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Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate[1]

This standard is issued under the fixed designation D7522/D7522M; 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 apparatus and procedure for evaluating the pull-off strength of wet lay-up or pultruded (shop-fabricated) Fiber Reinforced Polymer (FRP) laminate systems adhesively bonded to a flat concrete substrate. The test determines the greatest perpendicular force (in tension) that an FRP system can bear before a plug of material is detached. Failure will occur along the weakest plane within the system comprised of the test fixture, FRP laminate, adhesive and substrate.

1.2 This test method is primarily used for quality control and assessment of field repairs of structures using adhesive-applied composite materials.

1.3 This test method is appropriate for use with FRP systems having any fiber orientation or combination of ply orientations comprising the FRP laminate.

1.4 This test method is not appropriate for use as an "acceptance" or "proof" wherein the FRP system remaining intact at a prescribed force is an acceptable result.

1.5 Pull-off strength measurements depend upon both material and instrumental parameters. Different adhesion test devices and procedures will give different results and cannot be directly compared.

1.6 This test method can be destructive. Spot repairs may be necessary. The test method will result in an exposed cut FRP section; repair methods must consider the potential for moisture uptake through this cut section.

1.7 Prior to the installation of some adhesively bonded FRP systems, the substrate concrete must be patched (often to replace lost concrete volume). This test method is not appropriate for determining the pull-off strength of the FRP from the patch material. An additional test method is required to determine the pull-off strength of the patch from the substrate concrete. Throughout this standard, "substrate" is understood to mean the concrete or concrete patch material to which the FRP is adhered.

1.8 The values stated in either SI units or inch-pound units are to be regarded 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.

1.9 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C125 Terminology Relating to Concrete and Concrete Aggregates

D883 Terminology Relating to Plastics

D3878 Terminology for Composite Materials

D5229/D5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials

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

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 C125 defines terms relating to concrete. In the event of a conflict between terms, Terminology D3878 shall have precedence over the other standards.

[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.

3.2 *Symbols:*
3.2.1 *D*—diameter of the loading fixture.
3.2.2 F_p—pull-off force.
3.2.3 σ_p—pull-off bond stress.

4. Summary of Test Method

4.1 The pull-off test is performed by securing a circular loading fixture (dolly) normal (perpendicular) to the flat surface of the FRP laminate with an affixing adhesive. An adhesion testing device is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is gradually increased and monitored until a plug of material is detached exposing the plane of limiting strength within the system. The nature of the failure is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The pull-off strength is computed based on the maximum indicated force, the instrument calibration data, and the original surface area stressed. Pull-off strength results using different devices may vary, as results are sensitive to test device parameters.

5. Significance and Use

5.1 The pull-off strength of a bonded FRP system is an important performance property that has been used in specifications, particularly those for assessing the quality of an application. This test method serves as a means for uniformly preparing and testing bonded FRP systems, and evaluating and reporting the results.

5.2 Variations in results obtained using different devices are possible. Therefore, it is recommended that the type of adhesion test device (including manufacturer and model) be mutually agreed upon between the interested parties.

5.3 This test method is intended for use in both the field and the laboratory.

5.4 The basic material properties obtained from this test method can be used in the control of the quality of adhesives and in the theoretical equations for designing FRP systems for external reinforcement to strengthen existing structures.

6. Interferences

6.1 *Material and Specimen Preparation*—Improper preparation of the surface of the composite material before bonding the circular loading fixture is known to cause premature failures at this interface. Improper curing of the bonding adhesive can also cause failure at this interface. Non-uniform FRP or FRP-to-substrate adhesive thickness in one specimen can affect an individual test result and lead to non-symmetric or mixed-mode failure pattern. Variation in FRP or adhesive thickness between specimens can cause biased or scattered test results. Improper fixturing of the hole cutter relative to the specimen can lead to a non-circular hole or damage to the FRP composite/substrate interface around the perimeter of the hole. This can cause biased or scattered test results and non-symmetric or mixed-mode failure patterns. Misalignment between the circular test fixture and the drilled circle can also lead to biased or scattered test results and non-symmetric or mixed-mode failure patterns.

6.2 *Adhesion Testing Device*—Improper alignment of the adhesion tester grip (see 7.1.3) can lead to biased or scattered test results and non-symmetric or mixed-mode failure patterns. Variation in the rate of loading between specimens can cause biased or scattered test results.

6.3 *Environmental Conditions at Time of Testing*—Testing at non-standard temperature or relative humidity may affect the test results. Specimens tested in field conditions should be noted as such.

7. Apparatus

7.1 *Adhesion Test Device,* commercially available, or comparable apparatus conforming to the following specifications. A specific example of an appropriate commercially available tester is provided in Annex A1.

7.1.1 The tester is comprised of detachable circular loading fixtures, screws with spherical heads that are screwed into the center of a fixture, a socket in the testing assembly that holds the head of the screw, pressure gage or dynamometer, and a mechanical or hydraulic means of applying the force in a controlled manner.

7.1.2 *Loading Fixtures,* having a minimum diameter of 50 mm [2.0 in.], a flat surface on one end that can be adhered to the FRP surface and a means of attachment to the tester on the other end.

7.1.3 *Adhesion Tester Grip,* having a central grip for engaging the loading fixture in a manner such that the resultant force is normal to the FRP surface (typically achieved with a spherical head bearing).

7.1.4 *Adhesion Tester Base,* permitting a uniform bearing against the FRP surface to react the test force.

7.1.5 Means of moving the grip away from the base in as smooth and continuous a manner as possible so that a torsion-free, co-axial (opposing pull of the grip and push of the base along the same axis) force results between them.

7.1.6 *Timer,* or means of limiting the rate of stress applied to the FRP-concrete interface being tested to less than or equal to 1 MPa/min. [150 psi/min.]. A timer is the minimum equipment when used by the operator along with the force indicator in 7.1.7.

7.1.7 *Force Indicator and Calibration Information,* for determining the actual force delivered to the loading fixture.

7.2 *Loading Fixture Bonding Adhesive,* for securing the fixture to the FRP laminate such that laminate properties are not affected. The bonding adhesive must have a tensile capacity greater than the expected tensile capacity of the FRP system and the concrete substrate and be sufficient to mitigate a Failure Mode A (see 12.2.1). Two component epoxies have been found to be appropriate.

7.3 *Circular Hole Cutter,* having an inside diameter equal to that of the loading fixture to score through the FRP laminate into the substrate around the loading fixture. The hole cutter must not damage the FRP laminate while scoring through it; therefore a thin-walled diamond grit hole saw is appropriate. In most cases a center drill arbor may be used to facilitate the scoring operation without affecting test results.