral pressure applied to the test specimen by the support fixture. Sources of variation in this lateral pressure include fixture bolt torque, hydraulic gripping pressure, and fixture shimming choices, and should be controlled and reported as required in the Procedure and Report sections.

6.4 *Material Orthotropy*—The degree of laminate orthotropy strongly affects the failure mode and measured OHC strength. Valid OHC strength results should only be reported when appropriate failure modes are observed, in accordance with 11.10.

6.5 *Thickness Scaling*—Thick composite structures do not necessarily fail at the same strengths as thin structures with the same laminate orientation (that is, strength does not always scale properly). Thus, data gathered using this test method may not translate directly into equivalent thick-structure properties.

7. Apparatus

7.1 *Micrometers*—The micrometer(s) shall use a 4- to 5-mm [0.16- to 0.20-in.] nominal diameter ball-interface on irregular surfaces such as the bag-side of a laminate, and a flat anvil interface on machined edges or very smooth-tooled surfaces. The accuracy of the instrument(s) shall be suitable for reading to within 1 % of the sample width and thickness. For typical specimen geometries, an instrument with an accuracy of $\pm 25 \mu\text{m}$ [$\pm 0.001 \text{ in.}$] is desirable for thickness measurement, while an instrument with an accuracy of $\pm 76 \mu\text{m}$ [$\pm 0.003 \text{ in.}$] is desirable for width measurement. Additionally, a micrometer

or gage capable of determining the hole diameter to $\pm 25 \mu\text{m}$ [$\pm 0.001 \text{ in.}$] is required.

7.2 *Support Fixture*—The fixture is a face-supported compressive test fixture as shown in Fig. 1. The fixture consists of two short-grip/long-grip assemblies, two support plates, and stainless steel shims as required to maintain a nominally zero (0.00- to 0.12-mm [0.000- to 0.005-in.] tolerance) gap between support plates and long grips. If this gap does not meet the minimum requirement, shim the contact area between the support plate and the short grip with stainless steel shim stock. If the gap is too large, shim between the support plate and the long grip, holding the shim stock on the support plate with tape. Fig. 2 shows shim requirements. The fixture should be checked for conformity to engineering drawings. Each short-grip/long-grip assembly is line-drilled as shown in Figs. 3 and 4 and must be used as a matched set. The threading of the support plate is optional. Standard test specimens are 36 by 300 mm [1.5 by 12 in.]. The fixture is hydraulically gripped on each end and the compressive load is sheared by means of friction through the fixture and into the test specimen. A cutout exists on both faces of the fixture for a thermocouple, fastener, or extensometer, if required by the requesting organization. The long and short fixtures have an undercut along the corner of the specimen grip area so that specimens are not required to be chamfered and to avoid damage caused by the radius. The fixtures also allow a slight clearance between the fixture and the gage section of the specimen, in order to minimize grip failures and friction effects. This fixture does not allow specimens to be end loaded.

7.2.1 *Support Fixture Details*—The detailed drawings for manufacturing the support fixture are contained in Figs. 5-12.

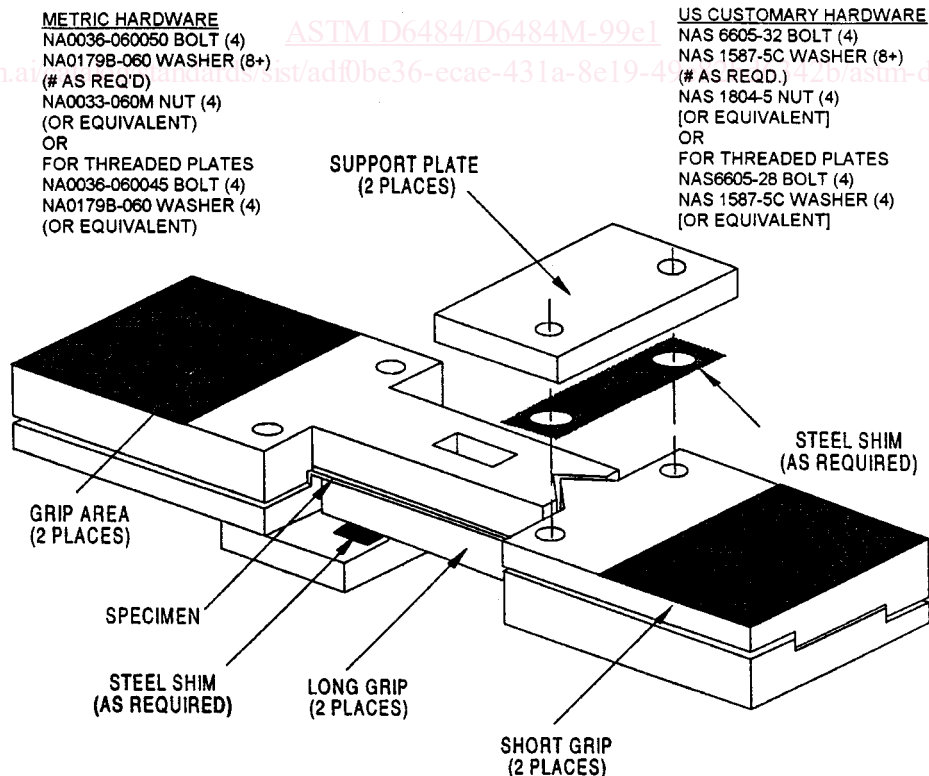


FIG. 1 Support Fixture Assembly

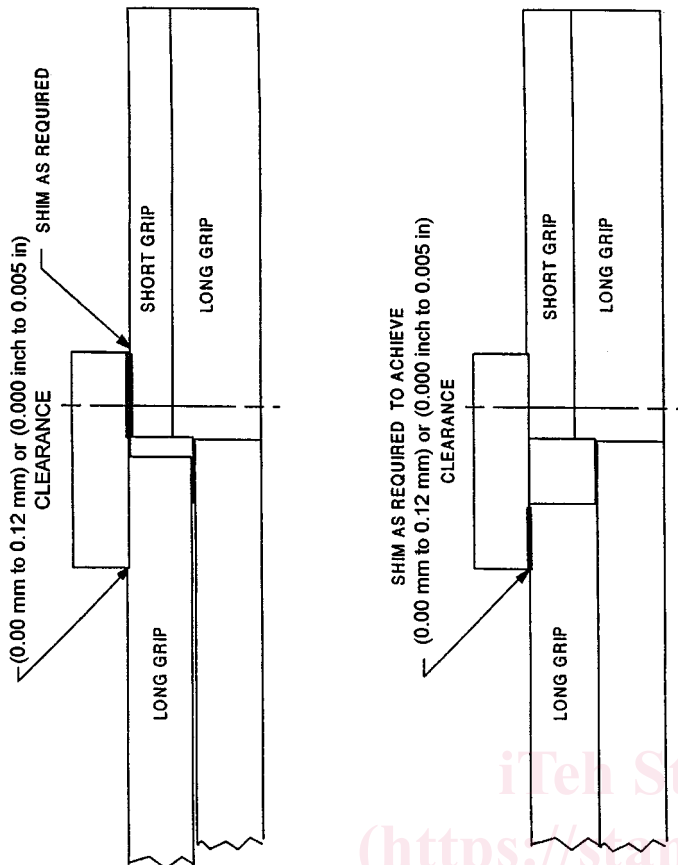
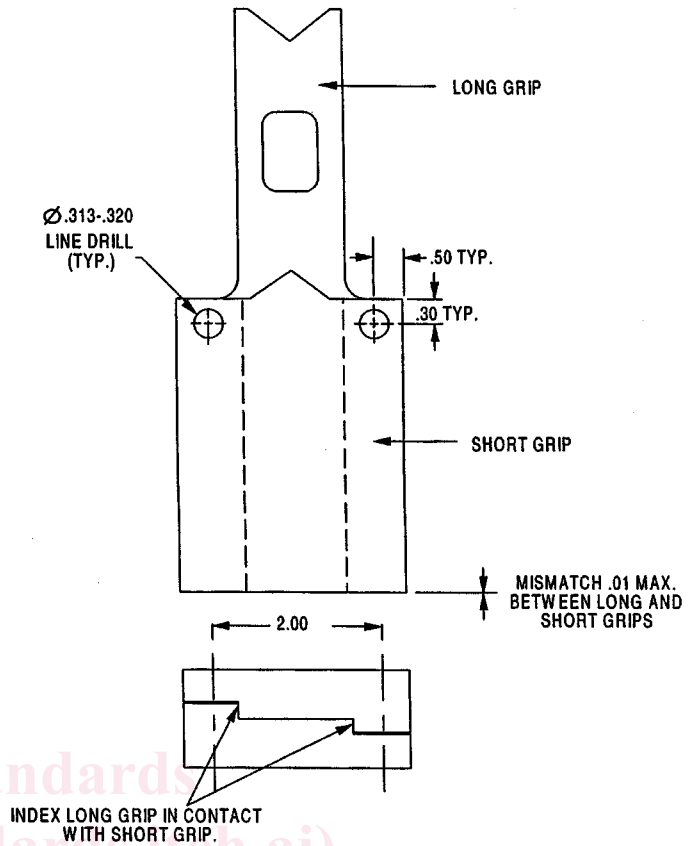


FIG. 2 Support Fixture—Shim Requirements



INDEX LONG GRIP IN CONTACT WITH SHORT GRIP.

NOTE 1—

- (a) All dimensions in inches.
- (b) The long grip and short grip should be part marked with a unique test fixture assembly identification.
- (c) Tolerance except as noted is linear ± 0.01 in.

FIG. 3 Support Fixture—Line Drilling Details (Inch-Pound Version)

An optional threaded support plate is shown in Figs. 13 and 14, to be used instead of the support plate shown in Figs. 11 and 12 and the nuts called out in Fig. 1. Other fixtures that meet the requirements of this section may be used (for example, MTS Open Hole Compressive Fixture Model 605.21A or Wyoming Test Fixtures, Inc. Models CU-OH and WTF-OH). The following general notes apply to these figures:

7.2.1.1 Machine surfaces to a 3.2 [125] finish unless otherwise specified.

7.2.1.2 Break all edges.

7.2.1.3 Specimen-gripping area shall be thermal sprayed using high-velocity oxygen fueled (HVOF), electrospark deposition (ESD), or equivalent process.

7.2.1.4 The test fixture may be made of low-carbon steel for ambient temperature testing. For non-ambient environmental conditions, the recommended fixture material is a nonheat-treated ferritic or precipitation-hardened stainless steel (heat treatment for improved durability is acceptable but not required).

NOTE 2—Experience has shown that fixtures may be damaged in use, thus periodic reinspection of the fixture dimensions and tolerances is important.

7.3 Testing Machine—The testing machine shall be in accordance with Practices E 4 and shall satisfy the following requirements:

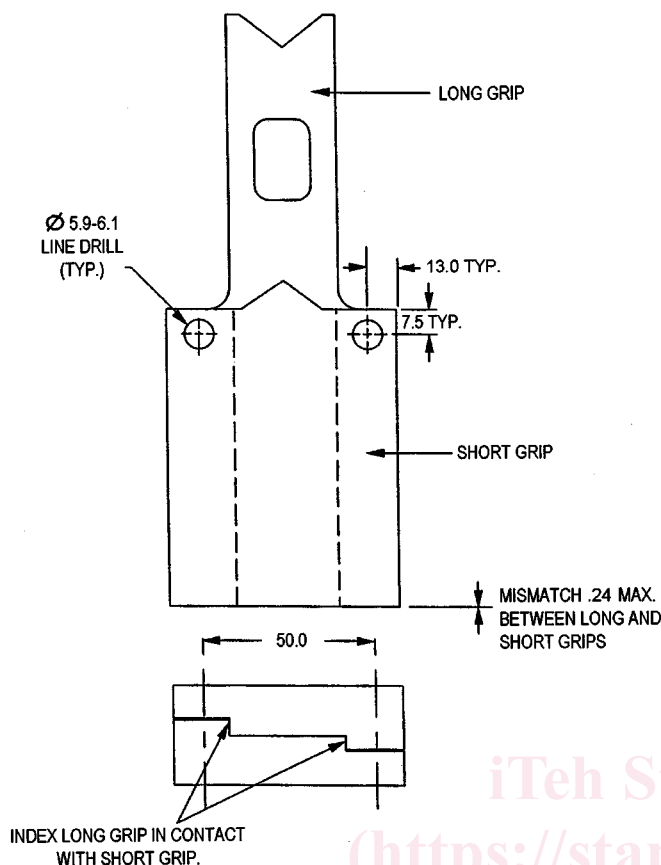
7.3.1 Testing Machine Configuration—The testing machine shall have both an essentially stationary head and a movable head. A short loading train and rigidly mounted hydraulic grips shall be used.

7.3.2 Grips—Each head of the testing machine shall be capable of holding one end of the test assembly so that the direction of load applied to the specimen is coincident with the longitudinal axis of the specimen. Hydraulic wedge grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the support fixture.

7.3.3 Drive Mechanism—The testing machine drive mechanism shall be capable of imparting to the movable head a controlled velocity with respect to the stationary head. The velocity of the movable head shall be capable of being regulated in accordance with 11.4.

7.3.4 Load Indicator—The testing machine load-sensing device shall be capable of indicating the total load being carried by the test specimen. This device shall be essentially free from inertia lag at the specified rate of testing and shall indicate the load with an accuracy over the load range(s) of interest of within $\pm 1\%$ of the indicated value.

7.3.5 Extensometers—The extensometer gage length shall be 25 mm [1.0 in.]. Extensometers shall satisfy, at a minimum,



NOTE 1—

- (a) All dimensions in mm.
- (b) The long grip and short grip should be part marked with a unique test fixture assembly identification.
- (c) Tolerance except as noted is linear ± 0.24 mm.

FIG. 4 Support Fixture—Line Drilling Details (SI Version)

Practice E 83, Class B-1 requirements for the strain range of interest, and shall be calibrated over that range in accordance with Practice E 83. The extensometers shall be essentially free of inertia lag at the specified speed of testing.

7.4 *Conditioning Chamber*—When conditioning materials at non-laboratory environments, a temperature/vapor-level controlled environmental conditioning chamber is required that shall be capable of maintaining the required temperature to within $\pm 3^\circ\text{C}$ [$\pm 5^\circ\text{F}$] and the required relative humidity level to within $\pm 3\%$. Chamber conditions shall be monitored either on an automated continuous basis or on a manual basis at regular intervals.

7.5 *Environmental Test Chamber*—An environmental test chamber is required for test environments other than ambient testing laboratory conditions. This chamber shall be capable of maintaining the gage section of the test specimen at the required test environment during the mechanical test.

8. Sampling and Test Specimens

8.1 *Sampling*—Test at least five specimens per test condition unless valid results can be gained through the use of fewer specimens, as in the case of a designed experiment. For statistically significant data, consult the procedures outlined in Practice E 122. Report the method of sampling.

8.2 Geometry:

8.2.1 *Stacking Sequence*—The standard tape and fabric laminates shall have multidirectional fiber orientations (fibers shall be oriented in a minimum of two directions), and balanced and symmetric stacking sequences. The nominal thickness shall be 4 mm [0.160 in.], with a permissible range from 3 to 5 mm [0.125 to 0.200 in.], inclusive. Fabric laminates containing satin-type weaves shall have symmetric warp surfaces, unless otherwise specified and noted in the report.

NOTE 3—Typically, a $[45_i/-45_j/0_k]_{ms}$ tape or $[45_i/0_j]_{ms}$ fabric laminate should be selected such that a minimum of 5% of the fibers lay in each of the four principal orientations. This laminate design has been found to yield the highest likelihood of acceptable failure modes.

8.2.2 *Specimen Configuration*—The geometry of the coupon is shown in Figs. 15 and 16.

8.3 *Specimen Preparation*—Guide D 5687/D 5687M provides recommended specimen preparation practices and should be followed where practical.

8.3.1 *Panel Fabrication*—Control of fiber alignment is critical. Improper fiber alignment will reduce the measured properties. The panel must be flat and of uniform thickness to ensure even loading. Erratic fiber alignment will also increase the coefficient of variation. Report the panel fabrication method.

8.3.2 *Machining Methods*—Specimen preparation is extremely important for this specimen. Take precautions when cutting specimens from plates to avoid notches, undercuts, rough or uneven surfaces, or delaminations due to inappropriate machining methods. Obtain final dimensions by water-lubricated precision sawing, milling, or grinding. The use of diamond tooling has been found to be extremely effective for many material systems. Edges should be flat and parallel within the specified tolerances. Holes should be drilled undersized and reamed to final dimensions. Take special care to ensure that creation of the specimen hole does not delaminate or otherwise damage the material surrounding the hole. Machining tolerances and surface finish requirements are as noted in Figs. 15 and 16. Record and report the specimen cutting and hole preparation methods.

8.3.3 *Labeling*—Label the coupons 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.

9. Calibration

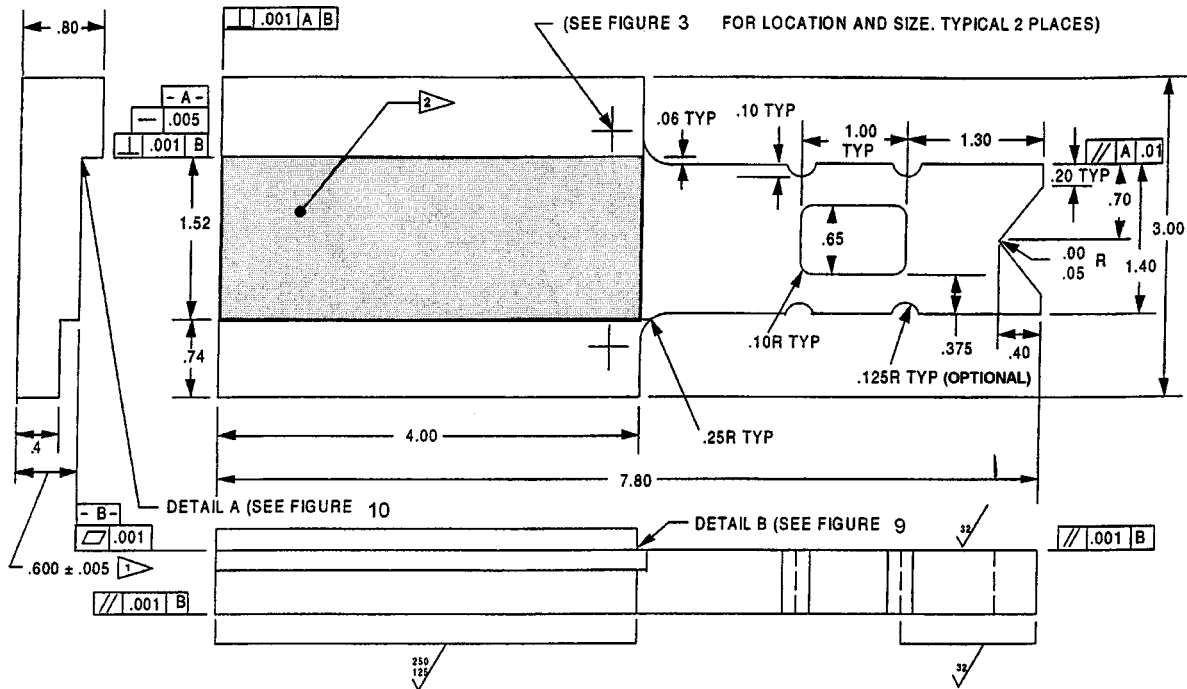
9.1 The accuracy of all measuring equipment shall have certified calibrations that are current at the time of use of the equipment.

10. Conditioning

10.1 *Standard Conditioning Procedure*—Unless a different environment is specified as part of the experiment, condition the test specimens in accordance with Procedure C of Test Method D 5229/D 5229M, and store and test at standard laboratory atmosphere ($23 \pm 3^\circ\text{C}$ [$73 \pm 5^\circ\text{F}$] and $50 \pm 10\%$ relative humidity).

11. Procedure

11.1 *Parameters to Be Specified Before Test:*

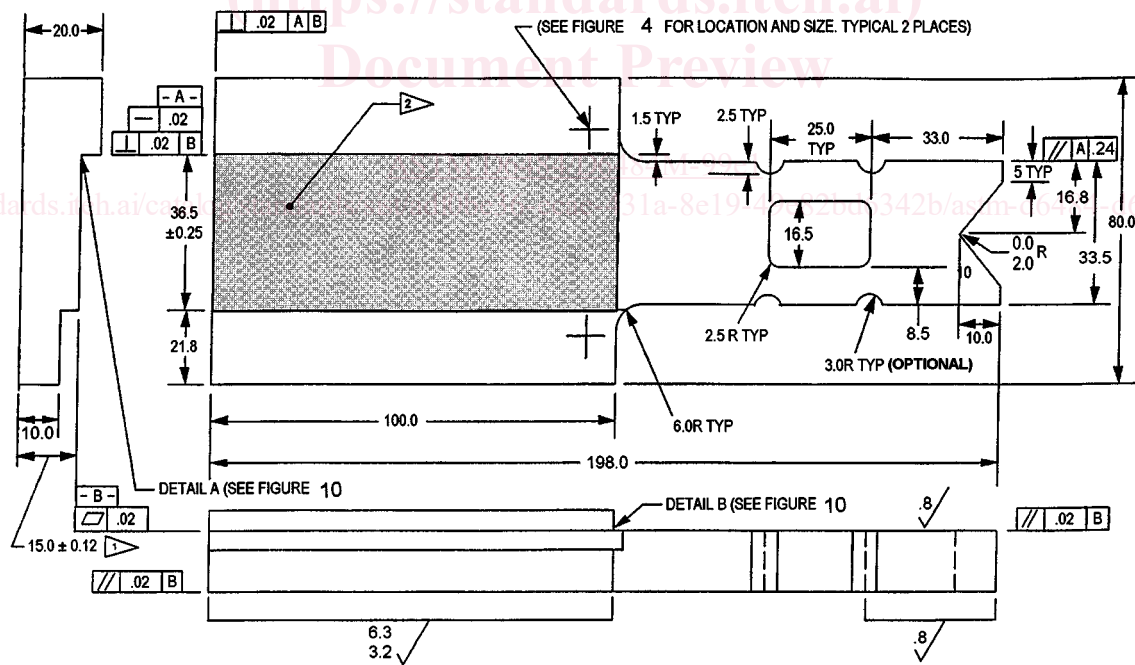


NOTE 1—See 7.2.1 for general notes.

(Flag symbol 1) For existing fixtures this dimension is 0.60 ± 0.02 ; however, all four fittings must be within ± 0.005 of each other.

(Flag symbol 2) Thermal spray surface using either high velocity oxygen fueled (HVOF) process or electrospark deposition (ESD) process.

FIG. 5 Support Fixture—Long Grip Details (Inch-Pound Version)



NOTE 1—See 7.2.1 for general notes.

(Flag symbol 1) For existing fixtures this dimension is 15 ± 0.5 ; however, all four fittings must be within ± 0.12 of each other.

(Flag symbol 2) Thermal spray surface using either high velocity oxygen fueled (HVOF) process or electrospark deposition (ESD) process.

FIG. 6 Support Fixture—Long Grip Details (SI Version)

11.1.1 The specimen sampling method, coupon type and geometry, and conditioning travelers (if required).

11.1.2 The compressive properties and data reporting format desired.