Standard Test Method for
Pull-Off Strength of Coatings Using Portable Adhesion Testers[1]

This standard is issued under the fixed designation D 4541; 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.

ε[1] NOTE—Research report added editorially in August 1995.

1. Scope

1.1 This test method covers a procedure for evaluating the pull-off strength (commonly referred to as adhesion) of a coating by determining either the greatest perpendicular force (in tension) that a surface area can bear before a plug of material is detached, or whether the surface remains intact at a prescribed force (pass/fail). Failure will occur along the weakest plane within the system comprised of the test fixture, adhesive, 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. Further, pull-off strength measurements depend upon both material and instrumental parameters. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

1.2 This test method uses 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 adhesion bonds between the loading fixture and the specimen surface or the cohesive strengths of the adhesive, coating layers, and substrate.

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

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.5 *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:*
D 2651 Guide for Preparation of Metal Surfaces for Adhesive Bonding[3]
D 3933 Guide for Preparation of Aluminum Surfaces for Structural Adhesives Bonding (Phosphoric Acid Anodizing)[3]
D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[4]
2.2 *ANSI Standard:*
N512 Protective Coatings (Paints) for the Nuclear Industry[5]
2.3 *ISO Standard:*
4624 Paints and Varnish—Pull-Off Test for Adhesion[5]

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 an adhesive. After the adhesive 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 increased and monitored until either a plug of material is detached, or a specified value is reached. When a plug of material is detached, the exposed surface represents 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 load, the instrument calibration data, and the original surface area stressed. Pull-off strength results obtained using different devices may be different because the results depend on instrumental parameters (see Appendix X1).

4. Significance and Use

4.1 The pull-off strength of a coating is an important performance property that has been used in specifications. This test method serves as a means for uniformly preparing and testing coated surfaces, and evaluating and reporting the

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[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.46 on Industrial Protective Coating.
Current edition approved Feb. 15, 1995. Published April 1995. Originally published as D 4541 – 93. Last previous edition D 4541 – 93.
[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] *Annual Book of ASTM Standards*, Vol 15.06.
[4] *Annual Book of ASTM Standards*, Vol 06.01.
[5] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

results. This test method is applicable to any portable apparatus meeting the basic requirements for determining the pull-off strength of a coating.

4.2 Variations in results obtained using different devices or different substrates with the same coating are possible (see Appendix X1). Therefore, it is recommended that the type of apparatus and the substrate be mutually agreed upon between the interested parties.

5. Apparatus

5.1 *Adhesion Tester*, commercially available, or comparable apparatus specific examples of which are listed in Annex A1-Annex A4.

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.

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 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.

5.1.5 *Timer*, or means of limiting the rate of stress to less than 150 psi/s (1 MPa/s) so that the maximum stress is obtained in less than about 100 s. A timer is the minimum equipment when used by the operator along with the force indicator in 5.1.6.

NOTE 1—Obtaining the maximum stress in 100 s or less by keeping the maximum rate of shear to less than 150 psi/s (1 MPa/s) is valid for the levels of pull-off strength measured with these types of apparatuses.

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, and oxides tend to be the primary contaminants.

5.3 *Fine Sandpaper*, or other means of cleaning the coating that will not alter its integrity by chemical or solvent attack. If any light sanding is anticipated, choose only a very fine grade abrasive (400 grit or finer) that will not introduce flaws or leave a residue.

5.4 *Adhesive*, for securing the fixture to the coating that does not affect the coating properties. Two component epoxies[6] and acrylics[7] have been found to be the most versatile.

5.5 *Magnetic or Mechanical Clamps*, if needed, for holding the fixture in place while the adhesive cures.

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[6] Araldite Adhesive, available from Ciba-Geigy Plastics, Duxford, Cambridge, CB2 4QA, England, Hysol Epoxy Patch Kit 907, available from Hysol Div., The Dexter Corp., Willow Pass Rd., Pittsburg, CA 94565, and Scotch Weld Adhesive 1838B/A, available from 3M, Adhesives, Coatings amd Sealers Div., 3M Center, St. Paul, MN 55144, have been found satisfactory for this purpose.

[7] Versiloc 201 and 204 with accelerator, available from Lord Corp., Industrial Adhesive Div., 2000 W. Grandview Blvd., P.O. Box 10038, Erie, PA 16514, have been found satisfactory for this purpose.

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

5.7 *Circular Hole Cutter* (optional), to score through 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:

6.1.1 The selected test area must be a flat surface large enough to accommodate the specified number of replicate tests. The surface may have any orientation with reference to gravitational pull. Each test site must be separated by at least the distance needed to accommodate the detaching apparatus. The size of a test site is essentially that of the secured loading fixture. At least three replications are usually required in order to statistically characterize the test area.

6.1.2 The selected test areas must also have enough perpendicular and radial clearance to accommodate the apparatus, be flat enough to permit alignment, and be rigid enough to support the counter force. It should be noted that measurements close to an edge may not be representative of the coating as a whole.

6.2 Since the rigidity of the substrate affects pull-off strength results and is not a controllable test variable in field measurements, some knowledge of the substrate thickness and composition should be reported for subsequent analysis or laboratory comparisons. For example, steel substrate of less than $\frac{1}{8}$-in. (3.2-mm) thickness usually reduce pull-off strength results compared to $\frac{1}{4}$-in. (6.4-mm) thick steel substrates.

6.3 Subject to the requirements of 6.1, select representative test areas and clean the surfaces in a manner that will not affect integrity of the coating or leave a residue. Surface abrasion may introduce flaws and should generally be avoided. A fine abrasive (see 5.3) should only be used if needed to remove loose or weakly adhered surface contaminants.

6.4 Clean the loading fixture surface as indicated by the apparatus manufacturer. Failures at the fixture-adhesive interface can often be avoided by treating the fixture surfaces in accordance with an appropriate ASTM standard practice for preparing metal surfaces for adhesive bonding.

NOTE 2—Guides D 2651 and D 3933 are typical of well-proven methods for improving adhesive bond strengths to metal surfaces.

6.5 Prepare the adhesive in accordance with the adhesive manufacturer's recommendations. Apply the adhesive to the fixture or the surface to be tested, or both, using a method recommended by the adhesive manufacturer. Be certain to apply the adhesive across the entire surface. Position fixture on the surface to be tested. Carefully remove the excess adhesive from around the fixture.

NOTE 3—**Caution:** Movement, especially twisting, can cause tiny bubbles to coalesce into large holidays that constitute stress discontinuities during testing.

6.6 Based on the adhesive manufacturer's recommendations

and the anticipated environmental conditions, allow enough time for the adhesive to set up and reach the recommended cure. During the adhesive set and early cure stage, a constant contact pressure should be maintained on the fixture. Magnetic or mechanical clamping systems work well, but systems relying on tack, such as masking tape, should be used with care to ensure that they do not relax with time and allow air to intrude between the fixture and the test area.

6.7 Scoring around the fixture violates the fundamental in-situ test criterion that an unaltered coating be tested. If scoring around the test surface is employed, extreme care is required to prevent micro-cracking in the coating, since such cracks may cause failures at diminished strengths. Scored samples constitute a different test, and this procedure should be clearly reported with the results.

6.8 Note the approximate temperature and relative humidity during the time of test.

7. Test Procedure

7.1 The general procedure for conducting pull-off tests is described in this section. More specific procedures are given in Annex A1-Annex A4 for the types of testers used in the round-robin.

7.2 Select an adhesion-tester with a detaching assembly having a force calibration spanning the range of expected values along with its compatible loading fixture. Mid-range measurements are usually the best, but read the manufacturer's operating instructions before proceeding.

7.3 If a bearing ring or comparable device (5.1.3) is to be used, place it concentrically around the loading fixture on the coating surface. If shims are required when a bearing ring is employed, place them between the tester base and bearing ring rather than on the coating surface.

7.4 Carefully connect the central grip of the detaching assembly to the loading fixture without bumping, bending, or otherwise prestressing the sample and connect the detaching assembly to its control mechanism, if necessary. For nonhorizontal surfaces, support the detaching assembly so that its weight does not contribute to the force exerted in the test.

7.5 Align the device according to the manufacturer's instructions and set the force indicator to zero.

Note 4—Proper alignment is critical, see Appendix X2. If alignment is required, use the procedure recommended by the manufacturer of the adhesion tester and report the procedure used.

7.6 Increase the load to the fixture in as smooth and continuous a manner as possible, at a rate of less than 150 psi/s (1 MPa/s) so that failure occurs or the maximum stress is reached in about 100 s or less (see Note 1).

7.7 Record the force attained at failure or the maximum force applied.

7.8 If a plug of material is detached, label and store the fixture for qualification of the failed surface in accordance with 8.3.

7.9 Report any departures from the procedure such as possible misalignment, hesitations in the force application, etc.

8. Calculation and Interpretation of Results

8.1 If instructed by the manufacturer, use the instrument calibration factors to convert the indicated force for each test

into the actual force applied in units of pounds-force (1 N = 0.1 kgf).

8.2 Either use the calibration chart supplied by the manufacturer or compute the relative stress applied to each coating sample as follows:

$$X = 4F/\pi d^2 \qquad (1)$$

where:
X = greatest mean pull-off stress applied during a pass/fail test, or the pull-off strength achieved at failure. Both have units of psi (MPa = 1 N/mm^2).
F = actual force applied to the test surface as determined in 8.1, and
d = equivalent diameter of the original surface area stressed having units of inches (or millimetres). This is usually equal to the diameter of the loading fixture.

8.3 For all tests to failure, estimate the percent of adhesive and cohesive failures in accordance to their respective areas and location within the test system comprised of coating and adhesive layers. A convenient scheme that describes the total test system is outlined in 8.3.1 through 8.3.3. (See ISO 4624.)

Note 5—A laboratory tensile testing machine is used in ISO 4624.

8.3.1 Describe the specimen as substrate A, upon which successive coating layers B, C, D, etc., have been applied, including the adhesive, Y, that secures the fixture, Z, to the top coat.

8.3.2 Designate cohesive failures by the layers within which they occur as A, B, C, etc., and the percent of each.

8.3.3 Designate adhesive failures by the interfaces at which they occur as A/B, B/C, C/D, etc., and the percent of each.

8.4 A result that is very different from most of the results may be caused by a mistake in recording or calculating. If either of these is not the cause, then examine the experimental circumstances surrounding this run. If an irregular result can be attributed to an experimental cause, drop this result from the analysis. However, do not discard a result unless there are valid nonstatistical reasons for doing so or unless the result is a statistical outlier. Valid nonstatistical reasons for dropping results include alignment of the apparatus that is not normal to the surface, poor definition of the area stressed due to improper application of the adhesive, poorly defined glue lines and boundaries, holidays in the adhesive caused by voids or inclusions, improperly prepared surfaces, and sliding or twisting the fixture during the initial cure. Scratched or scored samples may contain stress concentrations leading to premature fractures. Dixon's test, as described in Practice D 3980, may be used to detect outliers.

8.5 Further information relative to the interpretation of the test results is given in Appendix X2.

9. Report

9.1 Report the following information:

9.1.1 Brief description of the general nature of the test, such as, field or laboratory testing, generic type of coating, etc.

9.1.2 Temperature and relative humidity and any other pertinent environmental conditions during the test period.

9.1.3 Description of the apparatus used, including: apparatus manufacturer and model number, loading fixture type and dimensions, and bearing ring type and dimensions.

9.1.4 Description of the test system, if possible, by the indexing scheme outlined in 8.3 including: product identity and generic type for each coat and any other information supplied, the substrate identity (thickness, type, orientation, etc.), and the adhesive used.

9.1.5 Test results.

9.1.5.1 Date, test location, testing agent.

9.1.5.2 For pass/fail tests, stress applied along with the result, for example, pass or fail and note the plane of any failure (see 8.3 and ANSI N512).

9.1.5.3 For tests to failure, report all values computed in 8.2 along with the nature and location of the failures as specified in 8.3, or, if only the average strength is required, report the average strength along with the statistics.

9.1.5.4 If corrections of the results have been made, or if certain values have been omitted such as the lowest or highest values or others, reasons for the adjustments and criteria used.

9.1.5.5 For any test where scoring was employed, indicate it by placing a footnote superscript beside each data point affected and a footnote to that effect at the bottom of each page on which such data appears. Note any other deviations from the procedure.

10. Precision and Bias [8]

10.1 *Precision*—In an interlaboratory study of this test method, operators made measurements, generally in triplicate but in a few cases in duplicate, on coated panels covering a moderate range at the intermediate adhesion level using four different types of instruments (see Annex A1-Annex A4 and Appendix X1). The number of participating laboratories varied with each instrument and in the case of one instrument with the material. Only two laboratories had access to Type I instruments but two operators in each made the triplicate tests. During the statistical analysis of the results three individual results and one set of triplicates obtained with Type II

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[8] Supporting data are available from ASTM Headquarters. Request RR: D01-1094.

instruments were rejected as outliers; one single test with Type III instruments and three single results with Type I instruments were rejected. The pooled intra- and inter-laboratory coefficients of variation were found to be those shown in Table 1. Based on these coefficients the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

10.1.1 *Replicate Repeatability*—Triplicate results obtained by the same operator using instruments from the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

NOTE 6—Difference in percent relative to two results, x_1 and x_2, is the absolute value of

$$\frac{(x_1 - x_2)}{(x_1 + x_2)/2} \times 100. \qquad (2)$$

10.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by operators in different laboratories using instruments of the same category should be considered suspect if they differ in percent relative by more than the values given in Table 1.

10.2 *Bias*—This test method has no bias statement since there is no acceptable reference material suitable for determining the bias of this test method.

11. Keywords

11.1 adhesion; coatings; field; paint; portable; pull-off strength; tensile test

TABLE 1 Precision of Adhesion Pull-Off Measurements

Instrument	Coefficient of Variation, v, %	Degrees of Freedom	Maximum Acceptable Difference, %
Intralaboratory Instrument:			
Type IV	8.5	48	29.0
Type I			
Type II	12.2	129	41.0
Type III			
Total		177	
Interlaboratory Instrument:			
Type IV	8.7	20	25.5
Type I			
Type II	20.6	58	58.7
Type III			
Total		78	

ANNEXES

(Mandatory Information)

A1. FIXED-ALIGNMENT ADHESION TESTER, TYPE I

A1.1 *Apparatus:*

A1.1.1 A fixed-alignment portable tester as shown in Fig. A1.1[9]

NOTE A1.1—Precision data for Type I instruments described in Table 1 were obtained using the devices illustrated in Fig. A1.1.

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[9] The Dyna Z5 tester is available from PROCEQ SA, Riesbachstrasse 57, CH-8034, Zurich, Switzerland.

A1.1.2 The tester is comprised of detachable aluminum loading fixtures, 1.97 in. (50 mm) in diameter, 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, dynamometer, wheel and crank.

A1.1.3 The testers are available in four models, with maximum tensile forces of 1125, 3375, 5625, and 11 250 lb (5, 15, 25, and 50 kN) respectively. For a fixture having a 1.97-in.
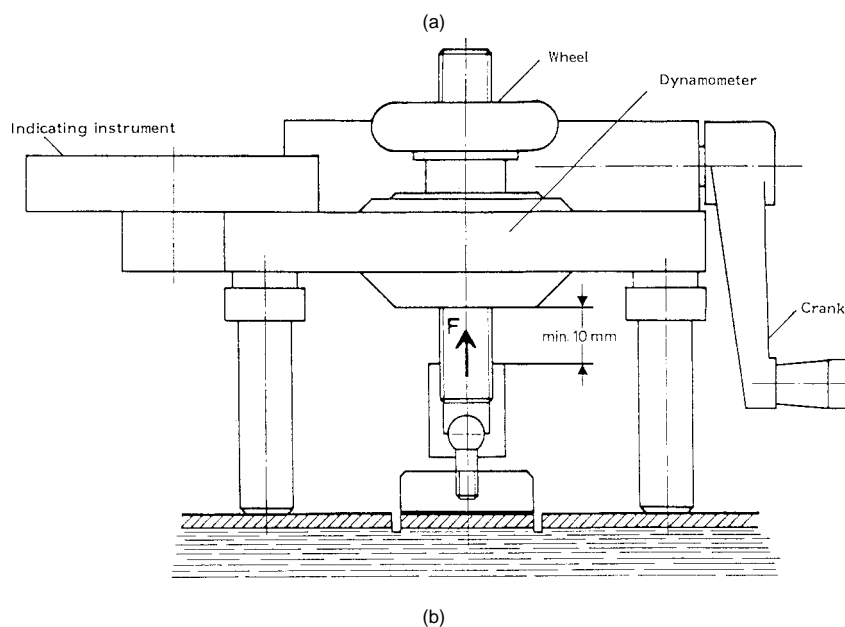
(a)

(b)

FIG. A1.1 Photograph (a) and sketch (b) of Type I instruments

(50-mm) diameter, a 5 kN device corresponds to a range of 0 to 360 psi (2.5 MPa).

A1.2 *Procedure:*

A1.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A1.2.2 Set the pointer on the zero mark by first pressing the push-button located on the left of the indicator. While holding the push-button, turn the little knob located on the upper part of the indicator to set the pointer at zero. Set the zero after testing by pressing the push-button.

A1.2.3 After fixing a loading fixture to a substrate, insert a screw with a spherical head into the center of the fixture. Position the testing equipment on the metal disc. Then by means of the notched wheel, fix the head of the spherical screw into the socket at the base of the equipment. For the first mechanical approach, stop screwing down the wheel when the pointer on the indicator shifts from the ZERO mark. Tests are done by turning the crank. After each test, turn the crank in the opposite direction until it stops.

A2. FIXED-ALIGNMENT ADHESION TESTER TYPE II

A2.1 *Apparatus:*

A2.1.1 This is a fixed-alignment portable tester, as shown in Fig. A2.1.[10]

NOTE A2.1—Precision data for Table 1 were obtained using the devices illustrated in Fig. A2.1.

A2.1.2 The tester is comprised of detachable aluminum loading fixtures having a flat conic base that is 0.8 in. (20 mm) in diameter on one end for securing to the coating, and a circular *T*-bolt head on the other end, a central grip for engaging the loading fixture that is forced away from a tripod base by the interaction of a handwheel (or nut), and a coaxial bolt connected through a series of belleville washers, or springs in later models, that acts as both a torsion relief and a spring that displaces a dragging indicator with respect to a scale.

A2.1.3 The force is indicated by measuring the maximum spring displacement when loaded. Care should be taken to see that substrate bending does not influence its final position or the actual force delivered by the spring arrangement.

A2.1.4 The devices are available in four ranges: From 0 to 500, 0 to 1000, 0 to 2000, and 0 to 4000 psi (3.5, 7.0, 14, and 28 MPa).

A2.2 *Procedure:*

A2.2.1 Center the bearing ring on the coating surface concentric with the loading fixture. Turn the hand wheel or nut of the tester counter-clockwise, lowering the grip so that it slips under the head of the loading fixture.

A2.2.2 Align or shim the three instrument swivel pads of the tripod base so that the instrument will pull perpendicularly to the surface at the bearing ring.

A2.2.3 Take up the slack between the various members and slide the dragging (force) indicator located on the tester to zero.

A2.2.4 Firmly hold the instrument with one hand. Do not allow the base to move or slide during the test. With the other hand, turn the handwheel clockwise using as smooth and constant motion as possible. Do not jerk or exceed a stress rate of 150 psi/s (1 Mpa/s) that is attained by allowing in excess of 7 s/1000 psi (7 s/7 MPa), stress. If the 2000 or 4000 psi (14 or 28 MPa) models are used, the handwheel is replaced with a nut requiring a wrench for tightening. The wrench must be used in a plane parallel to the substrate so that the loading fixture will not be removed by a shearing force or misalignment, thus negating the results. The maximum stress must be reached within about 100 s.

A2.2.5 The pulling force applied to the loading fixture is increased to a maximum or until the system fails at its weakest locus. Upon failure, the scale will rise slightly, while the dragging indicator retains the apparent load. The apparatus scale indicates an approximate stress directly in pounds per square inch, but may be compared to a calibration curve.

(a)

(b)

FIG. A2.1 Photograph (a) and schematic (b) of Type II, Fixed Alignment Pull-Off Tester

A2.2.6 Record the highest value attained by reading along the bottom of the dragging indicator.

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[10] The Elcometer, Model 106, adhesion tester is available from Elcometer Instruments, Ltd., Edge Lane, Droylston, Manchester M35 6UB, United Kingdom, England.
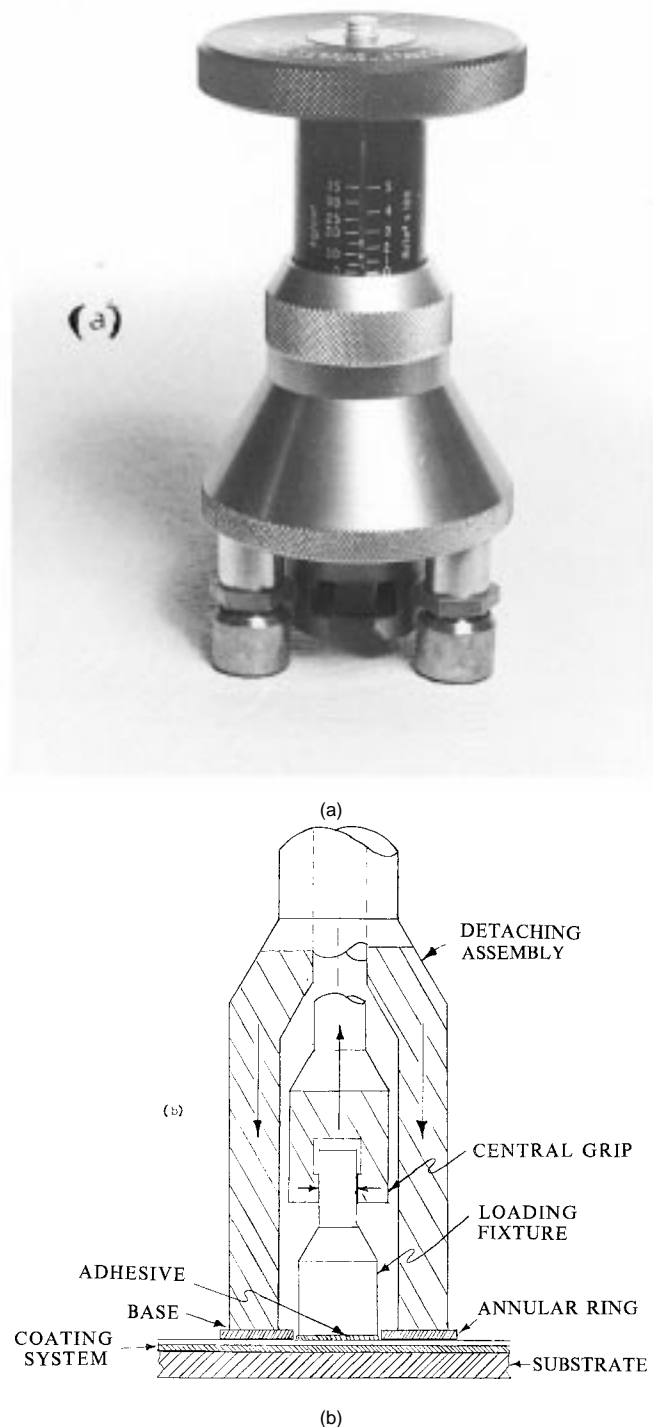
A3. SELF-ALIGNING ADHESION TESTER TYPE III

A3.1 *Apparatus:*

A3.1.1 This is a self-aligning tester, as shown in Fig. A3.1.[11]

NOTE A3.1—Precision data for Type II instruments shown in Table 1 were obtained using the devices described in Fig. A3.1.

A3.1.2 Load is applied through the center of the dolly by a hydraulic piston and pin. The diameter of the piston bore is sized so that the area of the bore is equal to the net area of the dolly. Therefore, the pressure reacted by the dolly is the same as the pressure in the bore and is transmitted directly to a pressure gage.

A3.1.3 The apparatus is comprised of: a dolly, 0.75-in. (19-mm) outside diameter, 0.125-in. (3-mm) inside diameter, hydraulic piston and pin by which load is applied to the dolly, hose, pressure gage, threaded plunger and handle.

A3.1.4 The force is indicated by the maximum hydraulic pressure as displayed on the gage, since the effective areas of the piston bore and the dolly are the same.

A3.1.5 The testers are available in three standard working ranges: 0 to 1500 psi (0 to 10 MPa), 0 to 2250 psi (0 to 15

MPa), 0 to 3000 psi (0 to 20 MPa). Special dollies shaped to test tubular sections are available.

A3.2 *Procedure:*

A3.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to this instrument are described in this section.

A3.2.2 Insert a decreased TFE-fluorocarbon plug into the dolly until the tip protrudes from the surface of the dolly. When applying adhesive to the dolly, avoid getting adhesive on the plug. Remove plug after holding the dolly in place for 10 s.

A3.2.3 Ensure that the black needle of the tester is reading zero. Connect a test dolly to the head and increase the pressure by turning the handle clockwise until the pin protrudes from the dolly. Decrease pressure to zero and remove the test dolly.

A3.2.4 Connect the head to the dolly to be tested, by pulling back the snap-on ring, pushing the head and releasing the snap-on ring. Ensure the tester is held normal to the surface to be tested and that the hose is straight.

A3.2.5 Increase the pressure slowly by turning the handle clockwise until either the maximum stress or failure is reached.

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[11] The Hate Mark VII adhesion tester is available from Hydraulic Adhesion Test Equipment, Ltd., 629 Inlet Rd., North Palm Beach, FL 33408.
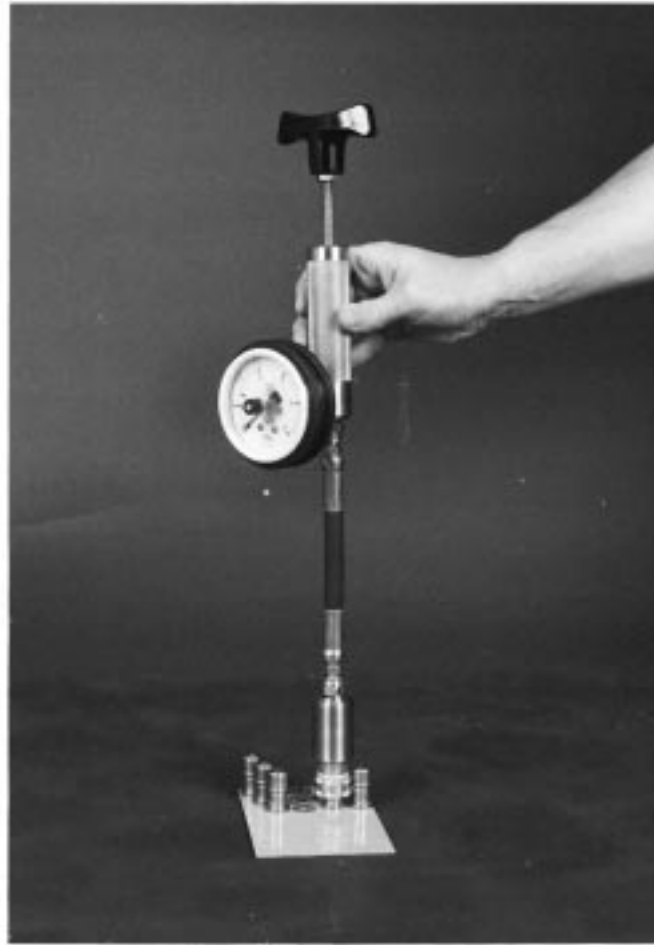
(a)
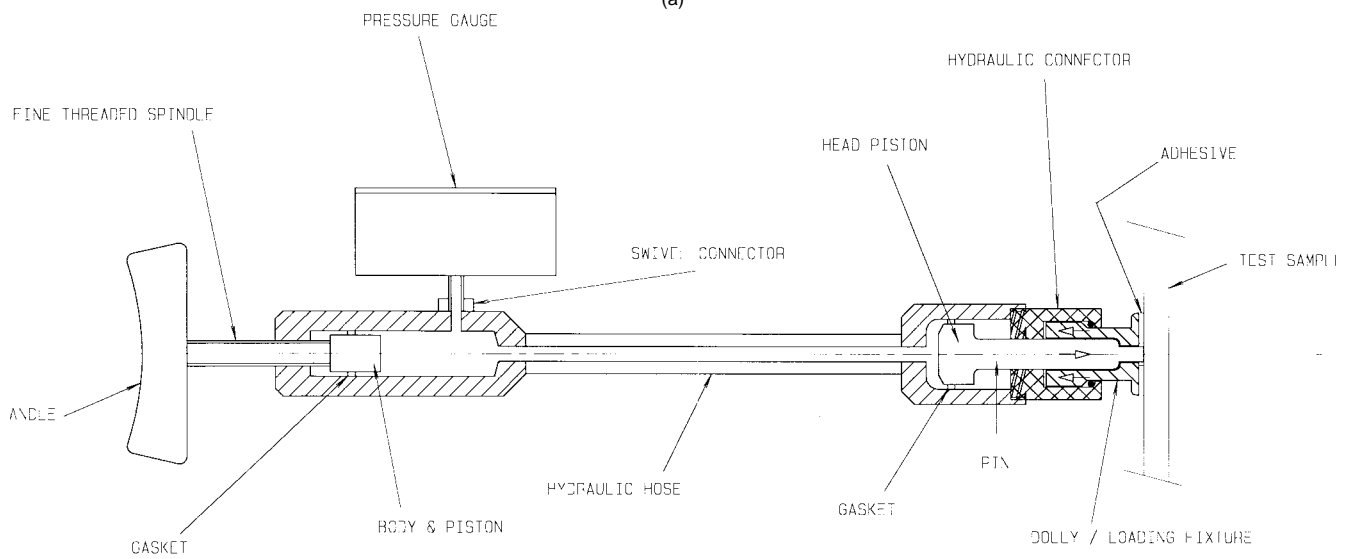
HYDRAULIC ADHESION TESTER

(b)

FIG. A3.1 Photograph (a) and schematic (b) of Type III, Self-Alignment Tester

A4. SELF-ALIGNMENT ADHESION TESTER TYPE IV

A4.1 *Apparatus:*

A4.1.1 This is a self-aligning tester, which may have a self-contained pressure source and has a measuring system that controls a choice of different load range detaching assemblies. It is shown in Fig. A4.1.[12]

NOTE A4.1—Precision data for Type IV instruments shown in Table 1 were obtained using the devices illustrated in Fig. A4.1.

A4.1.2 The apparatus is comprised of: (*1*) a loading fixture having a flat cylindrical base that is 0.5 in. (12.5 mm) in diameter on one end for attachment to the test coating and a cut-off ring used with the fixture to reproducibly define the area of adhesive. The other end of the fixture has 3/8-16 UNC threads; (*2*) a central threaded grip for engaging the loading fixture through the center of the detaching assembly that is forced away by the interaction of a self-aligning seal; and (*3*) a pressurized gas that enters the detaching assembly through a flexible hose connected to a pressurization rate controller and a pressure gage (or electronic sensor).

A4.1.3 The force is indicated by the maximum gas pressure times the active area of the detaching assembly and can be directly calibrated.

A4.1.4 The detaching assemblies are available in six standard ranges in multiples of two from 0 to 500 psi (3.5 MPa) to 10 000 psi (70 MPa). Special ranges are available.

A4.1.5 Three models of control modules that control all ranges of detaching assemblies are available.

A4.2 *Procedure:*

A4.2.1 Follow the general procedures described in Sections 6 and 7. Procedures specific to Type IV testers are described in the following section.

A4.2.2 Position the annular detaching assembly over the fixture attached to the coating to be tested, and loosely engage the fixture via the central threaded grip. Leave at least 1.16-in. (1.6-mm) clearance between the detaching assembly and the bottom of the threaded grip so that the seal can protrude enough to align itself when pressurized.

A4.2.3 Make the appropriate pneumatic connections and open the rate valve 1/4 turn.

A4.2.4 Zero the pressure measuring system.

[12] The PATTI self-alignment adhesion tester is available from SEMicro Corp., 15817 Crabbs Branch Way, Rockville, MD 20855.
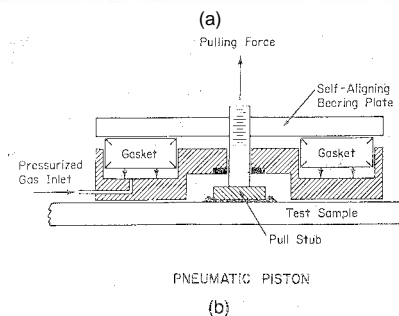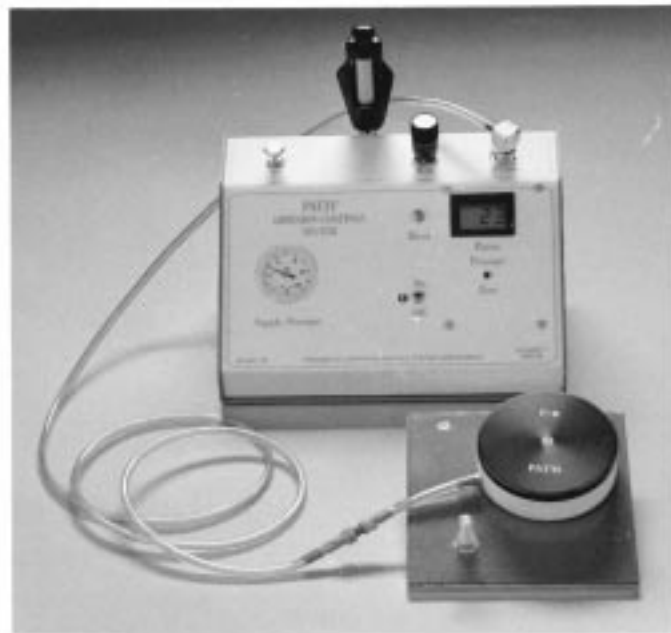

FIG. A4.1 Photograph (a) and schematic of piston (b) of Type IV Self-Alignment Adhesion Tester

A4.2.5 Press the run button to control the gas flow to the detaching assembly and make final adjustment of rate valve so that rate of stress does not exceed 150 psi/s (1 MPa/s) yet reaches its maximum within 100 s.

A4.2.6 Record both the maximum pressure attained and the specific detaching assembly. Conversion to coating stress for ½-in. (12-mm) stud is found in a table supplied for each detaching assembly.

APPENDIXES

(Nonmandatory Information)

X1. INTERLABORATORY PULL-OFF DATA

X1.1 Table X1.1 is a summary of the interlaboratory round-robin data. It is included in this appendix to illustrate the dependence of a pull-off result upon the type of testing device.

TABLE X1.1 Summary of Round-robin Data

Instrument	Type I	Type II	Type III	Type IV
Paint Sample	Mean of Three Results, psi (outliers discarded)			
A	201	586	1185	1160
B	185	674	1157	1099
C	190	827	1245	1333
D	297	888	1686	1678
	Range of Mean Results, psi			
	112	302	529	579

X2. STRESS CALCULATION

X2.1 The stress computed in 8.2 is equal to the uniform pull-off strength of the analogous rigid coating system if the applied force is distributed uniformly over the critical locus at the instant of failure. For any given continuous stress distribution where the peak-to-mean stress ratio is known, the uniform pull-off strength may be approximated as:

$$U = XR_o \qquad (X2.1)$$

where:
U = uniform pull-off strength, representing the greatest force that could be applied to the given surface area, psi (MPa),
X = measured in-situ pull-off strength calculated in 8.2, psi (MPa) and
R_o = peak-to-mean stress ratio for an aligned system.

It is important to note that a difference between these pull-off strengths does not necessarily constitute an error; rather the in-situ measurement simply reflects the actual character of the applied coating system with respect to the analogous ideal rigid system.

X2.2 An error is introduced if the alignment of the apparatus is not normal to the surface. An approximate correction by the peak-to-mean stress ratio is:

$$R = R_o (1 + 0.14 \, az/d), \qquad (X2.2)$$

where:
z = distance from the surface to the first gimbal or the point at which the force and counter force are generated by the action of the driving mechanism, in. (mm),
d = diameter of the loading fixture, in. (mm),
a = angle of misalignment, degrees (less than 5), and
R = maximum peak-to-mean stress ratio for the misaligned rigid system.