



Designation: D4541 – 22

Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers¹

This standard is issued under the fixed designation D4541; 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 covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating system from metal substrates. Pull-off strength of coatings from concrete is described in Test Method D7234. This test offers two test protocols. Protocol 1 (test to fracture) determines the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached. Protocol 2 (pass/fail) determines if the coated surface remains intact at a defined load criteria. Fracture will occur along the weakest plane within the system comprised of the test fixture, glue, coating system, and substrate, and will be exposed by the fracture surface. This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scratch or knife adhesion, and results may not be comparable.

NOTE 1—The procedure in this standard was developed for metal substrates, but may be appropriate for other rigid substrates such as plastic and wood. Factors such as loading rate and flexibility of the substrate must be addressed by the user/specifier.

NOTE 2—The procedure in this standard was developed for use on flat surfaces. The results could have greater variability with lower values and averages for surfaces other than flat.

1.2 Pull-off strength measurements depend upon material, instrumentation and test parameters. Results obtained by each test method may give different results. Results should only be assessed for each test method and not be compared with other instruments. There are five instrument types, identified as Test Methods B-F. It is imperative to identify the test method used when reporting results.

NOTE 3—Method A, which appeared in previous versions of this standard, has been eliminated as its main use is for testing on concrete substrates (see Test Method D7234).

1.3 This test method describes a class of apparatus known as portable pull-off adhesion testers.² They are capable of applying a concentric load and counter load to a single surface so

that coatings can be tested even though only one side is accessible. Measurements are limited by the strength of adhesive bonds between the loading fixture and the specimen surface or the cohesive strengths of the glue, coating layers, and substrate.

1.4 This test can be destructive and spot repairs may be necessary.

1.5 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.

1.6 *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:*³

D2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding

D3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)

D7234 Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

¹ This test method is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coatings.

Current edition approved July 1, 2022. Published July 2022. Originally approved in 1993. Last previous edition approved in 2017 as D4541 – 17. DOI: 10.1520/D4541-22.

² The term adhesion tester may be somewhat of a misnomer, but its adoption by two manufacturers and at least two patents indicates continued usage.

³ 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.

*A Summary of Changes section appears at the end of this standard

3. Summary of Test Method

3.1 The general pull-off test is performed by securing a loading fixture (dolly, stud) normal (perpendicular) to the surface of the coating with a glue. After the glue is cured, a testing apparatus is attached to the loading fixture and aligned to apply tension normal to the test surface. The force applied to the loading fixture is then gradually and uniformly increased and monitored until either the loading fixture is detached, or a specified load value is reached and the test terminated. The two common uses of this test are test to fracture (Protocol 1), and pass/fail testing (Protocol 2). Test to fracture is used to determine a maximum load that can be achieved when a plug of material is detached with the selected testing parameters. Pass/fail is used to verify the results of a testing procedure can meet a minimum load criterion. When the loading fixture is detached, the exposed surface represents the plane of limiting strength within the system. The nature of the plane of fracture is qualified in accordance with the percent of adhesive and cohesive failures, and the actual interfaces and layers involved. The reported load is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Results obtained using different test devices will vary because the results depend on instrumentation parameters. Variations in results are also expected when tests are performed under different test procedures or environmental conditions (see 4.2).

4. Significance and Use

4.1 The pull-off strength of a coating is a performance property that may be referenced in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the results. This test method is applicable to any portable apparatus meeting the requirements for determining the pull-off strength of a coating in this standard (see [Annex A1 – Annex A5](#)).

4.2 Variations in results with the same coating are likely when any parameter of the test is changed. This includes change in glue, load fixture size, substrate coating cure time, pull rate, environmental conditions, if the coating is scored, or using a different device. Therefore, when a series of results will be compared with one another or used for statistical analysis, the type of apparatus, substrate, test procedures, glue type, and if scoring is used should be the same for the pulls considered.⁴ It is recommended that these parameters and the environmental conditions allowed during the test be mutually agreed upon between the interested parties.

4.3 The purchaser or specifier shall designate a specific test method procedure; B, C, D, E, or F and test Protocol; 1, or 2, when calling out this standard. In cases where either the Protocol or a pass/fail criterion is not designated, Protocol 1 shall be used.

5. Apparatus

5.1 *Adhesion Tester*, commercially available, or comparable apparatus to the specific examples listed in [Annex A1 – Annex A5](#).

5.1.1 *Loading Fixtures*, having a flat surface on one end that can be adhered to the coating and a means of attachment to the tester on the other end. Optimal size of the loading fixture is determined by the adhesion tester capabilities. The fixture and tester combination should be chosen so that the expected maximum pull load the coating will be subjected to during the test is within the range of the tester.

5.1.2 *Detaching Assembly* (adhesion tester), having a central grip for engaging the fixture.

5.1.3 *Base*, on the detaching assembly, or an annular bearing ring if needed for uniformly pressing against the coating surface around the fixture either directly, or by way of an intermediate bearing ring. A means of aligning the base is needed so that the resultant force is normal to the surface.

5.1.4 Means of moving the grip away from the base to allow the loading of the fixture in as smooth and uniform a manner as possible and 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.

5.1.5 *Timer*, or means of limiting the loading rate. A timer is the minimum equipment when used by the operator along with the force indicator in 5.1.6.

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

5.2 *Solvent*, or other means for cleaning the loading fixture surface. Finger prints, moisture, oxides, and dust tend to be the primary contaminants.

5.3 *Sandpaper*, or other means, used to roughen the surfaces for glue application and adherence to the coating. When using sandpaper it is recommended to use 100 grit or finer.

5.4 *Glue*—the material used for securing the loading fixture to the coating. Two component epoxies and cyanoacrylates are two commonly used glues. Select a glue that does not affect the coating properties, flow through the coating or attack the coating.

5.5 *Clamps*, magnetic, mechanical, tape or similar, if needed for holding the fixture in place while the glue cures.

5.6 *Cotton Swabs*, or other means for removing excess glue and defining the adhered area. Any method for removing excess glue that damages the surface, such as scoring (see 6.7), must generally be avoided since induced surface flaws may cause premature failure of the coating.

5.7 *Scoring Tool*, circular hole cutter, or similar tool to score the coating to the substrate around the loading fixture.

6. Test Preparation

6.1 The method for selecting the coating sites to be prepared for testing depends upon the objectives of the test and agreements between the contracting parties. There are, however, a few physical restrictions imposed by the general method and apparatus. The following requirements apply to all sites:

⁴ Reference to potential variability of the adhesion test has been made in various publications, including the assessment of variability completed for the test method found in ASTM Research Report RR:D01-1147.