Surface Preparation and Coating Application Inspection Instruments for the Pipeline Industry

VOLUME 3

VERIFYING THE QUALITY OF COATING INSTALLATION POST-APPLICATION KTA E-Book Series ----- Written by KTA COO Bill Corbett

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Preface

The last of three volumes, this eBook provides information on the proper use of test instruments for verifying the quality of the application of protective coatings after the installation process is complete. It is applicable to new pipe in the shop, field splices (girth weld areas), existing pipe in the field, and painted steel in general. Verifying the quality of surface preparation is the subject of Volume 1 and verifying the quality during application is the subject of Volume 2.

Successful corrosion prevention using protective coating systems is based in part on the quality of the surface preparation and coating system installation. To verify quality, we rely heavily on data generated by coatings inspection instruments and on visual inspection of the prepared surfaces. We rely on this same information to determine contractual compliance with the project specification.

This eBook was prepared with both the novice and the experienced coatings professional in mind. While it does not include *every* inspection instrument from every manufacturer, it does contain a cross-section of common instruments, with references to industry standards throughout. Both traditional methods and novel techniques for verifying quality are explored.

Instrument use, however, is only part of the coatings inspection equation. It must be combined with thorough knowledge of cleaning and painting, the project specification, and field constructability. Formal training in coatings inspection techniques remains a critical component of the process. This publication is not intended to replace formal training, but rather to supplement the learning process before, during and after training.

Introduction

Common quality control checkpoints associated with post-coating application inspection include:

- Holiday Detection
- Hardness Testing
- Adhesion Testing

Holiday Detection

Project specifications for the application of coatings to liquid and gas pipelines frequently require a continuous coating system. Rather than relying on a visual inspection, special detectors are used to determine the number and location of skips, misses, and pinholes, so that they can be repaired prior to placing the pipeline into service. The pipeline industry



Figure 1 – Courtesy of Pipeline Inspection Company

frequently refers to this procedure as "jeep" testing (Figure 1). If holiday, pinhole or "jeep" testing is not performed, and there are undetected voids in the coating system, the performance of the cathodic protection system could be affected (if the voids are extensive), and the exposed substrate could corrode, with the potential for pitting corrosion, section loss, and in a worse case, perforation of the

substrate. Holiday testing is governed by three industry standards: ASTM D5162, Standard Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates, ASTM G62, Standard Test Methods for Holiday Detection in Pipeline Coatings, and NACE SP0188, Discontinuity (Holiday) Testing of New Protective Coatings on Conductive Substrates. Pinhole or holiday detection is usually conducted after the final coat has been applied, but before it has achieved complete cure in the event repair of the coating film is required.

The terms "pinhole" and "holiday" are often used interchangeably. However, they represent two different types of "breaches" in the coating system. *Pinholes* are tiny voids in the coating that penetrate through a layer or layers of the system, potentially to the substrate. These voids allow the service environment to have direct or nearly direct access to the metal substrate via tiny "pathways." Holidays are considered "skips" or "misses" in the coating/lining system (just like holidays are skips in the work calendar). These uncoated areas also permit easy access to the unprotected substrate.

Pinholes can be caused by poor wetting of the

coating on the surface during application, or outgassing (displacement) of air without subsequent flow-out of the coating. Holidays are areas that are missed by the applicator. They may be caused by the configuration of the structure being coated (i.e., difficult to access with the application equipment), or lack of attention to detail by the applicator. Most holidays and pinholes are found on areas that are difficult to protect or access, such as edges and corners, welds, bolts, nuts and threads, behind angles and clips, inside holes, between back-to-back angles, etc. Large, flat surfaces that are easier to access and

coat usually contain fewer pinholes and holidays.

There are two different types of holiday detectors, low voltage and high voltage; selection of the specific type is based on the total thickness of the coating/lining system. Low voltage or "wet sponge" holiday detectors are used on coatings/linings that are less than 20 mils (508 μ m) thick. High voltage holiday detectors or "spark testers" are typically used on coatings greater than 20 mils thick. Independent of coating thickness, both detectors will only work on non-conductive coatings applied to a conductive substrate. For example, epoxy coatings

applied to steel can be tested for holidays, while a zinc-rich coating applied to the same steel cannot (zinc is a conductive metal in the coating).

Low Voltage (wet sponge) Holiday Detection



Figure 2

There are several manufacturers of low voltage holiday detectors; all operate on a similar principle, and most operate on 67.5 volts DC using battery power (Figure 2). A sponge is clamped to the end of a wand and is wetted with tap water containing a low-sudsing wetting agent (about 0.5 oz./gallon [15 mL/3.8 L]) supplied by most low voltage holiday detector manufacturers/suppliers. Kodak Photo-Flo photographic development wetting agent can also be used. The wetting agent reduces natural water surface tension, and is particularly important to use when coatings are in the 10-20 mil (254-508 μm) range. The detector unit is grounded to an uncoated area of steel using a ground wire clip. Both the wand and the ground wire are connected to the detector. The wet sponge



Figure 3 – Courtesy of DeFelsko Corporation

is scanned across the coated surface (Figure 3) at a rate not to exceed one linear foot per second. If a pinhole or holiday is present, the water from the sponge will contact the steel, complete the circuit (since the detector is grounded to the bare metal) and cause the detector to signal using a visible and/or an audible alarm.

Calibration and Verification of Continuity

Calibration of any coating inspection instrument is paramount to the reliability of the data it produces. Annual calibration by the manufacturer or an authorized service center is recommended by most instrument manufacturers. A certificate of calibration is provided.

Continuity can be verified by touching the wet sponge to the ground wire or an uncoated area, or by creating an intentional pinhole and touching the wet sponge to the area of the void. Some low voltage detectors have 80 ohm (80K) and 90 ohm (90K) resistance buttons



(see Figure 4) that are used to indicate the sensitivity of the device. For the model shown, the detector should signal and the LED should light when the 80K (80 ohm) button is pressed, provided the detector is to be used on coated steel structures and it is in calibration. The 90K (90 ohm) setting is for coatings on concrete.

High Voltage (spark) Holiday Detection

The operation of high voltage holiday detectors is somewhat more complex than low voltage detectors, since the test voltage is variable and selection of the voltage is based on the thickness of the coating to be tested and to some degree the conductivity of the surrounding air. While both NACE International and ASTM International have tables in their respective standards listing coating thickness ranges and corresponding test voltage ranges, it is best to contact the coating manufacturer to obtain their recommended voltage setting or calculate the required test voltage (discussed on Page 11), since the ranges listed in the tables are quite broad and only "suggested." To prevent potential damage to a coating film when

using high voltage test instrumentation, total film thickness and dielectric strength of the coating is considered in selecting the appropriate voltage for detection of discontinuities. Atmospheric conditions are also considered since the voltage required for the spark to "bridge" a given distance in air varies with the conductivity of the air at the time the test



Figure 5 -Courtesy of Tinker & Rasor Company

is conducted. Newer digital detectors (Figure 5) enable the operator to select or "dialin" the exact test voltage, versus the older models (Figure 6) that have



Figure 6

limited operator interface with test voltage settings. For example, on older models if the calculated test voltage was 6,525 volts, the operator could only select either the 6,000 or 7,000 volts setting.

Calculating the test voltage is straightforward. Simply calculate the square root of the thickness of the applied coating (Tc), then multiply the resulting value by a constant (K) of either 525 or 1250. The constant of 525 is used when the applied coating thickness is less than (<) 40 mils $(1016 \ \mu m)$; the constant of 1250 is used when the applied coating thickness is greater than or equal to (>) 40 mils. An example of each is shown below:

Tc: 25 mils (square root is 5)

5 x 525 (K) = 2,625 volts (2.6 kV) Tc: 50 mils (square root is 7.1)

7.1 x 1250 (K) = 8,875 volts (8.9 kV)

Once the test voltage is established, the ground cable is attached to the uncoated substrate (or the ground cable is dragged along the ground, provided the pipe is grounded to earth and the ground cable maintains contact with the earth). The exploring electrode that will be run across the coating is then selected. Choices of electrodes include flat conductive Neoprene rubber, brass or stainless-steel brush, and half-coil or full coil springs. The electrode is coupled to the wand, the unit is powered-on and



Figure 7 – Courtesy of Pipeline Inspection Company

the voltage is set. The electrode is scanned across the coated surface (Figure 7) at a rate not to exceed one linear foot per second. If a pinhole or holiday is present, a spark is generated at the precise location of the flaw and the detector signals with a visible and/or an audible alarm. While it is acceptable to retest any repairs made to the coating, it is recommended that retesting be limited to the areas of repair, rather than the entire coated surface. Also, holiday detection should never be conducted on a wet surface, and misleading results or damage could occur when testing a coating or lining system that has been in service. ASTM D5162 specifically states, "This practice is intended for use with new coatings applied to metal substrates. Its use on a coating previously exposed to an immersion condition has often resulted in damage to the coating and has produced erroneous detection of discontinuities due to

permeation or moisture absorption of the coating. Deposits may also be present on the surface causing telegraphing (current traveling through a moisture path to a discontinuity, giving an erroneous indication) or current leakage across the surface of the coating due to contamination. The use of a high voltage tester on previously exposed coatings has to be carefully considered because of possible sparkthrough, which will damage an otherwise sound coating. Although a low voltage tester can be used without damaging the coating, it may also produce erroneous results."

Calibration and Verification of Continuity

Similar to the low voltage detectors, annual calibration by the manufacturer or an authorized service center is recommended by most instrument manufacturers. A certificate of calibration is provided.

Continuity can be verified by touching the electrode to the ground wire or an uncoated area, or by creating an intentional



Figure 8a – Courtesy of Tinker & Rasor Company



Figure 8b – Courtesy of Tinker and Rasor Company

pinhole and touching the electrode to the area of the void. The actual voltage output (compared to the set point) can be verified using a Peak Reading Voltmeter (Figure 8a/8b).

To address the concerns over prevailing conductivity of the air (e.g., pressure, humidity) interfering with the test and the potential to exceed the dielectric strength of the coating itself, a plastic sheet comparable in thickness to the applied coating can be placed on a section of uncoated steel and an intentional pinhole created in the plastic. The voltage setting on the detector can be adjusted (as necessary) to the point where it alarms. However, if the coating has slight conductivity (e.g., carbon in vinyl ester linings) this procedure may not be viable, since the use of a lower inspection voltage may be necessary.

Hardness Testing

The hardness of a coating material is an indication of its degree of cure and its inherent performance characteristics. Hardness testing of newly coated cut-backs at splices is often performed prior to burying the pipe, to reduce the opportunity for coating damage during the backfill process.

The hardness of thick film coatings is typically measured using an indentor-type tester, which measures the resistance to indentation under a specific spring force load. The project specification should indicate the minimum acceptable hardness value prior to placing the coating system into service. The minimum acceptable hardness value is often established by the manufacturer of the coating.

Measuring Durometer Hardness

Durometer hardness testing is performed according to the procedure described in ASTM D2240, Standard Test Method for Rubber Property – Durometer Hardness. The standard includes several types of measurement devices (Types A, B, C, D, DO, O, OO, OOO, OOO-S and R), each used for different types and hardness of materials. We will focus on the use of a Shore D Durometer, since many of the thick film, chemically resistant coatings used in the pipeline industry fall into the hardness range that a Shore D durometer can accurately measure. For softer, thick film coating materials, a Shore

A durometer may be more useful since it has a lower spring force. According to the ASTM standard, hardness values obtained using durometers that are less than 20 and greater than 90 are not considered reliable and it suggests not recording them. In fact, the digital durometer described later automatically discards readings less than 20 and greater than 90. It should be noted that ASTM D2240 is written primarily for laboratory applications; however, Durometers can be used in the field.

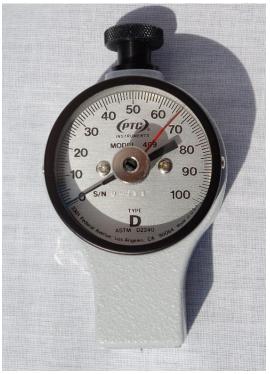


Figure 9

A Shore D Durometer is a small hand-held analog device (Figure 9), or an electronic device (Figure 10) with a remote probe that is used to measure the indention hardness of various materials like hard rubber, plastics, soft metals, and epoxy coatings. A small coneshaped indentor protrudes from the pressor foot (the base of



Figure 10 – Courtesy of DeFelsko Corporation

the tester or probe). The durometer contains a calibrated spring that is used to apply perpendicular force to the indentor. A cured, hardened coating will provide great resistance to the indentor under the force of the applied load, compared to an uncured, softer coating. This resistance to indention is displayed on the gage dial or digital display as a hardness value.

Verifying the Accuracy of the Durometer

Durometers should be calibrated annually by the manufacturer or their authorized service center. Some will even provide a 10-point calibration certification traceable to a **National Metrology** Institution like the National Institute of Standards and Technology (NIST). The operator cannot calibrate a durometer, but should verify proper operation prior to each period of use.

Test blocks are used to verify proper operation (accuracy). The set shown (Figure 11) represents



Figure 11 – Courtesy of DeFelsko Corporation

hardness values of 25, 46 and 75 on the D scale. A measurement is taken on each test block and compared to the hardness value displayed on the durometer. If the value displayed by the durometer does not conform to the tolerance of the test block value (for example 25 +/- 5, which means that the displayed hardness value obtained on the test block can range from 20-30), the durometer should not be used to measure the hardness of a coating and

should be returned to the manufacturer or service center for repair and calibration.

The surface of the coating to be tested should be clean and smooth. Any inherent surface roughness can produce erroneous hardness values. Since temperature and humidity can influence the hardness value, the surface temperature of the coated surface and the relative humidity of the surrounding air should be measured and recorded prior to testing. While the temperature and humidity data is required to be reported by the ASTM standard, there is no correction of the hardness values based on the

prevailing ambient conditions.

Measuring Coating Hardness (Analog Durometer)

After verifying accuracy using the test blocks and returning the red ancillary pointer to zero, the durometer is cupped in the operator's hand and vertical pressure is



Figure 12

applied using even, steady hand/thumb pressure (Figure 12) until the base of the instrument seats evenly on the coated surface. The maximum force will be maintained by the red ancillary pointer, even though the black pointer will return to zero once the downward pressure is released. A minimum of five measurements is obtained (spaced at least 1/4 inch apart), the average indention hardness is calculated, and the results are compared to the requirements of the project specification or coating manufacturer. The analog-type durometers may be difficult to seat correctly on small diameter pipe. The durometer should always

be positioned so that measurements are obtained along the length of the pipe and not across it.

Measuring Coating Hardness (Digital Durometer)

After verifying accuracy using the test blocks, the remote probe is pressed into the coating until the presser foot is in full, flat contact with the surface, and held in place (Figure



Figure 13 – Courtesy of DeFelsko Corporation

13). After the durometer emits a single audible signal, it will display a symbol indicating a reading is in the process of being obtained. The test timer will begin counting down. When the timer reaches zero, the durometer will emit a double audible signal and display the measurement value. The probe is removed from the surface. Because of the relative small diameter of the test foot, its use is more amenable to curved surfaces; however, the full measuring surface of the probe must sit flush on the surface without rocking to obtain a reliable reading.

Adhesion Testing

There are multiple methods that can be used to measure the adhesion of coating systems, including knife (ASTM D6677, Standard Test Method for Evaluating Adhesion by Knife), knife and tape (ASTM D3359, Standard Test Methods for Measuring Adhesion by Tape Test), and tensile or pull-off (ASTM D4541, Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers for coatings on metal surfaces and ASTM D7234, Standard Test Method for Pull-Off Strength of Coatings on Concrete Using Portable Adhesion Testers). The information that follows focuses on ASTM D4541

(specifically, the 2017 version), and ASTM D6677. The knife and tape test (ASTM D3359) is not described since it is not commonly used to test thick-film pipe coatings.

Tensile (pull-off) Adhesion Testing

When performing a tensile or pull-off adhesion test, the strength of a coating bond is being assessed at several different "planes," including the adhesion of the coating system to the substrate, and the adhesion of the coating layers to each other if there is more than one layer of coating on the surface. In both cases, the adhesive strength of a coating, or the bond of the layers to one another

and to the substrate is being assessed. The innerstrength of each coating layer is also being assessed, which is known as the *cohesive* strength of a coating, or the ability of each layer to hold itself together or maintain its "inner-strength."

The adhesion of a coating system to a surface is highly variable, and can be influenced by a multitude of factors too numerous to list here. That is likely why there is no industry-wide standard that says that a certain type of coating must have a minimum adhesive or cohesive strength. However, project specifications may require a minimum adhesion value as a contract

requirement, and coating manufacturers will often report an adhesion value on their product data sheets that may be adopted into a project specification.

Test Protocols

There are two protocols that are applicable to tensile (pull-off) adhesion testing of coatings: Protocol 1 - Test to Fracture and Protocol 2 -Pass/Fail test.

Protocol 1 - Test to Fracture: Protocol 1 is typically used when the minimum adhesion/cohesion properties of the coating system are unspecified. In this case, the load is applied to the fixture until detachment occurs, or the

maximum capacity of the test instrument is reached. High levels of applied force may result in glue breaks prior to coating breaks (an epoxy glue is typically used to attach the test fixtures to the coated surface). According to the 2017 version of ASTM D4541, unless otherwise agreed upon by the contracting parties, test results are discarded for all tests where the glue break is in excess of ¼ of the loading area (test fixture area).

Protocol 2 – Pass/Fail

Test: Protocol 2 is typically used when the minimum adhesion/cohesion properties of the coating system are specified. In this case, the load is applied to the fixture until the specified value is attained or detachment occurs, whichever happens first. High levels of applied force may again result in glue breaks prior to coating breaks. According to the 2017 version of ASTM D4541, if a visibly detectable glue break occurs (defined as 5% or more of the loading area) and the specified minimum value is not attained, additional loading fixtures may need to be attached and pulled. If the specified value is achieved and the test fixture remains attached, the pressure is released and the adhesion tester removed. The test fixture is either left in place, or removed by tapping the

side with a hammer to break the bond.

There are a variety of test instruments that can be used to assess the tensile or pull-off strength of a coating or coating system; however, all of them require that a loading fixture (a.k.a. pull stub or dolly) be attached to the surface of the coating using an adhesive (Figure 14 a and b). Once the adhesive (glue) cures, a vertical load is applied to the loading fixture,



Figure 14a



Figure 14b

perpendicular to the substrate using mechanical, hydraulic, or pneumatic induced pressure. The pull-off strength displayed by the instrument accounts for the applied force (e.g., pounds or megapascals) and size of the contact surface of the loading fixture.

Annual calibration of adhesion testers by the manufacturer or an authorized service center is recommended by most instrument manufacturers. A certificate of calibration is provided, frequently accompanied by a conversion table or curve so that adhesion values can be converted. Independent of the adhesion tester type or manufacturer, there is nothing that can be done to verify the accuracy of the instrument during use in the field.

Scoring the coating around the perimeter of the loading fixture is discouraged, as it may create microcracks in the coating, artificially lowering the pull-off value. Scoring may be necessary for thick-film coatings or coating systems that contain reinforcement, but is only performed if agreeable to all parties.

The ASTM standard includes five annexes that form a mandatory part of the standard (the appendices are nonmandatory). Each annex describes the proper use of a different apparatus.

Fixed Alignment Adhesion Testers (Annex A1)

A fixed alignment adhesion tester (Figure 15) consists of three basic components: A hand wheel or hexagon-shaped nut at the top; a black column housing a spring or series of Belleville washers, and containing a dragging indicator pin and scale in the middle; and a



Figure 15



Figure 16

base containing three legs and a pulling "jaw" at the bottom, designed to fit the head of the loading fixture. The "jaw" of the instrument is lowered and inserted under the head of the loading fixture (Figure 16). The load is applied by rotating the handwheel (or nut, using a ratchet) clockwise. The tension on the spring or washers applies a perpendicular, upward force on the loading fixture. The tension is increased smoothly and evenly using a moderate speed not to exceed 150 psi/second (1 MPa/second). The test should be completed in 100 seconds or less. The pull-off value is read from the scale on the black column (Figure 17). The

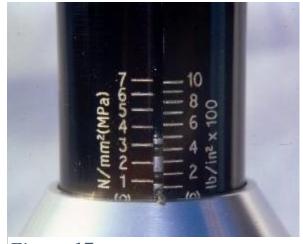


Figure 17

mechanical adhesion testers are fixed and cannot align with any slight mis-attachment of the loading fixture, so the force may not be applied truly perpendicular to the surface. If this happens, shear forces are applied to the loading fixture (and the coating system) instead of, or in addition to, tensile forces. In addition, the pulling forces are not applied at a constant rate since the operator cannot turn the handwheel or nut continuously. Frequently

pull-off values at the point of detachment are roughly 50% of those obtained with self-aligning adhesion testers.

Self-Aligning Adhesion Testers

Self-aligning adhesion testers are hydraulically or pneumatically operated; each type is described herein.

Self-Aligning Adhesion Testers – Hydraulic (Annex A2, A4, A5)

There are three manufacturers of selfaligning hydraulic adhesion testers. In each case a loading fixture is attached to the coated surface (as described earlier) and a self-aligning quick connect (Figure 18

and 20), or actuator (Figure 19) is coupled to



Figure 18



Figure 19



Figure 20

the head of the loading fixture and hydraulic pressure is applied. The adhesion tester shown in Figure 21 applies a continuous load at a predetermined rate (not to exceed 150 psi/second) until the loading fixture becomes detached. The rate (and continuity of the rate) for the other two hydraulic adhesion testers (Figure 22 and 23) are controlled by the operator. The instruments automatically convert the force to psi or MPa based on the size of the contact surface of the loading fixture used.



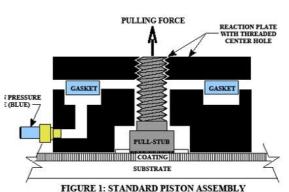
Figure 21 – Courtesy of DeFelsko Corporation



Figure 22



Figure 23



CROSS-SECTIONAL SCHEMATICS OF SELF-ALIGNING PISTON ASSEMBLIES

Figure 24 – Courtesy of M.E Taylor Engineering, Inc. /SEMicro Division



Figure 25

Self-Aligning Adhesion Testers – Pneumatic (Annex A3)

Pneumatic adhesion testers use an airoperated piston threaded onto the shaft of a specially-designed loading fixture to apply perpendicular, tensile force (Figure 24). There are several piston sizes; each with a corresponding range (i.e., an F-2 piston is 0-1000 psi, an F-4 piston is 0-2000 psi and an F8 piston is 0-4000 psi). Air pressure is generated using small CO₂ cartridges, which produce pressured air that travels through a small diameter hose into the piston. The pneumatic adhesion tester shown in Figure 25 applies a continuous pressure load at a rate pre-established by the operator (not to exceed 150 psi/second) until the loading fixture becomes detached. A chart corresponding to each piston size is used to convert the burst pressure to psi or MPa.

Loading Fixtures *Type:*

The manufacturers of the various test instruments (mechanical, hydraulic, pneumatic) also manufacturer the corresponding loading fixtures (Figure 26). There is no "universal" fixture. Loading fixtures are typically manufactured from aluminum, steel or stainless steel. Most operators consider the aluminum loading fixtures to be disposable, as the cost associated with



Figure 26

cleaning them often exceeds the cost of new fixtures. However steel and stainless-steel loading fixtures are reusable. Coating/glue can be removed from the base of loading fixtures using chemical paint strippers, heat or abrasive blast cleaning. If cleaned by abrasive blast cleaning, care must be taken to avoid beveling or changing the shape of the contact surface of the fixture.

Diameter: Twentymillimeter (20 mm) loading fixtures are common for coatings on metal, although smaller diameter fixtures (e.g., 10 and 14 mm) are available from some of the instrument manufacturers. Fiftymillimeter (50 mm) loading fixtures are required for testing the tensile strength of coatings applied to concrete (per ASTM D7234).

Shape: Many of the adhesion test instrument manufacturers can produce loading fixtures with concave and convex bases. The loading fixtures with a concave base are used on the exterior of pipe, while the loading fixtures with a convex base are used on the interior of pipe. However, since there is no universal curvature (pipe diameters vary widely), it is important to tell the equipment supplier the diameter of the pipe

section being tested. Concave/convex loading fixtures are speciallymanufactured and need to be ordered well in advance of the intended test date. Note: Determining the need to use curved loading fixtures is based on the diameter of the coated pipe to be tested and the diameter of the loading fixture. Concave/convexshaped fixtures may not be required for testing the adhesion of coatings on larger diameter pipe. To determine whether curved loading fixtures are required, a fixture (of the desired diameter) with a flat surface can be placed onto the pipe surface and checked to see whether it can be rocked back and forth or whether it seats

level on the surface. If rocking is evident, the use of curved fixtures is recommended.

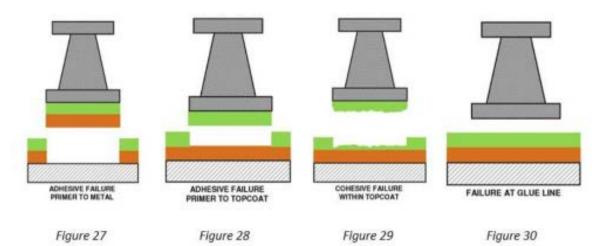
Frequency of Testing

ASTM D4541 states, "At least three replications are usually required in order to statistically characterize the test area (*i.e.*, *location*);" however it does not indicate how many test locations to select in order to characterize the adhesion properties of the coating system on the entire structure. Therefore, it is important to establish a test frequency upfront. Considerations may include the number of heterogeneous areas on a given structure, variations in coating thickness, etc.

A statistically significant sampling may or may not be feasible, given that these tests are destructive to the coating film and each area of test may need to be repaired. Other considerations include whether adhesion testing is part of a quality assessment (where destructive testing should be minimized), or if it is being employed to help diagnose the cause of a coating failure, where additional destructive tests have little negative impact, but can provide value in examining a problem.

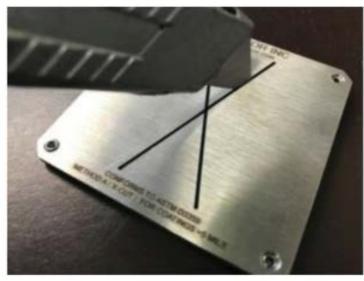
Reporting the Type and Amount of Break

The type of break and amount of each type of break arguably provides as much information as the pull-off value itself. The types of break include adhesive, cohesive or glue, and all three may be present on a single pull test. An adhesive break is a clean break between the substrate and the first coating layer (Figure 27), or a clean break between layers (Figure 28) when there are multiple coating layers in the system. A cohesive break is a split within a given coating layer (Figure 29). A glue break (Figure 30) is the failure of the glue itself that was used to attach the loading fixture to the coated surface (may or may not require a retest, as described earlier).



The approximate percentage of each type of break that occurred should also be reported (e.g., 80% adhesive [primer/topcoat]; 20% cohesive (within topcoat layer). The total should add up to 100% of the loading area.

Knife Adhesion Testing



The adhesion of a coating system can also be evaluated using ASTM D6677, "Evaluating Adhesion by Knife," which is a quick and easy way to assess adhesion in the field. Once a test area is selected, a straight

edge is used in conjunction with a knife blade (Figure 31) to make a 1.5" long cut through the coating system (down to the substrate) followed by a second cut across

Figure 31

the first cut to form an "X." The legs at the top and bottom of the "X" should be approximately 1" apart, and the intersection of the "X" should be close to a 30-45° angle.



Starting at the intersection of the "X," the tip of the knife blade is used to attempt to lift the coating from the substrate or the underlying coating layers (Figure 32).

The adhesion is rated on a scale of 10 to 0 (Figure 33).

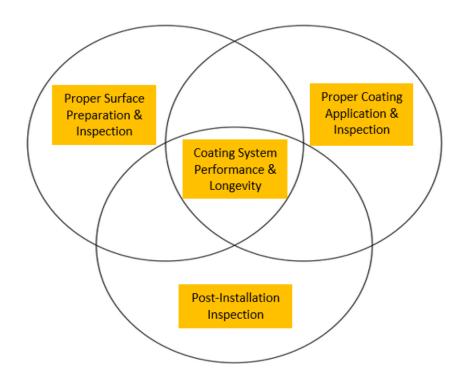
Figure 32

Rating	Description
10	Coating is extremely difficult to remove. Fragments no larger than 1/32" x 1/32" removed with great difficulty
8	Coating is difficult to remove. Coating chips from $1/16'' \ge 1/16'' \ge 1/8'' \ge 1/8'''$ removed with difficulty
6	Coating is somewhat difficult to remove. Coating chips from $1/8'' \times 1/8''$ to $1/4'' \times 1/4''$ removed with slight difficulty
4	Coating is somewhat difficult to remove. Coating chips in excess of $1/4'' \times 1/4''$ removed using light pressure with knife blade
2	Coating is easy to remove. Once started with the knife blade, the coating can be grasped with fingers and easily peeled to a length of at least 1/4"
0	Coating is easy to remove. Once started with the knife blade, the coating can be grasped with fingers and easily peeled to a length greater than 1/4"



Conclusion

Proper surface preparation/inspection (the foundation for the coating system), proper application/inspection of the coating system and post-installation inspection are critical to the protection of the substrate, and to prevent premature coating failure and preserve pipeline integrity. This approach to quality is illustrated in the Venn Diagram below.



Post-installation inspection includes veryfying that the coating system is continuous, properly cured prior to service, and well adhered. Common post-installation quality check points include those described in this Volume 3 of the eBook series - *Surface Preparation and*

Coating Application Inspection Instruments for the Pipeline Industry. Instruments used during surface preparation are presented in Volume 1; instruments used during the coating application process are presented in Volume 2.

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