Designation: D7616/D7616M – 11 (Reapproved 2023)

# Standard Test Method for Determining Apparent Overlap Splice Shear Strength Properties of Wet Lay-Up Fiber-Reinforced Polymer Matrix Composites Used for Strengthening Civil Structures [1]

This standard is issued under the fixed designation D7616/D7616M; 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 describes the requirements for sample preparation and tensile testing of single-lap shear splices formed with fiber-reinforced polymer (FRP) composite materials commonly used for strengthening of structures made of materials such as metals, timber, masonry, and reinforced concrete. The objective of this method is to determine the apparent shear strength of an overlap splice joint through the application of a far-field tensile force. The method applies to wet lay-up FRP material systems fabricated on site or in a laboratory setting. The FRP composite may be of either unidirectional (0°) or cross-ply (0/90 type) reinforcement. For cross-ply laminates, the construction may be achieved using multiple-layers of unidirectional fibers at either 0 or 90°, or one or more layers of stitched or woven 0/90 fabrics. The composite material forms are limited to continuous fiber or discontinuous fiber-reinforced composites in which the laminate is balanced and symmetric with respect to the test direction. The method is often used to determine the length of the overlap splice needed to ensure that a tension failure occurs in the material away from the splice rather than the splice connection itself.

1.2 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 non-conformance with the standard.

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

1.3 *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.*

1.4 *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]

D883 Terminology Relating to Plastics

D3039/D3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials

D3878 Terminology for Composite Materials

D4896 Guide for Use of Adhesive-Bonded Single Lap-Joint Specimen Test Results

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

D7565/D7565M Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures

E6 Terminology Relating to Methods of Mechanical Testing

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

[1] This test method is under the jurisdiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.10 on Composites for Civil Structures.

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[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.

2.2 *Other Standards:*[3]

DOT/FAA/AR-01/33 Investigation of Thick Bondline Adhesive Joints, June 2001

DOT/FAA/AR-02/97 Shear Stress-Strain Data for Structural Adhesives, November 2002

## 3. Terminology

3.1 *Definitions*—Terminology D3878 defines terms relating to high-modulus fibers and their composites. 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 *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 *screed, v*—to move a flat rule along the top of a saturated laminate to level the top of the laminate and simultaneously remove excess resin.

3.2.3 *wet lay-up FRP composite, n*—an FRP composite material fabricated by manually impregnating dry fibers with a matrix of polymeric resin. Semi-automated processes such as machine-aided wetting of fabrics before placement or vacuum aided impregnation of laminates after placement are considered part of wet lay-up FRP. For civil infrastructure strengthening applications, the degree of control over the volume fractions of fibers, matrix, and voids as well as the overall cross-sectional geometry in wet lay-up FRP composites may be less than that for shop manufactured FRP composites on account of the manual process. For strengthening applications, wet lay-up FRP composites are typically applied to the substrate at the same time the dry fiber is impregnated. The impregnating resin may act as the saturant for the FRP composite as well as the bonding agent between the composite reinforcement and the substrate. Wet lay-up specimens may be fabricated in either a field or a laboratory setting.

3.3 *Symbols:*

3.3.1 $F^*$—strength of FRP laminate per unit width.

3.3.2 $h_1$—laminate thickness measured outside of the overlap splice on the bottom (flat) laminate.

3.3.3 $h_2$—laminate thickness measured outside of the overlap splice on the top (kinked) laminate.

3.3.4 $h_3$—laminate thickness measured within the overlap splice region.

3.3.5 $h'$ —the reference thickness of a fiber, fabric or preform layer without resin, measured outside of the overlap splice.

3.3.6 $L$—entire length of the overlap splice specimen including the portion dedicated to gripping.

3.3.7 $L'$—length of the overlap splice region

3.3.8 $n$—number of specimens.

3.3.9 $P$—force carried by test specimen.

3.3.10 $P^{max}$—maximum tensile force.

3.3.11 $w$—coupon width.

3.3.12 $V^*$—apparent shear strength of the overlap splice per unit width for the L' under consideration.

## 4. Summary of Test Method

4.1 Overlap splice specimens are prepared using a wet lay-up procedure. Wet lay-up material may be prepared in a laboratory or field setting, as the testing objectives dictate. For testing in single shear, two thin, flat strips of material having a nominally constant cross section are joined together with a specified overlap and allowed to cure. The cured specimen is mounted in the grips of a mechanical testing machine and monotonically loaded in tension while force is recorded. The following items are reported for each specimen: ultimate force at failure, failure mode, and the apparent shear strength per unit width at failure.

## 5. Significance and Use

5.1 Overlap splices are used in field applications of FRP composites when site conditions prohibit continuous access to a structural element or when the specified length of the FRP composite is such that saturation and placement of the entire length would be cumbersome. This method can be used as a quality control mechanism for ensuring that overlap splices constructed under field conditions meet or exceed the requirements established by the design engineer or FRP system manufacturer. Both the saturant mixing and fiber saturation method can be verified for wet-layup FRP systems.

5.2 Caution is recommended when interpreting apparent shear strength results obtained from this method. Single shear lap splices develop non-uniform shear stress distributions within the overlap splice region during testing. Additional guidance on the interpretation and use of results obtained from lap shear testing is found in D4896.

5.3 This test method focuses on the FRP material itself, irrespective of gripping method. Therefore, strengths resulting from failure or pullout at either grip are disregarded. The strength measurements are based solely on test specimens that fail in the gauge section (away from the grips) or at the splice.

## 6. Interferences

6.1 A summary of the interferences, specifically material and specimen preparation, gripping, system alignment, and edge effects in cross-ply laminates, are presented in D3039/D3039M.

6.2 Additional interferences may arise from lack of control in wet lay-up specimen preparation procedures outlined in 8.3.1. Specimen variations in resin content, ply thickness, void content and degree of cure may contribute to variability in test results.

6.3 Construction of single lap-splice samples using wet-lay FRP will result in kinked fibers for the top laminate (see Fig.

[3] Available at the Federal Aviation Administration William J. Hughes Technical Center Full-Text Technical Reports page: http://207.67.203.68/F10011.

1). The effects of this kink on lap shear results will be magnified as the thickness, $h_1$ and $h_2$, of the FRP increases. This kink may also result in laminate failure outside the region of the bondline and the severity of the kink can impart moment loading to the bonded joint.

6.4 Overlap splice length, *L'*, is identified in D4896, 5.3.2 as a geometric parameter which affects apparent shear strength properties obtained from overlap splice tests. The results obtained using this test method are valid exclusively for the overlap splice length under consideration.

6.5 If a supplementary adhesive material (for example, thickened epoxy tack coat) is used to promote bond between composite layers within the overlap splice region, it should be noted that variations in the bond-line thickness may result in different apparent shear strength values or different failure modes. The typically observed trend is that increasing bondline thickness results in decreased apparent shear strength (DOT/FAA/AR-01/33 and DOT/FAA/AR-02/97).

6.6 The fiber/ply orientation within the overlap splice region has also been shown to influence the apparent shear strength or failure mode, or both, in lap shear specimens (DOT/FAA/AR-02/97).

6.7 The temperature and moisture conditions experienced by a specimen during curing and load testing can affect the apparent shear strength of an overlap splice joint. Additional guidance is provided in D3039/D3039M, 11.4.

## 7. Apparatus

7.1 Requirements for testing machines and instrumentation are the same as those given in D3039/D3039M, Section 7.

## 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, such as in the case of a designed experiment. For statistically significant data, the procedures outlined in Practice E122 shall be consulted. Report the method of sampling.

NOTE 1—If specimens are to undergo environmental conditioning to equilibrium, and are of such type or geometry that the weight change of the material cannot be properly measured by weighing the specimen itself (such as a tabbed mechanical coupon), then use another traveler coupon of the same nominal thickness and appropriate size (but without tabs) to determine when equilibrium has been reached for the specimens being conditioned.

8.2 *Geometry*—Recommended geometries for single shear specimens are provided in Fig. 2.

8.2.1 *Splice Length*—The desired overlap splice length shall be specified. A designed experiment may involve the testing of groups of specimens with varying overlap splice lengths. See Table 1 for recommended overall specimen lengths for varying overlap splice lengths. Variation in the overlap splice length as measured along both edges of the specimen shall be no greater than ± 5 %.

8.2.2 *Specimen Width*—Minimum specimen width for unidirectional wet lay-up FRP specimens shall be 25 mm [1.0 in.]. Minimum width for cross-ply specimens shall be 38 mm [1.5 in.] for wet lay-up composites. Variation in specimen width shall be no greater than ± 1 %.

8.3 *Specimen Preparation:*

8.3.1 *Wet Lay-up FRP*—Make field-prepared specimens in a manner similar to the actual field installation of the material. A polymer release film, typically 600 mm by 600 mm [24 in. by 24 in.] is placed on a smooth, flat horizontal surface. The release film shall be at least 0.076 mm [0.003 in.] thick and made of a polymer that will not adhere to the resin used to impregnate the fibers. Usually, acetate and nylon are acceptable. Resin is first applied to the release film. The dimensions of each ply should be no less than 150 mm by 300 mm [6 in. by 12 in.] (or longer as required by the specimen size, see Fig. 2). In order to facilitate the construction of the overlap splice joint and to ensure the desired overlap splice length, *L'*, is obtained, the width of the bottom laminate may be slightly larger (5 mm to 10 mm) than the width of the top laminate. Any excess material present in the bottom laminate shall be removed and discarded during the specimen machining process described in 8.3.4. The dry fibers are saturated or coated with the specified amount of resin and placed on the release film. This can be done using a properly calibrated saturator machine or using a manufacturer-specified fiber to resin weight ratio. The specified number of plies at the specified angles (0 or 90°) for the bottom laminate of the single lap splice are sequentially impregnated with resin and stacked onto the release film using the specified amount of resin per ply per unit area as in the actual installation. Using the flat edge of a small hand tool or a grooved roller, air bubbles are worked out of the material. The bubbles shall be worked out in the direction of the primary fibers to ensure that no damage is caused to the fibers. At this point the specified number of plies for the top laminate of the lap splice are sequentially impregnated with resin and stacked onto a second piece of release film. If a supplementary adhesive material is specified, it shall be applied uniformly to both saturated laminates in the region of the overlap splice as in the actual installation. One of the saturated laminates is then placed on top of the other overlapping the bottom portion by the specified overlap splice distance, *L'*. If the release film on the top laminate does not extend past the entire length of the bottom laminate, the release film on the top laminate shall be removed and replaced with a longer piece such that the entire specimen is protected. An alternative method to eliminate air bubbles is to use the flat edge of a small paddle on the outer

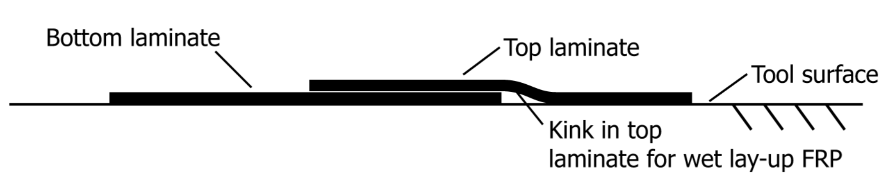


**FIG. 1 Interference in Wet-Lay FRP Sample due to Kink in Top Laminate**