Designation: D3359 – 17

Standard Test Methods for Rating Adhesion by Tape Test[1]

This standard is issued under the fixed designation D3359; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 These test methods cover procedures for assessing the adhesion of relatively ductile coating films to metallic substrates by applying and removing pressure-sensitive tape over cuts made in the film.

1.2 Test Method A is primarily intended for use in the field while Test Method B is more suitable for use in laboratory or shop environments. Also, Test Method B is not considered suitable for films thicker than 125µm (5 mils) unless wider spaced cuts are employed and there is an explicit agreement between the purchaser and seller.

1.3 These test methods are used to evaluate whether the adhesion of a coating to a substrate is adequate for the user's application. They do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required.

1.4 This test method is similar in content (but not technically equivalent) to ISO 2409.

1.5 In multicoat systems adhesion failure may occur between coats so that the adhesion of the coating system to the substrate is not determined.

1.6 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.7 *This standard does not purport to address 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]

D609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products

D823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

D1000 Test Methods for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications

D1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting

D2092 Guide for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting (Withdrawn 2008)[3]

D2370 Test Method for Tensile Properties of Organic Coatings

D3330/D3330M Test Method for Peel Adhesion of Pressure-Sensitive Tape

D3924 Specification for Environment for Conditioning and Testing Paint, Varnish, Lacquer, and Related Materials (Withdrawn 2016)[3]

D4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

2.2 *Other Standard:*

ISO 2409 Paint and Varnishes — Cross-cut test[4]

PSTC 101 International Standard for Peel Adhesion of Pressure Sensitive Tape[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] These test methods are under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials, and Applications and are the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

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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] The last approved version of this historical standard is referenced on www.astm.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[5] Available from the Pressure Sensitive Tape Council (PSTC), 1833 Centre Point Circle, Suite 123, Naperville, IL 60563, http://www.pstc.org.

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

3.1.1 *adhesion, n*—the molecular attraction and mechanical bonds between a coating and its substrate.

3.1.2 *batch, n*—as it pertains to tape, a unique production run during manufacturing.

3.1.3 *blemish, n*—an obvious surface flaw, such as cracking or discoloration of the coating.

3.1.4 *environmental conditions, n*—the characteristics of the immediate surroundings during the tests, such as temperature, and relative humidity.

3.1.5 *immersion conditions, n*—the characteristics of the fluid to which the test specimen was exposed, such as type of fluid, temperature of fluid and duration of immersion.

3.1.6 *lap, n*—one complete turn of the tape on a roll; the outer exposed layer of tape.

3.1.7 *lattice pattern, n*—one series of parallel lines intersected by another set of parallel lines that are at 90° to and centered on the first set.

3.1.8 *mean, n*—the classification rating that is obtained by adding together the digits of the classification ratings of the tests performed and dividing by the number of tests, frequently rounded to the nearest whole number classification rating.

3.1.9 *pressure-sensitive tape, n*—tape with an adhesive that requires some degree of pressure, and only pressure, to adequately bond to a surface.

3.1.10 *range, n*—the span of classification ratings for a set of tests, from minimum classification rating to maximum classification rating.

3.1.11 *solvent, n*—a liquid agent capable of dissolving or dispersing contaminants from the surface of the coating or film.

3.1.12 *substrate, n*—the structural foundation beneath the coating or film being tested.

3.1.13 *template, n*—a thin, rigid plate containing evenly distributed, parallel slits for use as a guide in generating the lattice pattern when accompanied by a single-blade cutting tool.

3.1.14 *test specimen, n*—the object whose coatings adhesion is of interest.

4. Summary of Test Methods

4.1 *Test Method A*—An X-cut is made through the film to the substrate, pressure-sensitive tape is applied over the cut and then removed, and adhesion is assessed qualitatively on a 0 to 5 scale.

4.2 *Test Method B*—A lattice pattern with either six or eleven cuts in each direction is made through the film to the substrate, pressure-sensitive tape is applied over the lattice pattern and then removed, and adhesion is assessed qualitatively on a 0 to 5 scale.

4.2.1 Subject to agreement between the purchaser and the seller, Test Method B can be used for films thicker than 125 µm (5 mils) if wider spaced cuts are employed.

5. Significance and Use

5.1 In order for a coating is to fulfill its function of protecting or decorating a substrate, the coating must remain adhered to the substrate. Because the substrate and its surface preparation (or lack thereof) have a drastic effect on the adhesion of coatings, a method to evaluate adhesion of a coating to different substrates or surface treatments, or of different coatings to the same substrate, is of considerable usefulness in the industry.

5.2 This test method is limited to evaluating lower levels of adhesion (see 1.3). The intra- and inter-laboratory precision of this test method is similar to other test methods for coated substrates (for example, Test Method D2370 and Test Method D4060), and is insensitive to all but large differences in adhesion. Limiting the range of rankings from 0 to 5 reflects the inability of this test method to make fine distinctions between levels of adhesion. Users shall not use intermediate values for ranking adhesion tests within this method.

5.3 Extremes in temperatures or relative humidity may affect the adhesion of the tape or the coating.

5.4 A given tape may not adhere equally well to different coatings due to several factors, including differences in coating composition and topology. As such, no single tape is likely to be suitable for testing all coatings. Furthermore, these test methods do not give an absolute value for the force required for bond rupture, but serves only as an indicator that some minimum value for bond strength was met or exceeded (**1, 2**).[6]

5.5 Operators performing these test methods must be trained and practiced in order to obtain consistent results. The accuracy and precision of the test result obtained by using these methods depends largely upon the skill of the operator and the operator's ability to perform the test in a consistent manner. Key steps that directly reflect the importance of operator skill include the angle and rate of tape removal and the visual assessment of the tested sample. It is not unexpected that different operators might obtain different results (**1, 2**).

5.6 The standard requires that the free end of the tape be removed rapidly at as close to a 180° angle as possible. When the peel angle and rate vary, the force required to remove the tape can change dramatically due to the rheological properties of the backing and adhesive. Variation in pull rate and peel angle can effect large differences in test values and must be minimized to assure reproducibility (**3**).

NOTE 1—These test methods have been reported being used to measure adhesion of organic coatings on non-metallic substrates (for example, wood and plastic), although related precision and bias data is lacking. If testing coatings on non-metallic substrates, either Test Method A or Test Method B may be more appropriate and the method employed should be discussed by interested parties. Issues with plastic substrates are noted in Appendix X1. A similar test method, ISO 2409, permits tests on non-metallic substrates (for example, wood and plaster). Precision and bias data on the latter is lacking. Test Method D3359 was developed with

[6] The boldface numbers in parentheses refer to the list of references at the end of this test method.

metal as the substrate and, in the absence of supporting precision and bias data, is so limited.

TEST METHOD A—X-CUT TAPE TEST

6. Apparatus and Materials

6.1 *Cutting Tool*—Sharp razor blade, scalpel, knife or other fine-edged cutting device. The cutting edges shall be in good condition, preferably new or newly sharpened.

6.2 *Cutting Guide*—Steel or other hard metal straightedge to ensure straight cuts.

6.3 *Tape*—25-mm (1.0-in.) wide transparent or semitransparent pressure-sensitive tape with an adhesive peel strength between 6.34 N/cm (58 oz/in.) and 7.00 N/cm (64 oz/in.), as tested in accordance with Test Method D3330/D3330M, Test Method A, (equivalent to PSTC 101) and utilizing a 90 second dwell time on a standard steel panel.

6.3.1 Other tapes may be used by agreement between the parties involved.

6.3.2 Due to variability in adhesion strength from batch-to-batch and changes in adhesion properties of tapes over time, tape from the same batch shall be used when tests are to be run in different laboratories. When use of the same batch is not followed the test method shall be used only for ranking a series of test coatings. Refer to X1.5 for additional information

6.4 *Pressure Application Device*—Although other devices may suffice, a rubber eraser or rubber roller is commonly used to ensure good and uniform wetting of the coating with the adhesive of the tape.

6.5 *Illumination*—A light source is helpful in determining whether the cuts have been made through the film to the substrate.

7. Test Specimens

7.1 When this test method is used in the field, the specimen is the coated structure or article on which the adhesion is to be evaluated.

7.2 For laboratory use apply the materials to be tested to panels of the composition and surface conditions on which it is desired to determine the adhesion.

NOTE 2—Applicable test panel description and surface preparation methods are given in Practice D609 and Practices D1730 and D2092.

NOTE 3—Coatings should be applied in accordance with Practice D823, or as agreed upon between the purchaser and the seller.

NOTE 4—If desired or specified, the coated test panels may be subjected to a preliminary exposure such as water immersion, salt spray, or high humidity before conducting the tape test. The conditions and time of exposure will be governed by ultimate coating use or shall be agreed upon between the purchaser and seller.

8. Procedure

8.1 Select an area free of blemishes and minor surface imperfections. The area chosen for testing shall be clean and dry.

8.1.1 For specimens which have been immersed: After immersion, clean and wipe the surface with an appropriate solvent which will not harm the integrity of the coating. Then dry or prepare the surface, or both, as agreed upon between the purchaser and the seller.

8.2 Make two cuts in the film each about 40 mm (1.5 in.) long that intersect near their middle with a smaller angle of between 30 and 45°. When making the incisions, use the straightedge and cut through the coating to the substrate in one steady motion.

8.3 Inspect the incisions for reflection of light from the metal substrate to establish that the coating film has been penetrated. If the substrate has not been reached make another X in a different location. Do not attempt to deepen a previous cut as this may affect adhesion along the incision.

8.4 At each day of testing, before initiation of testing, remove two complete laps of tape from the roll and discard. Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 75 mm (3 in.) long.

8.5 Place the center of the tape at the intersection of the cuts with the tape running in the same direction as the smaller angles. Smooth the tape into place by finger in the area of the incisions taking care not to entrap air under the tape. Rub firmly over the surface of the tape with the pressure application device until the color is uniform in appearance. This indicates good, uniform contact between the tape's adhesive and the coating surface.

8.6 Within 90 ± 30 s of application, remove the tape by seizing the free end and pulling it off rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

8.7 Inspect the X-cut area for removal of coating from the substrate or previous coating and rate the adhesion in accordance with the following scale:

5A	No peeling or removal,
4A	Trace peeling or removal along incisions or at their intersection,
3A	Jagged removal along incisions up to 1.6 mm (1⁄16 in.) on either side,
2A	Jagged removal along most of incisions up to 3.2 mm (⅛ in.) on either side,
1A	Removal from most of the area of the X under the tape, and
0A	Removal beyond the area of the X.

8.8 Repeat the test in two other locations on the test surface. For large structures make sufficient tests to ensure that the adhesion evaluation is representative of the whole surface.

8.9 After making several cuts examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone before using again. Discard cutting tools that develop nicks or other defects that tear the film.

9. Report

9.1 Report the substrate employed, the type of coating and the method of cure, if known.

9.2 Report the number of tests, their mean and range.

9.3 Report the adhesion strength of the pressure-sensitive tape determined in accordance with Test Method D3330/D3330M, Test Method A, (equivalent to PSTC 101) and utilizing a 90 second dwell time on a standard steel panel.

9.3.1 Where the adhesion strength of the tape has not been determined, report the specific product name of the tape used, the manufacturer and the lot number, if available.

9.4 Report an estimate of the interface at which the coating failure occurred as indicated by visible peeling or removal of the coating. For example, between the first coat and substrate, between the first and second coats, etc.

9.5 For field tests, report the type of coating (where known), the structure or article tested, the location and the environmental conditions at the time of testing.

9.6 If the test is performed after immersion, report immersion conditions, time between immersion and testing, and method of sample preparation.

10. Precision and Bias[7]

10.1 In an interlaboratory study of this test method in which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering a wide range of adhesion, the within-laboratories standard deviation was found to be 0.33 and the between-laboratories 0.44. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

10.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than 1 rating unit for two measurements.

10.1.2 *Reproducibility*—Two results, each the mean of triplicates, obtained by different operators should be considered suspect if they differ by more than 1.5 rating units.

10.2 Bias cannot be established for these test methods.

TEST METHOD B—CROSS-CUT TAPE TEST

11. Apparatus and Materials

11.1 *Cutting Tool* [8]—Sharp razor blade, scalpel, knife or other cutting device having a cutting edge angle between 15 and 30° that will make either a single cut or several cuts at once. The cutting edge shall be in good condition, preferably new or newly sharpened.

11.2 *Cutting Guide*—If cuts are made manually (as opposed to a mechanical apparatus) a steel or other hard metal straightedge or template to ensure straight cuts.

11.3 *Rule*—Tempered steel rule graduated in 0.5 mm for measuring individual cuts.

11.4 *Tape,* as described in 6.3.

11.5 *Pressure Application Device,* as described in 6.4.

11.6 *Illumination,* as described in 6.5.

11.7 *Magnifying Glass*—An illuminated magnifier to be used while making individual cuts and examining the test area.

12. Test Specimens

12.1 Test specimens shall be as described in Section 7. It should be noted, however, that multitip cutters[9] provide good results only on test areas sufficiently plane that all cutting edges contact the substrate to the same degree. Check for flatness with a straight edge such as that of the tempered steel rule (11.3).

13. Procedure

13.1 Where required or when agreed upon, subject the specimens to a preliminary test before conducting the tape test (see Note 4). After drying or testing the coating, conduct the tape test at room temperature as defined in Specification D3924, unless D3924 standard temperature is required or agreed.

13.1.1 For specimens which have been immersed: After immersion, clean and wipe the surface with an appropriate solvent which will not harm the integrity of the coating. Then dry or prepare the surface, or both, as agreed upon between the purchaser and the seller.

13.2 Select an area free of blemishes and minor surface imperfections, place on a firm base, and under the illuminated magnifier, make parallel cuts as follows:

13.2.1 For coatings having a dry film thickness up to and including 50 µm (2 mils) space the cuts 1 mm apart and make eleven cuts unless otherwise agreed upon.

13.2.2 For coatings having a dry film thickness between 50 µm (2 mils) and 125 µm (5 mils), space the cuts 2 mm apart and make six cuts. For films thicker than 125 µm (5 mils), it is generally recommended to use Test Method A. Subject to agreement between the purchaser and the seller, Test Method B can be used for films thicker than 125 µm (5 mils) if wider spaced cuts are employed.[10]

13.2.3 Make all cuts about 20 mm (¾ in.) long. Cut through the film to the substrate in one steady motion using just sufficient pressure on the cutting tool to have the cutting edge reach the substrate. When making successive single cuts with the aid of a guide, place the guide on the uncut area.

13.3 After making the required cuts brush the film lightly with a soft brush or tissue to remove any detached flakes or ribbons of coatings.

13.4 Examine the cutting edge and, if necessary, remove any flat spots or wire-edge by abrading lightly on a fine oil stone. Make the additional number of cuts at 90° to and centered on the original cuts.

13.5 Brush the area as before and inspect the incisions for reflection of light from the substrate. If the metal has not been reached make another grid in a different location.

[7] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D01-1008. Contact ASTM Customer Service at service@astm.org.

[8] Multiblade cutters are available from a few sources that specialize in testing equipment for the paint industry.

[9] The sole source of supply of the multitip cutter for coated pipe surfaces known to the committee at this time is Paul N. Gardner Co., 316 NE First St., Pompano Beach, FL 33060. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[10] Test Method B has been used successfully by some people on coatings greater than 0.13 mm (5 mils) by spacing the cuts 5 mm apart. However, the precision values given in 15.1 do not apply as they are based on coatings less than 0.13 mm (5 mils) in thickness.

13.6 At each day of testing, before initiation of testing, remove two complete laps of tape from the roll and discard. Remove an additional length at a steady (that is, not jerked) rate and cut a piece about 75 mm (3 in.) long.

13.7 Place the center of the tape over the grid and in the area of the grid. Smooth the tape into place by finger in the area of the incisions taking care not to entrap air under the tape. Rub firmly over the surface of the tape with the pressure application device until the color is uniform in appearance. This indicates good, uniform contact between the tape's adhesive and the coating surface.

13.8 Within 90 ± 30 s of application, remove the tape by seizing the free end and rapidly (not jerked) back upon itself at as close to an angle of 180° as possible.

13.9 Inspect the grid area for removal of coating from the substrate or from a previous coating using the illuminated magnifier. Rate the adhesion in accordance with the following scale illustrated in Fig. 1:

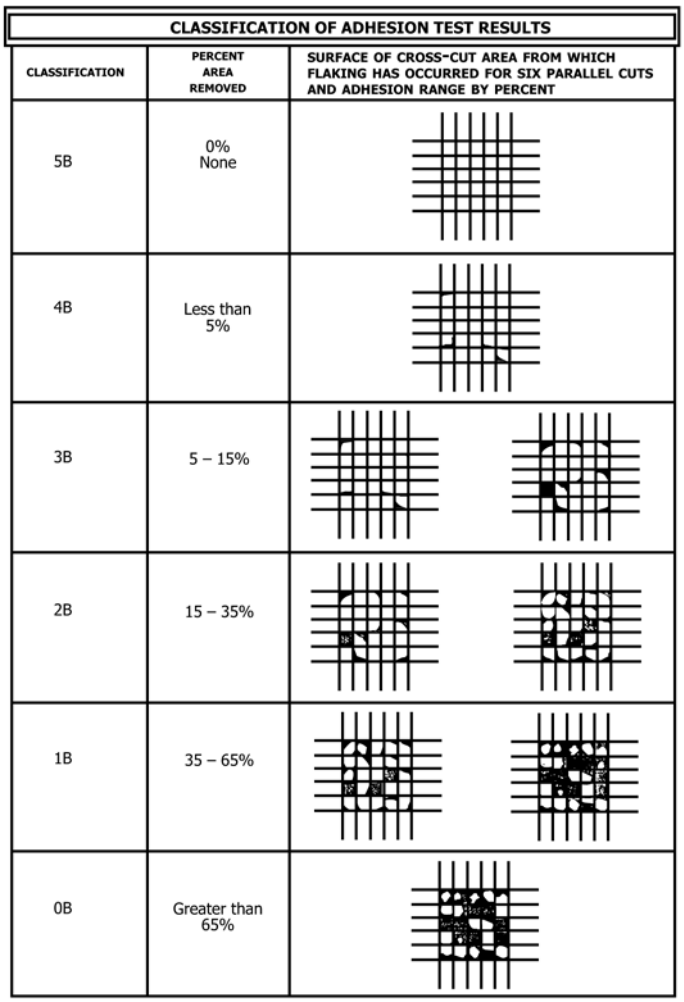

FIG. 1 Classification of Adhesion Test Results for Test Method B

5B The edges of the cuts are completely smooth; none of the squares of the lattice is detached.

4B Small flakes of the coating are detached at intersections; less than 5 % of the area is affected.

3B Small flakes of the coating are detached along edges and at intersections of cuts. The area affected is 5 to 15 % of the lattice.

2B The coating has flaked along the edges and on parts of the squares. The area affected is 15 to 35 % of the lattice.

1B The coating has flaked along the edges of cuts in large ribbons and whole squares have detached. The area affected is 35 to 65 % of the lattice.

0B Flaking and detachment worse than Classification 1B.

13.10 Repeat the test in two other locations on each test panel.

14. Report

14.1 Report the substrate employed, the type of coating and the method of cure, if known.

14.2 Report the number of tests, their mean and range.

14.3 Report the adhesion strength of the pressure-sensitive tape determined in accordance with Test Method D3330/D3330M, Test Method A (equivalent to PSTC 101) and utilizing a 90 second dwell time on a standard steel panel.

14.3.1 Where the adhesion strength of the tape has not been determined, report the specific product name of the tape used, the manufacturer and the lot number, if available.

14.4 Report an estimate of the interface at which the coating failure occurred as indicated by visible peeling or removal of the coating. For example, between the first coat and substrate, between the first and second coats, etc.

14.5 If the test is performed after immersion, report immersion conditions, time between immersion and testing, and method of sample preparation.

15. Precision and Bias[7]

15.1 On the basis of two interlaboratory tests of this test method in one of which operators in six laboratories made one adhesion measurement on three panels each of three coatings covering a wide range of adhesion and in the other operators in six laboratories made three measurements on two panels each of four different coatings applied over two other coatings, the pooled standard deviations for within- and between-laboratories were found to be 0.37 and 0.7. Based on these standard deviations, the following criteria should be used for judging the acceptability of results at the 95 % confidence level:

15.1.1 *Repeatability*—Provided adhesion is uniform over a large surface, results obtained by the same operator should be considered suspect if they differ by more than one rating unit for two measurements.

15.1.2 *Reproducibility*—Two results, each the mean of duplicates or triplicates, obtained by different operators should be considered suspect if they differ by more than two rating units.

15.2 Bias cannot be established for these test methods.

15.3 The manufacturer of the tape used in the interlaboratory study (see RR:D01-1008) has advised this subcommittee that the properties of the tape used in that study have changed since the study was performed and may not be relevant. Users of it should, therefore, check whether current material gives comparable results to previous supplied material.

16. Keywords

16.1 adhesion; crosscut adhesion test method; tape; tape adhesion test method; X-cut adhesion test method

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 Introduction

X1.1.1 Given the complexities of the adhesion process, can adhesion be measured? As Mittal (**4**) has pointed out, the answer is both yes and no. It is reasonable to state that at the present time no test exists that can precisely assess the actual physical strength of an adhesive bond. But it can also be said that it is possible to obtain an indication of relative adhesion performance.

X1.1.2 Practical adhesion test methods are generally of two types: "*implied*" and "*direct*." "Implied" tests include indentation or scribe techniques, rub testing, and wear testing. Criticism of these tests arises when they are used to quantify the strength of adhesive bonding. But this, in fact, is not their purpose. An "implied" test should be used to assess coating performance under actual service conditions. "Direct" measurements, on the other hand, are intended expressly to measure adhesion. Meaningful tests of this type are highly sought after, primarily because the results are expressed by a single discrete quantity, the force required to rupture the coating/substrate bond under prescribed conditions. Direct tests include the Hesiometer and the Adherometer (**5**). Common methods which approach the direct tests are peel, lap-shear, and tensile tests.

X1.2 Test Methods

X1.2.1 In practice, numerous types of tests have been used to attempt to evaluate adhesion by inducing bond rupture by different modes. Criteria deemed essential for a test to warrant large-scale acceptance are: use of a straightforward and unambiguous procedure; relevance to its intended application; repeatability and reproducibility; and quantifiability, including a meaningful rating scale for assessing performance.

X1.2.2 Test methods used for coatings on metals are: peel adhesion or "tape testing;" Gardner impact flexibility testing; and adhesive joint testing including shear (lap joint) and direct tensile (butt joint) testing. These tests do not strictly meet all the criteria listed, but an appealing aspect of these tests is that in most cases the equipment/instrumentation is readily available or can be obtained at reasonable cost.

X1.2.3 A wide diversity of tests methods have been developed over the years that measure aspects of adhesion (**4-8**). There generally is difficulty, however, in relating these tests to basic adhesion phenomena.

X1.3 The Tape Test

X1.3.1 By far the most prevalent test for evaluating coating "adhesion" is the tape-and-peel test, which has been used since the 1930's. In its simplest version a piece of adhesive tape is pressed against the paint film and the resistance to and degree of film removal observed when the tape is pulled off. Since an intact film with appreciable adhesion is frequently not removed at all, the severity of the test is usually enhanced by cutting into the film a figure *X* or a cross hatched pattern, before applying and removing the tape. Adhesion is then rated by comparing film removed against an established rating scale. If an intact film is peeled cleanly by the tape, or if it debonds just by cutting into it without applying tape, then the adhesion is rated simply as poor or very poor, a more precise evaluation of such films not being within the capability of this test.

X1.3.2 The current widely-used version was first published in 1974; two test methods are covered in this standard. Both test methods are used to establish whether the adhesion of a coating to a substrate is at an adequate level; however they do not distinguish between higher levels of adhesion for which more sophisticated methods of measurement are required. Major limitations of the tape test are its low sensitivity, applicability only to coatings of relatively low bond strengths, and non-determination of adhesion to the substrate where failure occurs within a single coat, as when testing primers alone, or within or between coats in multicoat systems. For multicoat systems where adhesion failure may occur between or within coats, the adhesion of the coating system to the substrate is not determined.

X1.3.3 Repeatability within one rating unit is generally observed for coatings on metals for both methods, with reproducibility of one to two units. The tape test enjoys widespread popularity and is viewed as "simple" as well as low in cost. Applied to metals, it is economical to perform, lends itself to job site application, and most importantly, after decades of use, people feel comfortable with it.

X1.3.4 When a flexible adhesive tape is applied to a coated rigid substrate surface and then removed, the removal process has been described in terms of the "peel phenomenon," as illustrated in Fig. X1.1.

X1.3.5 Peeling begins at the "toothed" leading edge (at the right) and proceeds along the coating adhesive/interface or the

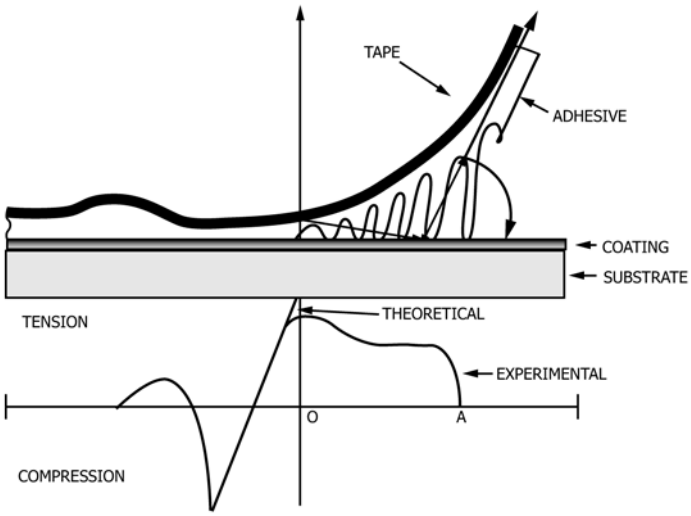

FIG. X1.1 Peel Profile (6)

coating/substrate interface, depending on the relative bond strengths. It is assumed that coating removal occurs when the tensile force generated along the latter interface, which is a function of the rheological properties of the backing and adhesive layer materials, is greater than the bond strength at the coating-substrate interface (or cohesive strength of the coating). In actuality, however, this force is distributed over a discrete distance (O-A) in Fig. X1.1, which relates directly to the properties described, not concentrated at a point (O) in Fig. X1.1 as in the theoretical case—though the tensile force is greatest at the origin for both. A significant compressive force arises from the response of the tape backing material to being stretched. Thus both tensile and compressive forces are involved in adhesion tape testing.

X1.3.6 Close scrutiny of the tape test with respect to the nature of the tape employed and certain aspects of the procedure itself reveal several factors, each or any combination of which can dramatically affect the results of the test as discussed (**9**).

X1.4 Peel Adhesion Testing on Plastic Substrates

X1.4.1 Tape tests have been criticized when used for substrates other than metal, such as plastics. The central issues are that the test on plastics lacks reproducibility and does not relate to the intended application. Both concerns are well founded: poor precision is a direct result of several factors intrinsic to the materials employed and the procedure itself. More importantly, in this instance the test is being applied beyond its intended scope. These test methods were designed for relatively ductile coatings applied to metal substrates, not for coatings (often brittle) applied to plastic parts (**1**). The unique functional requirements of coatings on plastic substrates cause the usual tape tests to be unsatisfactory for measuring adhesion performance in practice.

X1.5 The Tape Controversy

X1.5.1 With the withdrawal from commerce of the tape specified originally, 3M No. 710, current test methods no longer identify a specific tape. Differences in tapes used can lead to different results as small changes in backing stiffness and adhesive rheology cause large changes in the tension area. Some commercial tapes are manufactured to meet minimum standards. A given lot may surpass these standards and thus be suitable for general market distribution; however, such a lot may be a source of serious and unexpected error in assessing adhesion. One commercially available tape test kit had included a tape with adhesion strength variations of up to 50 % claimed by the manufacturer. Also, because tapes change on storage, bond strengths of the tape may change over time (**1, 2**).

X1.5.2 The specific choice for the range of recommended adhesive peel strengths for appropriate tapes of 6.34 N/cm (58 oz/in.) to 7.00 N/cm (64 oz/in.) was not chosen arbitrarily. Recent versions of this standard had recommended the use of a specific tape: Permacel P-99 tape. This tape was very popular and was commonly used in accordance with Test Method D3359 for many years. However, this tape was discontinued by the manufacturer. While the tape was still available and within its recommended shelf life, samples were sent to an independent laboratory for testing. The results of the testing showed that the Permacel product had an average adhesive peel strength on steel of 6.67 N/cm (61 oz/in.) when tested in accordance with Test Method D3330/D3330M, Test Method A (equivalent to PSTC 101) and utilizing a 90 second dwell time. In order to maintain a continuous testing program for current users of the standard, the range above was set to be in line with the discontinued Permacel product. At the time of this revision to the standard, several tapes were reported to be advertised as Permacel P-99 replacements and suitable for use with Test Method D3359. To locate these sources, perform a relevant internet search or contact your coatings testing supplier to ask for their recommendations of compliant tape.

X1.6 Procedural Problems

X1.6.1 *Visual Assessment:* The final step in the test is visual assessment of the coating removed from the specimen, which is subjective in nature, so that the coatings can vary among individuals evaluating the same specimen (**3**).

X1.6.1.1 Performance in the tape test is based on the amount of coating removed compared to a descriptive scale. The exposure of the substrate can be due to factors other than coating adhesion, including that arising from the requirement that the coating be cut (hence the synonym“ cross-hatch adhesion test”). Justification for the cutting step is reasonable as cutting provides a free edge from which peeling can begin without having to overcome the cohesive strength of the coating layer.

X1.6.1.2 Cutting might be suitable for coatings applied to metal substrates, but for coatings applied to plastics or wood, the process can lead to a misleading indication of poor adhesion due to the unique interfacial zone. For coatings on soft substrates, issues include how deep should this cut penetrate, and is it possible to cut only to the interface?

X1.6.1.3 In general, if adhesion test panels are examined microscopically, it is often clearly evident that the coating removal results from substrate failure at or below the interface, and not from the adhesive failure between the coating and the substrate. Cohesive failure within the coating film is also

frequently observed. However, with the tape test, failures within the substrate or coating layers are rare because the tape adhesive is not usually strong enough to exceed the cohesive strengths of normal substrates and organic coatings. Although some rather brittle coatings may exhibit cohesive failure, the tape test adhesion method does not make provision for giving failure locality (**1, 2**).

X1.6.2 Use of the test method in the field can lead to variation in test results due to temperature and humidity changes and their effect upon tape, coating and substrate.

X1.6.3 Test Method B has been used successfully, without affecting adhesion test results, by some coil coating users on coatings up to and including 50 µm (2 mils) by spacing the cuts 2 mm apart. While this may be an agreement between purchaser and seller, the precision values given in 15.1 do no apply, as they are based on cuts 1 mm apart.

X1.6.4 Some have found that the use of a suitable mechanical device is helpful in minimizing some of the variables in placing the tape onto the coatings (see 8.5 and 13.7) and removing the tape from the coatings (see 8.6 and 13.8) which maintains consistent pressure on the tape during application and ensures a 180° pull off.[11]

X1.7 Conclusion

X1.7.1 All the issues aside, if these test methods are used within the Scope Section and are performed carefully, some insight into the approximate, relative level of adhesion can be gained.

[11] The sole source of supply of a suitable mechanical device for laying down and removal of tape known to the committee at this time is ReliaPull, a registered trademark of Random Logic LLC, manufactured by Random Logic LLC, Cincinnati, OH 45245. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

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(7) Mittal, K. L., *Journal of Adhesion Science and Technology*, Vol 1, No. 3, 1987, pp. 247–259.

(8) Stoffer, J. O., and Gadodia, S. K., *American Paint and Coatings Journal*, Vol 70, Nos. 50 and 51, 1991, pp. 36–40 and 36–51, respectively.

(9) Souheng, Wu, *Polymer Interface and Adhesion*, Marcel Dekker, Inc., New York, NY, 1982, p. 531.

SUMMARY OF CHANGES

Committee D01 has identified the location of selected changes to this standard since the last issue (D3359-09$^{\varepsilon 2}$) that may impact the use of this standard. (Approved February 1, 2017.)

(1) Note 1 of the scope was revised to suggest Method A or Method B for coatings on soft non-metallic substrates. It was subsequently deleted as a Note and moved into Section 5 via Revision (10) below.
(2) A reference to PSTC 101 was added to Section 2.2 in Referenced Documents.
(3) Footnote 5 was added to identify the source of PSTC 101.
(4) Section 3 on Terminology was added in its entirety.
(5) Section 6.3 regarding the recommended tape for use with this standard was revised to suggest a range of acceptable peel adhesion strengths for these tapes. This choice was made 1) to provide more guidance to current users of the standard and 2) to eliminate references to specific tapes that my or may not be available in the future.
(6) Footnote 6 in Section 6.3 was removed.
(7) All units were rearranged to list the SI value first.
(8) Section X1.5.2 was added to Appendix X1.5. This section was added to aid users in selecting a viable tape.
(9) Changed the title to reflect that the test method results in a rating of a coating, not a true measurement.

(10) Overhauled the scope. Moved Note 1 of the scope to Section 5 and moved Note 2 to Section 4. Deleted Note 3 altogether.
(11) Revised 3.1.9 to describe "Pressure Sensitive Tape" rather than the term "Pressure Sensitive."
(12) The descriptions of the test methods in Section 4 were revised to utilize parallel language.
(13) Section 5 was revised for clarity.
(14) Renumbered Sections as needed.
(15) Footnote 6 was deleted and its text was moved to a new 15.3.
(16) Sections 6.4 and 11.5 were revised to more clearly describe what is required.
(17) Revised Sections 8.5 and 13.7 to update the use of the pressure application device.
(18) Modified the reporting recommendations in Section 9 and Section 14.
(19) Section X1.5.2 was deleted from the appendix and its content was moved into Section 5.4.
(20) Section X1.6.1 was deleted from the appendix and its content was moved into Section 5.5.
(21) Section X1.6.2 was deleted from the appendix and its content was moved into Section 5.6.
(22) Section X1.5.2 (newly numbered) was edited to remove the reference to specific test tape suppliers per ASTM guidelines.